2004 ASME BOILER & PRESSURE VESSEL CODE

AN INTERNATIONAL CODE

VIII

Division 3 –

Alternative Rules for Construction of High Pressure Vessels

RULES FOR CONSTRUCTION OF PRESSURE VESSELS

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Alternative Rules for Construction of High Pressure Vessels

2004 Edition
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ASME BOILER AND PRESSURE VESSEL COMMITTEE
SUBCOMMITTEE ON PRESSURE VESSELS

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
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2004 ASME BOILER AND PRESSURE VESSEL CODE

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ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2007 Code. The 2004 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2004 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

Beginning with the 2004 Edition, Interpretations of the Code will be distributed annually in July with the issuance of the edition and subsequent addenda. Interpretations previously distributed in January will be posted in January at www.cstools.asme.org/interpretations and included in the July distribution.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 2004 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2007 Code.

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FOREWORD

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The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety, relating only to pressure integrity, governing the construction[1] of boilers, pressure vessels, transport tanks and nuclear components, and inservice inspection for pressure integrity of nuclear components and transport tanks, and to interpret these rules when questions arise regarding their intent. This code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks and nuclear components, and the inservice inspection of nuclear components and transport tanks. The user of the Code should refer to other pertinent codes, standards, laws, regulations, or other relevant documents. With few exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. Recognizing this, the Committee has approved a wide variety of construction rules in this Section to allow the user or his designee to select those which will provide a pressure vessel having a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Accordingly, it is not intended that this Section be used as a design handbook; rather, engineering judgment must be employed in the selection of those sets of Code rules suitable to any specific service or need.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable designers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries

[1] *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published at *http://cstools.asme.org/wbpms/public/index.cfm?PublicReview=Revisions* to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

After Code revisions are approved by ASME, they may be used beginning with the date of issuance shown on the Addenda. Revisions, except for revisions to material specifications in Section II, Parts A and B, become mandatory six months after such date of issuance, except for boilers or pressure vessels contracted for prior to the end of the six-month period. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Guidelines for Acceptable ASTM Editions in Section II, Parts A and B. These Guidelines list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, methods of fabrication, inspection, and safety devices.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for Code use. Usage is limited to those materials and grades adopted by at least one of the other Sections of the Code for application under rules of that Section. All materials allowed by these various Sections and used for construction within the scope of their rules shall be furnished in accordance with material specifications contained in Section II or referenced in the Guidelines for Acceptable ASTM Editions in Section II, Parts A and B, except where otherwise provided in Code Cases or in the applicable Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis; Guideline for Acceptable ASTM Editions in Section II, Part A and Guideline for Acceptable ASTM Editions in Section II, Part B list editions of ASME and year dates of specifications that meet ASME requirements and which may be used in Code construction. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specifications listed in the Guideline for Acceptable ASTM Editions in Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding requirements of specifications listed in the Guideline for Acceptable ASTM Editions in Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Either U.S. Customary units or SI units may be used for compliance with all requirements of this edition, but one system shall be used consistently throughout for all phases of construction.

Either the U.S. Customary units or SI units that are listed in Mandatory Appendix 7 are identified in the text, or are identified in the nomenclature for equations, shall be used consistently for all phases of construction (e.g. materials, design, fabrication, and reports). Since values in the two systems are not exact equivalents, each system shall be used independently of the other without mixing U.S. Customary units and SI units.

When SI units are selected, U.S. Customary values in referenced specifications that do not contain SI units shall be converted to SI values to at least three significant figures for use in calculations and other aspects of construction.

With the publication of the 2004 Edition, Section II, Part D is published as two separate publications. One publication contains values only in U.S. Customary units and the other contains values only in SI units. The selection of the version to use is dependent on the set of units selected for construction.

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

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SUMMARY OF CHANGES

The 2004 Edition of this Code contains revisions in addition to the 2001 Edition with 2002 and 2003 Addenda. The revisions are identified with the designation **04** in the margin and, as described in the Foreword, become mandatory six months after the publication date of the 2004 Edition. To invoke these revisions before their mandatory date, use the designation "2004 Edition" in documentation required by this Code. If you choose not to invoke these revisions before their mandatory date, use the designation "2001 Edition through the 2003 Addenda" in documentation required by this Code.

Changes given below are identified on the pages by a margin note, **04**, placed next to the affected area.

Page	*Location*	*Change*
iii	List of Sections	Updated to reflect 04
xv–xvii	Foreword	Editorially revised
3	KG-150	(1) Revised (2) Table KG-150 deleted
4	Table KG-141	Fourth entry revised
7	KG-311.10(d)	Revised
11	KG-420	Revised in its entirety
19	KM-230	Revised
	KM-234.2	Revised
20	Table KM-234.2(a)	General Note revised
	Table KM-234.2(b)	Revised
24, 25	Table KHA-1	Revised
	KM-400(c)	Added
26	KD-100	(1) In KD-101 and KD-102, last paragraph revised (2) KD-104 deleted
29	KD-141(c)	Revised
33	KD-231	Revised
34, 35	Fig. KD-230	Figure and Notes revised
	KD-240	Subparagraphs (a) and (b) revised
36	KD-251	Equations in KD-251.1 through KD-251.4 revised
37	KD-301	Second paragraph revised
38	KD-312.4(b)	Revised
39	KD-321(c)	Last sentence revised
	KD-322(d)	Revised
40–43	Fig. KD-320.1	Revised
	Table KD-320.1	Revised

Page	*Location*	*Change*
40–43	Fig. KD-320.1M	Added
	Table KD-320.1M	Added
44, 45	Fig. KD-320.2	Revised
	Fig. KD-320.2M	Added
46, 47	Fig. KD-320.3	Revised
	Fig. KD-320.3M	Added
48, 49	Fig. KD-320.4	Revised
	Fig. KD-320.4M	Added
50–53	Fig. KD-320.5(a)	Revised
	Fig. KD-320.5M(a)	Added
	Fig. KD-320.5(b)	Revised
	Fig. KD-320.5M(b)	Added
59	KD-522.2	Subparagraphs (b) and (e)(1) revised
	KD-523	Revised
68	KD-810(f)	Added
79	KD-931	Revised in its entirety
81	Article KD-10	Deleted
82	KD-1110	Revised
90	KD-1254	In subparas. (a) and (b), equation revised
95	KF-101	Subparagraph (j) deleted
98	KF-211	Last sentence revised
99	KF-220(c)	Revised
127	Article KF-10	Deleted
140	KR-523.3	Fifth and sixth equation corrected by errata
141, 142	KR-531(b)	Nomenclature corrected by errata
164	KT-301	Revised
167	KS-100(g)	Revised
168	KS-120(c)	Added
172	KS-301(b)	Revised
175–179	1-100	Revised
180	2-100	Third sentence added
188	6-120(b)	Editorially revised
197	Mandatory Appendix 7	Added
217, 218	D-401	Under last equation, sentence added
221	D-403(a)	Paragraph under equation (2) revised
227	E-200	Last paragraph added

Page	*Location*	*Change*
233–240	G-300	Definitions of I_h, I_5, I_{5b}, I_{6b}, M_R, M_T, and ℓ_m corrected by errata
	Fig. G-100.1	In illustration (a), N corrected by errata to read N_H
	Fig. G-100.3	Illustrations (b) and (c) corrected by errata
241, 242	G-700(b)	(1) Editorially revised (2) Last equation corrected by errata
	G-800	Editorially revised
248–251	Nonmandatory Appendix I	Added

PART KG
GENERAL REQUIREMENTS

ARTICLE KG-1
SCOPE AND JURISDICTION

KG-100 SCOPE

KG-101 Intent

The rules of this Division constitute requirements for the design, construction, inspection, and overpressure protection of metallic pressure vessels with design pressures generally above 10 ksi (70 MPa). However, it is not the intent of this Division to establish maximum pressure limits for either Section VIII, Division 1 or 2, nor minimum pressure limits for this Division. Specific pressure limitations for vessels constructed to the rules of this Division may be imposed elsewhere in this Division for various types of fabrication.

KG-102 Description

Pressure vessels within the scope of this Division are pressure containers for the retainment of fluids, gaseous or liquid, under pressure, either internal or external.

This pressure may be generated by

(a) an external source

(b) the application of heat from

(1) direct source

(2) indirect source

(c) a process reaction

(d) any combination thereof

KG-103 Laws or Regulations

In those applications where there are laws or regulations issued by municipal, state, provincial, federal, or other governmental agencies covering pressure vessels, those laws or regulations should be reviewed to determine size or service limitations of the coverage which may be different or more restrictive than the rules of this Division.

KG-104 Location

KG-104.1 Fixed Location. Except as provided in KG-104.2, these rules cover vessels to be installed at a fixed (stationary) location for a specific service where operation and maintenance control is retained during the useful life of the vessel by the User who prepares the User's Design Specification required by KG-310.

KG-104.2 Mobile Vessels. These rules also apply to pressure vessels which are relocated from work site to work site between pressurizations, provided prior written agreement with the local jurisdictional authority can be obtained covering operation and maintenance control for a specific service. This operation and maintenance control shall be retained during the useful life of the pressure vessel by the User who prepares the User's Design Specification required by KG-310.

(a) Loading conditions imposed by loading, transportation, or unloading of the pressure vessel at or between work sites shall be considered according to Article KD-1.

(b) These rules shall not apply to fabrication of cargo tanks mounted on transport vehicles.

KG-105 Direct Fired

Pressure vessels which are subject to direct firing and are not within the scope of Section I may be constructed to the rules of this Division, except as excluded by KG-120.

KG-110 GEOMETRIC SCOPE OF THIS DIVISION

The scope of this Division includes only the vessel and integral communicating chambers and shall include the following (KG-111 through KG-117).

KG-111 External Piping and Jackets

Where external piping is to be connected to the vessel (see Article KD-6):

(a) the first threaded joint for screwed connections

(b) the face of the first flange for flanged connections

(c) the first sealing surface for proprietary connections or fittings

(d) the welding end connection for the first circumferential joint for welded connections to external piping, valves, instruments, and the like

(e) the welding pad for attachment of an external jacket

KG-112 Internal Pressure Piping

Internal pressure piping, when failure of such piping will affect the integrity of the pressure boundary.

KG-113 Nonpressure Parts

Nonpressure parts that are welded directly to the internal or external surface of a pressure vessel. For parts beyond this, and for stud-bolted attachments, see Articles KD-6 and KD-7.

KG-114 Covers and Closures

Pressure retaining permanent covers or closures, including seals and bolting, or other mechanical retainers, used in service for vessel openings (see Article KD-6).

KG-115 Instrument Connections

The first sealing surface for small proprietary fittings or instrumentation, such as gages and instruments, for which rules are not provided by this Division (see Article KD-6).

KG-116 Overpressure Protection

Pressure relief devices shall satisfy the requirements of Part KR.

KG-117 Combination Units

When a pressure vessel unit consists of more than one independent pressure chamber, only the parts of chambers which are within the scope of this Division need to be constructed in compliance with its provisions (see Articles KD-1 and KG-3).

KG-120 CLASSIFICATIONS OUTSIDE THE SCOPE OF THIS DIVISION

The following classes of pressure containing equipment are not within the scope of this Division:

(a) those within the scopes of other Sections of this Code

(b) fired process tubular heaters

(c) pressure containing equipment that is an integral part or component of a rotating or reciprocating mechanical device, such as

(1) pumps

(2) compressors

(3) turbines

(4) generators

(5) engines

(6) hydraulic or pneumatic cylinders

where the primary design considerations and/or stresses are derived from the functional requirements of the device

(d) structures whose primary function is the transport of fluids from one location to another within a system of which they are integral parts (piping systems)

KG-121 Stamping of Vessels Outside the Scope of This Division

Any pressure vessel which meets all applicable requirements of this Division may be stamped with the Code U3 symbol.

KG-130 FIELD ASSEMBLY OF VESSELS

Field assembly and testing of vessels constructed to this Division shall be performed using one of the following three alternatives.

(a) The Manufacturer of the vessel completes the vessel in the field.

(b) The Manufacturer of parts of a vessel to be completed in the field by some other party stamps these parts in accordance with Code rules and supplies the K-2 Manufacturer's Partial Data Report Forms to the other party. The other party, who shall also hold a valid U3 Certificate of Authorization, makes the final assembly, required nondestructive examination (NDE), and final pressure test; completes the K-1 Manufacturer's Data Report Form; and stamps the vessel.

(c) The field portion of the work is completed by a holder of a valid U3 Certificate of Authorization other

than the Manufacturer. The stamp holder performing the work is required to supply a K-2 Manufacturer's Partial Data Report Form covering the portion of the work completed by his organization (including data on the pressure test if conducted by the stamp holder performing the fieldwork) to the Manufacturer responsible for the Code vessel. The Manufacturer applies his U3 stamp in the presence of a representative from his Inspection Agency and completes the K-1 Manufacturer's Data Report Form with his Inspector.

In all three alternatives, the party completing and signing the K-1 Manufacturer's Data Report Form assumes full Code responsibility for the vessel. In all three cases, each Manufacturer's Quality Control System shall describe the controls to assure compliance for each Code stamp holder.

KG-140 STANDARDS REFERENCED BY THIS DIVISION

KG-141 Sections of the ASME Code

Sections of the ASME Boiler and Pressure Vessel Code referenced in this Division are:

- Section I, Rules for Construction of Power Boilers
- Section II, Materials
  - Part A — Ferrous Material Specifications
  - Part B — Nonferrous Material Specifications
  - Part C — Specifications for Welding Rods, Electrodes, and Filler Metals
  - Part D — Properties
- Section V, Nondestructive Examination
- Section VIII, Division 1, Rules for Construction of Pressure Vessels
- Section VIII, Division 2, Alternative Rules for Construction of Pressure Vessels
- Section IX, Welding and Brazing Qualifications

The referenced standards and specifications shall apply. These Sections and standards apply to the extent referenced in this Division (see Table KG-141).

KG-142 Standard Parts

Standard pressure parts which comply with an ASME product standard shall be made of materials permitted by this Division (see Part KM).

KG-150 UNITS OF MEASUREMENT 04

Either U.S. Customary units or SI units may be used for compliance with all requirements of this edition, but one system shall be used consistently throughout for all phases of construction.

Either the U.S. Customary units or SI units that are listed in Mandatory Appendix 7 are identified in the text, or are identified in the nomenclature for equations, shall be used consistently for all phases of construction (e.g., materials, design, fabrication, and reports). Since values in the two systems are not exact equivalents, each system shall be used independently of the other without mixing U.S. Customary units and SI units.

When SI units are selected, U.S. Customary values in referenced specifications that do not contain SI units shall be converted to SI values to at least three significant figures for use in calculations and other aspects of construction.[1]

In addition, the User may specify a duplicate nameplate according to KS-131 and add duplicate certified documents translated into the language appropriate at the site of the installation of the vessel.

[1] Guidance for conversion of units from U.S. Customary to SI is found in Nonmandatory Appendix I.

04

TABLE KG-141
REFERENCED STANDARDS IN THIS DIVISION AND YEAR OF ACCEPTABLE EDITION

Title	Number	Year
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1	1989 (R2001)
Pipe Flanges and Flanged Fittings	ASME B16.5	1996
Factory Made Wrought Steel Buttwelding Fittings	ASME B16.9	1993
Forged Fittings, Socket-Welding and Threaded	ASME B16.11	2001
Metallic Gaskets for Pipe Flanges — Ring-Joint, Spiral-Wound, and Jacketed	ASME B16.20	1993
Square and Hex Nuts (Inch Series)	ASME/ANSI B18.2.2	1987 (R1999)
Welded and Seamless Wrought Steel Pipe	ASME B36.10M	2000
Surface Texture (Surface Roughness, Waviness and Lay)	ASME B46.1	1995
Pressure Relief Devices	ASME PTC 25	2001
Qualifications for Authorized Inspection	QAI-1	1995 [Note(1)]
ASNT Central Certification Program	ACCP	Rev. 3, 1997
ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel	CP-189	1995
Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing	SNT-TC-1A	1996
Hardness Conversion Tables for Metals	ASTM E 140	1988
Standard for Use of the International System of Unit (SI); the Modern Metric System	IEEE/ASTM SI	1997
Guide for Metrication of Codes and Standards SI (Metric) Units	ASME SI-9	1981
Standard Method for Plane-Strain Fracture Toughness of Metallic Materials	ASTM E 399	1990
Standard Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement	ASTM E 1290	1999
Standard Test Method for Measurement of Fracture Toughness	ASME E 1820	1999a
Standard Terminology Relating to Fatigue and Fracture Testing	ASTM E 1823	1996

GENERAL NOTE: For product standards, pressure–temperature ratings and cyclic analysis may limit application (see Part KD).

NOTE:
(1) See KG-411.

ARTICLE KG-2
ORGANIZATION OF THIS DIVISION

KG-200 ORGANIZATION

KG-210 PARTS OF THIS DIVISION

This Division is divided into eight parts.

(a) Part KG contains the scope of the Division, establishes the extent of its coverage, and sets forth the responsibilities of the User and Manufacturer and the duties of the Inspectors of vessels constructed under these rules.

(b) Part KM contains

(1) the materials which may be utilized

(2) the permissible material specification identification numbers, special requirements, and limitations

(3) mechanical and physical properties upon which the design is based, and other necessary information concerning material properties (see Section II, Part D)

(c) Part KD contains requirements for the design of vessels and vessel parts.

(d) Part KF contains requirements for the fabrication of vessels and vessel parts.

(e) Part KR contains rules for pressure relief devices.

(f) Part KE contains requirements for nondestructive examination and repair of materials, vessels, and vessel parts.

(g) Part KT contains testing requirements and procedures.

(h) Part KS contains requirements for stamping and certifying vessels and vessel parts. It also gives requirements for Manufacturer's Data Reports and Records to be furnished to the User.

KG-220 APPENDICES

KG-221 Mandatory

The Mandatory Appendices address specific subjects not covered elsewhere in this Division. Their requirements are mandatory when applicable.

KG-222 Nonmandatory

The Nonmandatory Appendices provide information and suggested good practices.

KG-230 ARTICLES AND PARAGRAPHS

KG-231 Articles

The main divisions of the Parts of this Division are designated Articles. These are given numbers and titles such as Article KG-1, Scope and Jurisdiction.

KG-232 Paragraphs and Subparagraphs

The Articles are divided into paragraphs and subparagraphs which are given three-digit numbers, the first of which corresponds to the Article number. Each such paragraph or subparagraph number is prefixed with letters which, with the first digit (hundreds), indicate the Part and Article of this Division in which it is found, such as KD-140, which is a subparagraph of KD-100 in Article KD-1 of Part KD.

(a) Major subdivisions of paragraphs or subparagraphs are indicated by the basic paragraph number followed by a decimal point and one or two digits. Each of these subdivisions are titled and appear in the table of contents.

(b) Minor subdivisions of paragraphs are designated (a), (b), etc.

(c) Where further subdivisions are needed, they are designated by numbers in parentheses [e.g. KG-311.8(b)(1)].

KG-240 REFERENCES

When a Part, Article, or paragraph is referenced in this Division, the reference shall be taken to include all subdivisions under that Part, Article, or paragraph, including subparagraphs.

KG-250 TERMS AND DEFINITIONS

Terms and symbols used in this Division are defined in the various Parts, Articles, or paragraphs where they first apply or are of primary interest. A list of symbols is given in Mandatory Appendix 1.

ARTICLE KG-3
RESPONSIBILITIES AND DUTIES

KG-300 GENERAL

The User, Manufacturer, and Inspector involved in the production and certification of vessels according to this Division have definite responsibilities and duties in meeting the requirements of this Division. The responsibilities and duties set forth in the following relate only to compliance with this Division, and are not to be construed as involving contractual relations or legal liabilities. Whenever *User* appears in this document, it may be considered to apply also to an Agent (e.g., designee or licensor) acting in his behalf.

KG-310 USER'S RESPONSIBILITY

It is the responsibility of the User or his designated Agent to provide a User's Design Specification for each pressure vessel to be constructed in accordance with this Division (see Article KG-1).

The Design Specification shall contain sufficient detail to provide a complete basis for Division 3 design and construction. Such requirements shall not result in construction that fails to conform with the rules of this Division.

KG-311 User's Design Specification

The User's Design Specification shall include the following.

KG-311.1 Vessel Identification

(a) vessel number

(b) name, function, purpose

(c) service fluid

KG-311.2 Vessel Configuration

(a) shape

(b) vertical or horizontal

(c) nominal size or volume capacity

(d) support method and location, including the foundation type and allowable loading, if applicable (see KD-110 and Article KD-7)

(e) construction type

(f) functions and boundaries of the items covered in KG-110

(g) items furnished by Manufacturer

(h) items furnished by User

KG-311.3 Controlling Dimensions

(a) outline drawings

(b) openings, connections, closures

(1) quantity of each

(2) type and size

(3) purpose

(4) location, elevation, and orientation

KG-311.4 Design Criteria

(a) Design Pressure. Design pressure is the pressure at the top of the vessel and which, together with the applicable coincident (metal) temperature, is stamped on the nameplate. The pressure at the top of the vessel is also the basis for the pressure setting of the pressure relief devices protecting the vessel.

(b) Design Temperature. The maximum mean metal temperature specified by the User, at design pressure. See KD-112. This is the design temperature that is to be stamped on the vessel.

(c) More than one combination of design pressure and temperature may be specified.

(d) Minimum Design Metal Temperature (MDMT). The MDMT is the lowest temperature to which the vessel will be exposed when the primary stresses at any location in the vessel are greater than 6 ksi (40 MPa) (see KM-234). This temperature shall be determined considering the lowest process temperature to which the vessel will normally be exposed in service, including process upsets, dumps, jet impingement, etc. Also, see KD-112 and KD-113.

(e) Thermal gradients across the vessel sections.

KG-311.5 Operating Conditions

(a) operating pressure at coincident fluid temperature. The *operating pressure* is the maximum sustained process pressure that is expected in service. The operating pressure shall not exceed the design pressure. This pressure is expressed as a positive value, and may be internal or external to the vessel.

(b) upset and other combinations of operating pressures and coincident fluid temperature in sufficient detail to constitute an adequate basis for selecting materials

(c) proposed methods of heating and cooling, as well as those upset conditions that could lead to rapid heating or cooling of the vessel surfaces

(d) cyclic operating data and conditions

KG-311.6 Contained Fluid Data

(a) phase (liquid, gaseous, dual)

(b) density

(c) unusual thermodynamic properties

(d) inlet and outlet fluid temperatures

(e) flow rates

(f) jet impingement streams

(g) statement if noxious, hazardous, or flammable

KG-311.7 Materials Selection

(a) appropriate materials for resistance to process corrosion (specific or generic) including environmentally induced corrosion cracking

(b) corrosion/erosion allowance

When additional requirements are appropriate for the intended service, see KG-311.12.

KG-311.8 Loadings

(a) The User shall specify all expected combinations of coincident loading conditions as listed in KD-110. These shall include reaction load vectors.

(b) This loading data may be established by

(1) calculation

(2) experimental methods

(3) actual measurement for similar conditions

(4) computer analysis

(5) published data

(c) The source of loading data shall be stated.

KG-311.9 Useful Operating Life Expected. State years and cycles.

KG-311.10 Fatigue Analysis

(a) Fatigue analysis is mandatory for Division 3 vessels, except as provided in KG-311.10(b). It is the User's responsibility to provide, or cause to be provided, information in sufficient detail so an analysis for cyclic operation can be carried out in accordance with Articles KD-3 and KD-4.

(b) The User shall state if, for small vessels intended for laboratory use, the permissible exemption is to be taken according to KD-100(c).

(c) The User shall state if leak-before-burst can be established based on documented experience with similar designs, size, material properties, and operating conditions (see KD-141) or if leak-before-burst is to be established analytically. The number of design cycles shall be calculated by Article KD-4 if leak-before-burst cannot be established.

(d) The User shall state whether through-thickness leaks can be tolerated as a failure mode for protective liners and inner layers. See KD-103, KD-810(f), and KD-931. **04**

KG-311.11 Overpressure Protection. The User or his Designated Agent shall be responsible for the design, construction, and installation of the overpressure protection system. This system shall meet the requirements of Part KR. Calculations, test reports, and all other information used to justify the size, location, connection details, and flow capacity for the overpressure protection system shall be documented in the User Design Specification (see KR-100).

KG-311.12 Additional Requirements. The User shall state in the User's Design Specification what additional requirements are appropriate for the intended vessel service (see Part KE).

(a) For those services in which laminar discontinuities may be harmful, additional examination of materials prior to fabrication shall be specified by the User; for example, ultrasonic examination of plate to SA-435 and forgings to SA-388, in Section V.

(b) State additional requirements such as nondestructive examinations, restricted chemistry, or heat treatments.

(c) The User shall state any nonmandatory or optional requirements of this Division that are considered to be mandatory for this vessel.

(d) The User shall state whether U.S. Customary or SI units are to be used in all certified documents, and on all marking and stamping required by this Division. The User shall also state if duplicate nameplates and certified documents in a second language are required, and if there are any other special requirements for markings and their locations. See also KG-150 and KS-130.

(e) The User shall state requirements for seals and bolting for closures and covers (see KD-660).

(f) Specific additional requirements relating to pressure testing shall be listed in the User's Design Specification, such as

(1) fluid and temperature range

(2) position of vessel

(3) location, Manufacturer's facility or on-site

(4) cleaning and drying

(g) The User shall state in the User's Design Specification what construction reports, records, or certifications, in addition to those listed in KS-320, the Manufacturer is required to provide to the User.

KG-311.13 Installation Site

(a) location

(b) jurisdictional authority (the User shall state the name and address of the jurisdictional authority that has jurisdiction at the site of installation of the vessel, and state any additional requirements or restrictions of that authority that pertain to the design, construction, or registration of this vessel)

(c) inspection agency and certification

(d) environmental conditions

KG-311.14 Certification of User's Design Specification. A Professional Engineer, registered in one or more of the states of the United States of America or the provinces of Canada and experienced in high pressure vessel design, shall certify that the User's Design Specification complies with the above requirements. This Professional Engineer shall be other than the Professional Engineer who certifies the Manufacturer's Design Report, although both may be employed by or affiliated with the same organization.

KG-320 MANUFACTURER'S RESPONSIBILITY

KG-321 Structural and Pressure Retaining Integrity

The Manufacturer is responsible for the structural and pressure retaining integrity of a vessel or part thereof, as established by conformance with all rules of this Division which are required to meet the conditions in the User's Design Specification and shown in the Manufacturer's Design Report.

KG-322 Code Compliance

(a) The Manufacturer completing any vessel or part to be marked with the Code U3 symbol has the responsibility to comply with all the applicable requirements of this Division and, through proper certification, to ensure that any work done by others also complies with all requirements of this Division.

(b) The Manufacturer shall certify compliance with these requirements by the completion of the appro- priate Manufacturer's Data Report, as described in KS-300.

KG-323 Manufacturer's Design Report

As a part of his responsibility, the Manufacturer shall provide a Manufacturer's Design Report that includes

(a) design calculations and analysis that establish that the design as shown on the drawings, including as-built changes, complies with the requirements of this Division for the design conditions that have been specified in the User's Design Specification

(b) final and as-built drawings

(c) the results of the fatigue analysis according to Articles KD-3 and KD-4, and KD-1260, if applicable

(d) documentation of the consideration of the effects of heating, or heat treatments during manufacturing, and similarly, the maximum metal temperature specified, to show that the material properties or prestress used in the design are not adversely affected (see Parts KD and KF)

(e) statement of any openings for which he has not installed closures such as the service cover, or closure or other connections

(f) the limiting thermal gradients across the vessel section

KG-324 Certification of Manufacturer's Design Report

(a) A Professional Engineer, registered in one or more of the states of the United States of America or the provinces of Canada and experienced in high pressure vessel design, shall certify compliance of the Manufacturer's Design Report with the requirements of the User's Design Specification and of this Division. This registered Professional Engineer shall be other than the individual who certified the User's Design Specification, although both may be employed by or affiliated with the same organization.

(b) The Manufacturer's Design Report shall be certified only after

(1) all design requirements of this Division and the User's Design Specification have been met

(2) the Manufacturer's Construction Records are reconciled with the Manufacturer's Design Report and with the User's Design Specification

(c) Certification of the Design Report shall not relieve the Manufacturer of the responsibility for the structural integrity of the completed item for the conditions stated in the User's Design Specification.

KG-325 Manufacturer's Construction Records (MCR)

The Manufacturer shall prepare, collect, and maintain construction records and documentation of NDE reports, repairs, and deviations from drawings, as production progresses, to show compliance with the Manufacturer's Design Report. An index to the construction records file shall be maintained current. See KS-320.

KG-330 DESIGNER

The Designer is the individual engineer, or group of engineers, experienced in high pressure vessel design, who performs the required analysis of the vessel. The Designer may be in the employ of the Manufacturer, or an Agent acting in his behalf.

ARTICLE KG-4
GENERAL RULES FOR INSPECTION

KG-400 GENERAL REQUIREMENTS FOR INSPECTION AND EXAMINATION

The inspection and examination of pressure vessels stamped with the Code U3 symbol shall conform to the general requirements for inspection and examination in this Article and, in addition, to the specific requirements for inspection and examination given in the applicable paragraphs.

KG-410 MANUFACTURER'S RESPONSIBILITIES

KG-411 Inspection Contract

The Manufacturer shall have in force, at all times, a valid inspection contract or agreement with an accredited Authorized Inspection Agency,[1] employing Authorized Inspectors as defined in KG-431. A valid inspection contract or agreement is a written agreement between the Manufacturer and the Authorized Inspection Agency in which the terms and conditions for furnishing the service are specified and in which the mutual responsibilities of the Manufacturer and the Inspector are stated.

KG-412 Certification

The Manufacturer who completes any vessel to be marked with the Code U3 symbol has the responsibility of complying with all the requirements of this Division and, through proper certification, of ensuring that work done by others also complies with all requirements of this Division, as indicated by his signature on the Manufacturer's Data Report.

KG-413 Provisions for Inspection

KG-413.1 Access. The Manufacturer of the vessel or part thereof shall arrange for the Inspector to have free access to such parts of all plants as are concerned with the supply or manufacture of materials for the vessel, at all times while work on the vessel is being performed, and to the site of field erected vessels during the period of assembly and testing of the vessel.

KG-413.2 Progress. The Manufacturer shall keep the Inspector informed of the progress of the work and shall notify him reasonably in advance when the vessel or materials will be ready for any required tests or inspections.

KG-414 Documentation Furnished to Inspector

The Manufacturer shall provide documentation and records, with ready and timely access for the Inspector, and perform the other actions as required by this Division. Some typical required documents, which are defined in the applicable rules, are summarized as follows:

(a) the Certificate of Authorization to use the U3 symbol from the ASME Boiler and Pressure Vessel Committee (see Article KS-2)

(b) the drawings and design calculations for the vessel or part (see KG-323)

(c) the mill test report or material certification for all material used in the fabrication of the vessel or part including welding materials (see KM-101), and sample test coupons (see KT-110) when required

(d) any Partial Data Reports when required by KS-301

(e) reports of examination of all materials (except welding materials) before fabrication

(1) to make certain they have the required thickness in accordance with the Design Specification

(2) for detection of unacceptable defects

(3) to make certain the materials are permitted by this Division (see KM-100)

(4) and to make certain that the identification traceable to the mill test report or material certification has been maintained (see KF-112)

(f) documentation of impact tests when such tests are required (see KM-212, KM-230, and Article KT-2)

(g) obtain concurrence of the Inspector prior to any repairs when required by KF-113, KF-710 and 2-116 of Mandatory Appendix 2

[1] Whenever *Authorized Inspection Agency* or *AIA* is used in this Code, it shall mean an Authorized Inspection Agency accredited by ASME in accordance with the requirements in the latest edition of ASME QAI-1, *Qualifications for Authorized Inspection.*

(h) reports of examination of head and shell sections to confirm they have been properly formed to the specified shapes within permissible tolerances (see KF-120 and KF-130)

(i) qualification of the welding procedures before they are used in fabrication (see KF-210, KF-822, and KT-220)

(j) qualification of all Welders and Welding Operators before using Welders in production work (see KF-210 and KF-823)

(k) reports of examination of all parts prior to joining to make certain they have been properly fitted for welding and that the surfaces to be joined have been cleaned and the alignment tolerances are maintained (see KF-230)

(l) reports of examination of parts as fabrication progresses for material identification (see KG-413 and KS-301) that surface defects are not evident, and that dimensional geometries are maintained

(m) provision of controls to assure that all required heat treatments are performed (see Part KF)

(n) providing records of nondestructive examinations performed on the vessel or vessel parts. This shall include retaining the radiographic film

(o) making the required hydrostatic or pneumatic test and having the required examination performed during such test (see Article KT-3)

(p) applying the required stamping and/or nameplate to the vessel and making certain it is applied to the proper vessel (see Article KS-1)

(q) preparing the required Manufacturer's Data Report with the supplement, and having them certified by the Inspector (see Article KS-1)

(r) maintenance of records (see KS-310 and KS-320)

04 KG-420 CERTIFICATION OF SUBCONTRACTED SERVICES

(a) The Quality Control Manual shall describe the manner in which the Manufacturer (Certificate Holder) controls and accepts the responsibility for the subcontracted activities (see KG-322). The Manufacturer shall ensure that all subcontracted activities meet the requirements of this Division. This section of the manual will be reviewed with the Inspector together with the entire Quality Control Manual.

(b) Work such as forming, nondestructive examination, heat treating, etc., may be performed by others. It is the vessel Manufacturer's responsibility to ensure that all work performed complies with all the applicable requirements of this Division. After ensuring compliance, and obtaining permission of the Inspector, the vessel may be stamped with the ASME symbol.

(c) Subcontracts that involve welding on the pressure boundary components for construction under the rules of this Division, other than repair welds permitted by the ASME material specifications, shall be made only to subcontractors holding a valid U, U2, or U3 Certificate of Authorization.

(d) A Manufacturer may engage individuals by contract for their services as Welders or Welding Operators, at shop or site locations shown on his Certificate of Authorization, provided all of the following conditions are met:

(1) The work to be done by Welders or Welding Operators is within the scope of the Certificate of Authorization.

(2) The use of such Welders or Welding Operators is described in the Quality Control Manual of the Manufacturer. The Quality Control System shall include a requirement for direct supervision and direct technical control of the Welders and Welding Operators, acceptable to the Manufacturer's accredited Authorized Inspection Agency.

(3) The Welding Procedures have been properly qualified by the Manufacturer, according to Section IX.

(4) The Welders and Welding Operators are qualified by the Manufacturer according to Section IX to perform these procedures.

(5) Code responsibility and control is retained by the Manufacturer.

KG-430 THE INSPECTOR

KG-431 Identification of Inspector

All references to Inspectors throughout this Division mean the Authorized Inspector as defined in this paragraph. All inspections required by this Division shall be by an Inspector qualified according to KG-432 and regularly employed by an ASME accredited Authorized Inspection Agency defined as

(a) the inspection organization of a state or municipality of the United States, or of a Canadian province.

(b) an insurance company authorized to write boiler and pressure vessel insurance.

(c) a company that manufactures pressure vessels exclusively for its own use and not for resale which is defined as a User–Manufacturer. This is the only instance in which an Inspector may be in the employ of the Manufacturer.

KG-432 Inspector Qualification

All Inspectors shall have been qualified by a written examination under the rules of any state of the United States or province of Canada which has adopted the Code.

KG-433 Monitor Quality Control System

In addition to the duties specified, the Inspector has the duty to monitor the Manufacturer's Quality Control System as required in Mandatory Appendix 2.

KG-434 Maintenance of Records

The Inspector shall verify that the Manufacturer has a system in place to maintain the documentation for the Manufacturer's Construction Records current with production, and to reconcile any deviations from the Manufacturer's Design Report.

KG-440 INSPECTOR'S DUTIES

The Inspector of vessels to be marked with the Code U3 symbol has the duty of making all required inspections and such other inspections as he considers are necessary in order to satisfy himself that all requirements have been met. Some typical required inspections and verifications, which are defined in the applicable rules, are summarized as follows:

(a) to verify that the Manufacturer has a valid Certificate of Authorization and is working according to an approved Quality Control System

(b) to verify that applicable Design Report, User's Design Specification, drawings, and related documents are available (see KG-414)

(c) to verify that materials used in the construction of the vessel comply with the requirements of Part KM

(d) to verify that all Welding Procedures have been qualified

(e) to verify that all Welders and Welding Operators have been qualified

(f) to verify that the heat treatments, including postweld heat treatment (PWHT), have been performed [see KG-414(m)]

(g) to verify that material imperfections repaired by welding are acceptably repaired and reexamined

(h) to verify that the required nondestructive examinations, impact tests, and other tests have been performed and that the results are acceptable

(i) to make a visual inspection of the vessel to confirm that the material numbers have been properly transferred (see KF-112)

(j) to perform internal and external inspections where applicable, and to witness the hydrostatic or pneumatic tests (see Article KT-3)

(k) to verify that the required marking is provided, including stamping, and that the nameplate has been permanently attached to the proper vessel or vessel chamber (see Article KS-1)

(l) to sign the Certificate of Inspection on the Manufacturer's Data Report when the vessel, to the best of his knowledge and belief, is complete and in compliance with all the provisions of this Division (see Article KS-3)

(m) to verify that the Manufacturer has maintained proper records (see KS-320 and KG-320)

PART KM
MATERIAL REQUIREMENTS

ARTICLE KM-1
GENERAL REQUIREMENTS

KM-100 MATERIALS PERMITTED

(a) Materials that are to be used under the rules of this Division, except for integral cladding, welding filler metals, weld metal overlay, and liner materials, shall conform to a material specification given in Section II, and shall be listed in Tables KCS-1, KHA-1, or KNF-1. The term *material specification* used in this Division shall be the referenced specification in Section II together with the supplemental requirements listed in the User's Design Specification (see KG-311.7).

(b) Materials that are outside the limits of size and/or thickness stipulated in the title or scope clause of the material specifications given in Section II and permitted by Part KM may be used if the materials are in compliance with the other requirements of the material specification and no size or thickness limitation is specified in this Division. In those specifications in which chemical composition or mechanical properties vary with size or thickness, materials outside the range shall be required to conform to the composition and mechanical properties shown for the nearest specified range.

(c) Materials other than those allowed by this Division shall not be used for construction of the pressure retaining component, including bolting and prestressed inner layer, unless data thereon are submitted to and approved by the Boiler and Pressure Vessel Committee in accordance with Nonmandatory Appendix F.

(d) The User shall confirm the coupling of dissimilar metals will have no harmful effect on the corrosion rate or life of the vessel for the service intended (see KG-311.7).

KM-101 Certification by Materials Manufacturer

The Materials Manufacturer shall certify that all requirements of the applicable materials specifications in Section II, all special requirements of Part KM which are to be fulfilled by the Materials Manufacturer, and all supplementary material requirements specified by the User's Design Specification (KG-311) have been complied with. The certification shall include certified reports of numerical results of all required tests or certificates of compliance, and shall certify that all required examinations and repairs have been performed on the materials. Also see KE-200. All conflicts between the materials specifications and the special requirements herein shall be noted and compliance with the special requirements stated (see KF-111).

KM-102 Prefabricated or Preformed Pressure Parts

(a) Prefabricated or preformed parts that are subject to the pressure in the vessel and that are furnished by other than the shop of the Manufacturer responsible for the completed vessel shall conform to all applicable requirements of this Division as related to a completed vessel, except that inspection in the shop of the parts manufacturer and Partial Data Reports shall be required for welded parts only.

(b) When the prefabricated or preformed parts are furnished with a nameplate and the nameplate interferes with further fabrication or service, and where stamping on the material is prohibited, the Manufacturer of the completed vessel, with the concurrence of the Inspector,

may remove the nameplate. The removal of the nameplate shall be noted in the Remarks section of the vessel Manufacturer's Data Report and the nameplate shall be destroyed.

KM-102.1 Forged, Rolled, or Die-Formed Standard Pressure Parts. Standard pressure parts such as pipe fittings, flanges, nozzles, welding caps, and covers that are wholly formed by forging, rolling, or die forming shall not require material certification in accordance with KM-101, except that certified reports of numerical results or certificates of compliance of the required Charpy V-notch impact testing of the parts shall be supplied to the Manufacturer of the completed vessel.

(a) Standard pressure parts that comply with a referenced ASME standard[1] or manufacturer's standard pressure parts[2, 3] shall be marked with the name or trademark of the part's manufacturer and such markings as are required by the standard. Part markings shall also provide traceability to the Charpy V-notch impact test reports. Such markings shall be considered as the parts manufacturer's certification that the product complies with the material specifications and standards indicated, and is suitable for service at the pressure-temperature rating indicated, except as limited by the rules in KD-110 and KD-140.

(b) Standard pressure parts that comply with a referenced ASME standard may be used at the pressure-temperature ratings specified in the ASME standard; manufacturer's standard pressure parts may be used at the pressure-temperature ratings specified in the manufacturer's standard. Alternatively, pressure-temperature ratings for these parts may be determined using the rules of this Division.

KM-102.2 Forged, Rolled, or Die-Formed Nonstandard Pressure Parts. Nonstandard pressure parts such as shells, heads, removable doors, and pipe coils that are wholly formed by forging, rolling, or die forming may be supplied as materials. The manufacturer of such parts shall furnish material certification in accordance with KM-101. These parts shall be marked with the name or trademark of the manufacturer and with other such markings as will serve to identify the particular parts with accompanying material certification. The Manufacturer of the completed vessel shall satisfy himself that the part complies with the requirements of this Division for the design conditions specified for the completed vessel.

KM-103 Base Material for Integral Cladding, Weld Metal Overlay, and Other Protective Linings

Base materials over which integral cladding or weld metal overlay materials are applied shall satisfy the requirements of Part KM. Base materials in which corrosion-resistant or abrasion-resistant liners are used shall also meet the requirements of Part KM.

KM-104 Integral Cladding and Weld Metal Overlay Material

Integral cladding and weld metal overlay materials may be any metallic material of weldable quality that meets the requirements of Article KF-3.

KM-105 Protective Liner Material

Corrosion-resistant or abrasion-resistant liner materials may be any metallic or nonmetallic material suitable for the intended service conditions (see KG-311).

KM-106 Repetition of Specified Examinations, Tests, or Heat Treatments

The requirements of Article KM-2 shall be met in addition to the examination, testing, and heat treating requirements for a given material that are stated in its material specification. No heat treatment need be repeated except in the case of quenched and tempered steel as required by KF-602.

[1] These are pressure parts that comply with an ASME product standard accepted by reference elsewhere in this Division and listed in Table KG-141. The ASME product standard establishes the basis for the pressure-temperature rating and marking unless modified in this Division.

[2] These are pressure parts that comply with a parts manufacturer's standard that defines the pressure-temperature rating marked on the part and described in the parts manufacturer's literature. The Manufacturer of the completed vessel shall satisfy himself that the part complies with the requirements of this Division for the design conditions specified for the completed vessel.

[3] Pressure parts may be in accordance with an ASME product standard not covered by Footnote 1, but such parts shall satisfy the requirements applicable to a parts manufacturer's standard and Footnote 2.

ARTICLE KM-2
MECHANICAL PROPERTY TEST REQUIREMENTS FOR METALS

KM-200 GENERAL REQUIREMENTS

As permitted by KM-100, all forms of metal products may be used subject to meeting the requirements of the material specification as well as the mechanical test and examination requirements of this Division.

KM-201 Definition of Thickness

The requirements in this Article make reference to a thickness. For the purpose intended, the following definitions of thickness T at the time of heat treatment apply.

KM-201.1 Plates. The thickness is the dimension of the short transverse direction.

KM-201.2 Forgings. The thickness is the dimension defined as follows:

(a) for hollow forgings in which the axial length is greater than the radial thickness, the thickness is measured between the minimum inside and maximum outside surfaces (radial thickness), excluding flanges (protrusions) whose thicknesses are less than the wall thickness of the cylinder

(b) for disk forgings in which the axial length is less than or equal to outside diameter, the thickness is the axial length

(c) for ring forgings where the maximum axial length is less than the radial thickness, the maximum axial dimension is considered the thickness

(d) for rectangular solid forgings, the least rectangular dimension is the thickness

KM-201.3 Bars and Bolting Materials. The thickness for bars and bolting material shall be the diameter for round bars, the lesser of the two cross-section dimensions for rectangular bars, and the distance across the flats for hexagonal bars; or the length of a given bar, whichever is less.

KM-201.4 Pipe. The thickness for pipe shall be the nominal wall thickness.

KM-210 PROCEDURE FOR OBTAINING TEST SPECIMENS AND COUPONS

For austenitic stainless steels and for nonferrous alloys, the procedure for obtaining test specimen coupons shall conform to the applicable material specification. These materials are exempt from the requirements of KM-211.

KM-211 Product Forms

KM-211.1 Plates

(a) For thicknesses less than 2 in. (51 mm), specimens shall be taken in accordance with the requirements of the applicable material specification.

(b) For thicknesses 2 in. (51 mm) and greater, the centerline of the test specimens shall be taken in accordance with the requirements of the applicable material specification, but not closer than T to any heat-treated edge and not closer than $T/4$ to the nearest plate surface.

(c) Where a separate test coupon is used to represent the vessel material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test specimens are removed represents the cooling rate of the material at least $T/4$ deep and T from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with KM-220, the dimensions of the coupon shall be not less than $3T$ by $3T$ by T, where T is the maximum material thickness.

KM-211.2 Forgings. The datum point, defined as the midpoint of the gage length of tension test specimens or the area under the notch of impact test specimens, shall be located in accordance with one of the following methods. All testing shall be from integral prolongations of the forging, except as permitted in KM-211.2(d).

(a) For forgings having a maximum quenched thickness not exceeding 4 in. (100 mm), the datum points of the test specimens shall be located in the forging or test forging at mid-thickness and at least $2T/3$ (T is the maximum heat-treated thickness) from the quenched end surface or nearest adjacent surfaces.

(b) For forgings having a maximum quenched thickness in excess of 4 in. (100 mm), the datum points of the test specimens shall be removed *T*/4 from the nearest quenched surface and 2*T*/3 from the quenched end surface or nearest adjacent surfaces.

(c) For very thick or complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, a drawing prepared by the Manufacturer shall show the surfaces of the finished product which will be subjected to high tensile stresses in service. The distance between this surface and the nearest quenched surface is defined to be the thickness *t*.

Test specimens shall be removed from stock provided on the product. The coupons shall be removed so that the specimens shall have their longitudinal axes at a distance *t* below the nearest heat-treated surface. The midlength of the specimen shall be a minimum of twice this distance, 2*t*, from any second heat-treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than ¾ in. (19 mm) to any heat-treated surface, and the midlength of the specimens shall be at least 1½ in. (38 mm) from any second heat-treated surface. This is known as the *t* by 2*t* test location.

(d) With prior approval of the Manufacturer, test specimens may be taken from a separately forged piece under the following conditions:

(1) the separate test forging shall be of same heat of material and shall be subjected to substantially the same reduction and working as the production forgings it represents.

(2) the separate test forging shall be heat treated in a manner that produces a cooling rate similar to and no faster than the main body of the production forging. The holding time at temperature and the heat treating temperature for the separate forging shall be the same as for the production forging.

(3) the separate test forging shall be of the same nominal thickness as the production forgings.

KM-211.3 Bars and Bolting Materials

(a) For diameters or thicknesses less than 2 in. (50 mm), the specimens shall be taken in accordance with the requirements of the applicable material specification.

(b) For diameters or thicknesses 2 in. (50 mm) and over, specimens shall be at least *T*/4 from the outside or rolled surface and with the end of the specimen no closer than one diameter or thickness from a heat-treated end.

KM-211.4 Pipe

(a) For thicknesses less than 2 in. (50 mm), specimens shall be taken in accordance with the requirements of the applicable material specification.

(b) For thicknesses 2 in. (50 mm) and over, specimens shall be taken in accordance with the requirements of the applicable material specification and at least *T*/4 from any heat-treated surface, where *T* is the maximum wall thickness of the pipe, and with the ends of the specimens no closer than *T* from a heat-treated end of the pipe. Test specimens shall be removed from integral prolongations from the pipe after completion of all heat treatment and forming operations.

TABLE KM-212
CHARPY IMPACT TEST TEMPERATURE REDUCTION BELOW MINIMUM DESIGN METAL TEMPERATURE

Actual Material Thickness or Charpy Impact Specimen Width Along the Notch, in. (mm) [Note (1)]	Temperature Reduction, °F (°C)
0.394 (10.00) (full-size standard bar)	0 (0)
0.354 (9.00)	0 (0)
0.315 (8.00)	0 (0)
0.295 (7.50) (¾ size bar)	5 (3)
0.276 (7.00)	8 (4)
0.262 (6.67) (⅔ size bar)	10 (6)
0.236 (6.00)	15 (8)
0.197 (5.00) (½ size bar)	20 (11)
0.158 (4.00)	30 (17)
0.131 (3.33) (⅓ size bar)	35 (19)
0.118 (3.00)	40 (22)
0.098 (2.50) (¼ size bar)	50 (28)

NOTE:
(1) Straight line interpolation for intermediate values is permitted.

KM-212 Charpy Impact Specimens

KM-212.1 Bolting Materials

(a) Charpy V-notch impact test specimens shall be the standard 10 mm × 10 mm size and shall be oriented parallel to the axis of the bolt.

(b) Where Charpy V-notch impact testing is to be conducted and bolt diameter does not permit specimens in accordance with KM-212.1(a), subsize specimens may be used. Test temperature shall be reduced in accordance with Table KM-212.

(c) Where bolt diameter or length does not permit specimens in accordance with KM-212.1(a) or (b), impact testing is not required.

KM-212.2 Pressure Retaining Component Materials, Other Than Bolting, Not Containing Welds

(a) The test coupons for Charpy specimens shall be oriented such that their major axes lie transverse to the direction of maximum elongation during rolling or to the direction of major working during forging. Examples of

acceptable Charpy V-notch impact specimen orientations removed from plate and pipe are shown in Fig. KM-212 illustrations (a) and (b), respectively. Since the direction of major working in a forging can vary significantly depending upon its shape and the forging method used, a single, representative example of an acceptable Charpy specimen removed from such a forging cannot be shown. Corners of Charpy specimens parallel to and on the side opposite the notch may be as shown in Fig. KM-212 illustration (b-1), if necessary, to maintain the standard 10 mm cross section at the notch.

(b) Where Charpy V-notch impact testing is to be conducted and material size or shape does not permit specimens in accordance with KM-212.2(a), longitudinal specimens with their major axes parallel to the direction of maximum elongation or major working may be used as shown in Fig. KM-212 illustration (b-3).

(c) Where material size or shape does not permit Charpy V-notch specimens in accordance with KM-212.2(a) or (b), subsize longitudinal specimens may be used Test temperature shall be reduced in accordance with Table KM-212.

(d) Charpy V-notch impact testing is not required when the maximum obtainable subsize longitudinal specimen has a width along the notch of less than 0.098 in. (2.5 mm).

KM-212.3 Pressure Retaining Component Materials Containing Welds

(a) The test coupons for Charpy specimens shall be oriented such that their major axes lie transverse to the direction of the welded joint. Corners of Charpy specimens parallel to and on the side opposite the notch may be as shown in Fig. KM-212, if necessary, to maintain the standard 10 mm cross section at the notch.

(b) Where Charpy V-notch impact testing is to be conducted and material size or shape does not permit specimens per KM-212.3(a), subsize specimens may be used. Test temperature shall be reduced per Table KM-212.

(c) Charpy V-notch impact testing is not required when the maximum obtainable subsize specimen has a width along the notch of less than 0.098 in. (2.5 mm).

KM-213 Fracture Toughness Specimens

See KM-250 for supplementary toughness requirements for pressure retaining component materials.

KM-213.1 Bolting Materials. If applicable, fracture toughness specimens shall be oriented such that the plane of the precrack is transverse to the axis of the bolt.

KM-213.2 Pressure Retaining Component Materials, Other Than Bolting, Not Containing Welds. If applicable, fracture toughness specimens shall be oriented such that the plane of the precrack is parallel to the direction of maximum elongation during rolling or to the direction of major working during forging.

KM-213.3 Pressure Retaining Component Materials Containing Welds. If applicable, fracture toughness specimens shall be oriented such that the plane of the precrack is parallel to the direction of the welded joint.

KM-220 PROCEDURE FOR HEAT TREATING SEPARATE TEST SPECIMENS

When metal products are to be heat treated and test specimens representing those products are removed prior to heat treatment, the test specimens shall be cooled at a rate similar to and no faster than the main body of the product. This rule shall apply for specimens taken directly from the product as well as those taken from separate test coupons representing the product. The following general techniques may be applied to all product forms, test specimens, or test coupons representing the product.

(a) Any procedure may be applied that can be demonstrated to produce a cooling rate in the test specimen that matches the cooling rate of the main body of the product at the region midway between mid-thickness and the surface ($T/4$) and no nearer to any heat-treated edge than a distance equal to the nominal thickness being cooled (T). The cooling rate of the test specimen shall replicate that of the actual part within a temperature of 25°F (14°C) at any given instant, and any given temperature shall be attained in both the actual part and test specimen within 20 sec at all temperatures after cooling begins from the heat treating temperature. Cooling rate can be determined by any method agreed upon between the manufacturer and purchaser, and can include, but is not limited to, theoretical calculations, experimental procedures, duplicate test forgings, or any combination thereof.

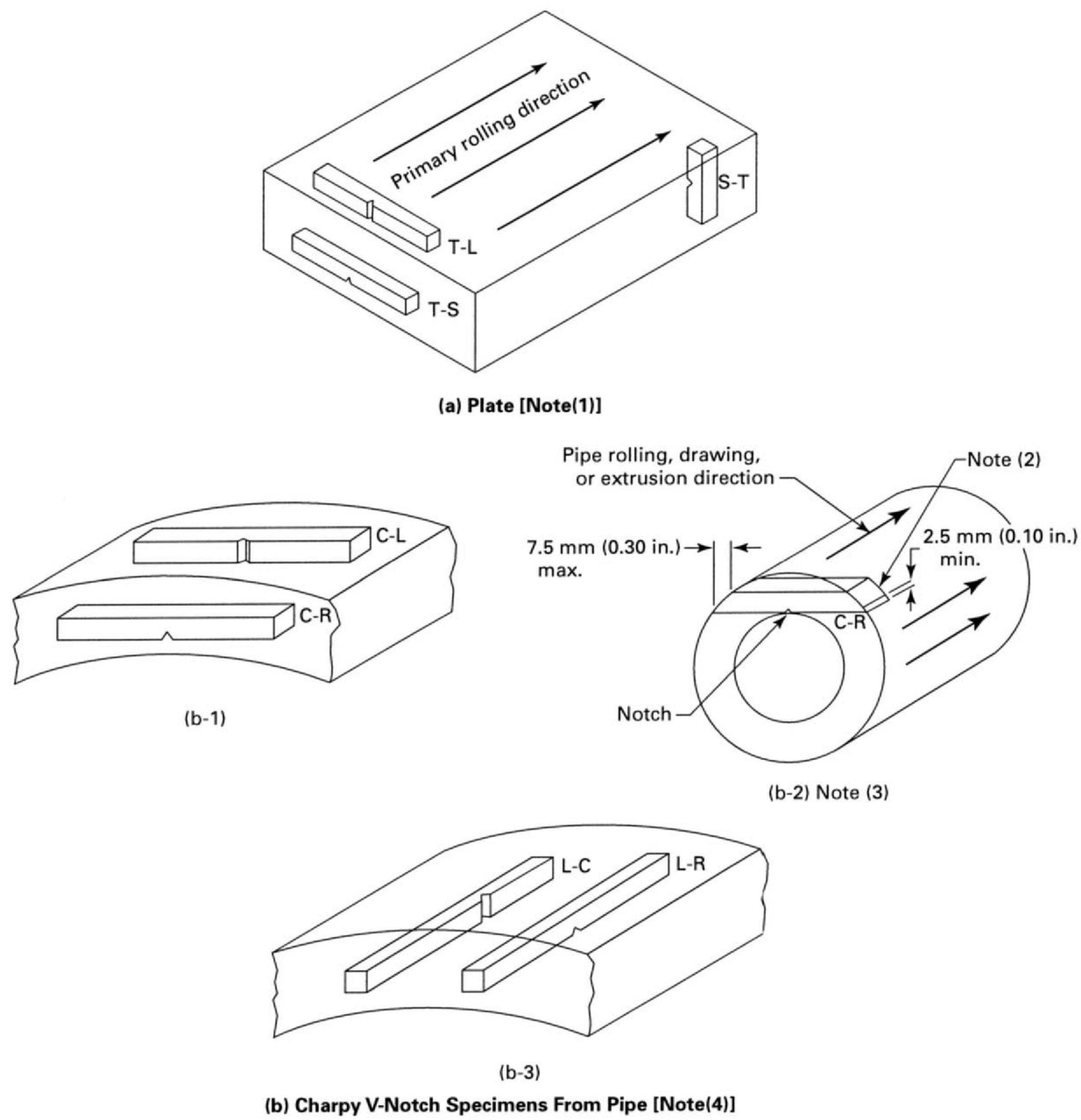
(b) Faster cooling rates at product edges may be compensated for by

(1) taking the test specimens at least T from a quench edge, where T equals the product thickness

(2) attaching a similar alloy pad at least T wide by a partial penetration weld to the product edge where specimens are to be removed

(3) using thermal barriers or insulation at the product edge where specimens are to be removed

(c) If cooling rate data for the product and cooling rate-control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the product provided that the provisions of KM-220(a) are met.



GENERAL NOTE: The Charpy impact specimen notch orientation codes shown are in accordance with ASTM E 1823, Annex A2.

NOTES:

(1) For plate greater than 2.2 in. (55 mm) in thickness, short transverse (S-T orientation) Charpy V-notch impact specimens may also be used.

(2) Corners of the Charpy specimens may follow the contour of the component within the dimension limits shown.

(3) This Figure illustrates how an acceptable transverse Charpy specimen can be obtained from a cylindrical pipe too small for a full length standard specimen in accordance with ASME SA-370. The corners of longitudinal specimens parallel to and on the side opposite the notch may also be as shown.

(4) The transverse Charpy V-notch specimen orientation for pipe shall be as shown in illustration (b-1); either notch orientation (C-R or C-L) is acceptable. If the transverse orientation shown in illustration (b-1) cannot be accommodated by the pipe geometry, then the orientation shall be as shown in illustration (b-2). If the alternate transverse orientation shown in illustration (b-2) cannot be accommodated by the pipe geometry, then the orientation shall be as shown in illustration (b-3); either notch orientation (L-R or L-C) is acceptable.

FIG. KM-212 EXAMPLES OF ACCEPTABLE IMPACT TEST SPECIMENS

(d) When the material is clad or weld deposit overlaid by the producer prior to heat treatment, the full thickness samples shall be clad or weld deposit overlaid before such heat treatments.

04 KM-230 MECHANICAL TESTING REQUIREMENTS

Tension and Charpy V-notch impact tests shall be conducted on representative samples of all materials used in the construction of pressure vessels, except that impact tests specified in Tables KM-234.2(a) and KM-234.2(b) are not required for nuts and washers, protective liner and inner layer materials, or for materials that do not contribute to the integrity of the pressure boundary. See also KM-250.

KM-231 Number of Test Specimens Required

(a) Components or material weighing 1,000 lb (454 kg) or less at the time of heat treatment require at least one tension test and one set of three Charpy V-notch impact test specimens per heat, per heat treatment load.

(b) Components or material weighing between 1,000 lb and 5,000 lb (454 kg and 2 270 kg) at the time of heat treatment require at least one tension test and one set of three Charpy V-notch impact test specimens per component, plate, or forging. If the component or forging length, excluding test prolongation(s), exceeds 80 in. (2 030 mm), then one set of tests shall be taken at each end and they shall be spaced 180 deg apart. For plate with a length exceeding 80 in. (2 030 mm), one set of tests shall be taken at each end and they shall be removed from diagonally opposite corners.

(c) Components or material weighing over 5,000 lb (2 270 kg) at the time of heat treatment require at least two tension tests and two sets of three Charpy V-notch impact test specimens per component, plate, or forging. One set of tests shall be taken at each end and they shall be spaced 180 deg apart for a component or forging, and at diagonally opposite corners for plate. If the component or forging length, excluding test prolongation(s), exceeds 80 in. (2 030 mm), then two sets of tests shall be taken at each end and they shall be spaced 180 deg apart. The tests at one end shall be offset from the tests at the other end by 90 deg. For plate with a length exceeding 80 in. (2 030 mm), two sets of tests shall be taken at each end and they shall be removed from both corners.

KM-232 Tensile Test Procedure

Tensile testing shall be carried out in accordance with SA-370 of Section II.

KM-233 Impact Test Procedure

Charpy V-notch impact testing shall be carried out in accordance with SA-370 using the standard 10 mm × 10 mm specimens, except as permitted in KM-212.

KM-234 Charpy V-Notch Impact Test Requirements

KM-234.1 Impact Test Temperature

(a) The impact test temperature shall not exceed the lower of 70°F (21°C) or the minimum design metal temperature specified in the User's Design Specification [see KG-311.4(d)] minus the appropriate temperature reduction value specified in Table KM-212, if applicable.

(b) The minimum design metal temperature for pressure retaining component materials exempted from impact testing by KM-212.1(c), KM-212.2, and KM-212.3(c) shall not be lower than −325°F (−200°C) for fully austenitic stainless steels, or −50°F (−45°C) for other materials.

KM-234.2 Absorbed Energy Acceptance Criteria 04

(a) Pressure-retaining component materials other than bolting shall meet the minimum Charpy V-notch impact value requirements specified in Table KM-234.2(a) unless exempted by KD-810(f) and KD-931.

(b) Bolting materials shall meet the minimum Charpy V-notch impact value requirements specified in Table KM-234.2(b).

KM-234.3 Lateral Expansion and Percentage Shear Reporting Requirements. The lateral expansion and percentage of shear fracture for all impact tests shall be measured in accordance with SA-370 and the results included in the test report.

KM-240 HEAT TREATMENT CERTIFICATION/VERIFICATION TESTS FOR FABRICATED COMPONENTS

Tests shall be made to verify that all heat treatments (i.e., quenching and tempering, solution annealing, aging, and any other subsequent thermal treatments that affect the material properties) as applicable have produced the required properties. Where verification tests shall be made from test specimens representative of the section being heat treated, the position and method of attachment of test coupons shall most nearly represent the entire item, taking into account its size and shape in accordance with testing requirements of the material specification. The requirements of KM-243 shall also apply.

04 TABLE KM-234.2(a)
MINIMUM REQUIRED CHARPY V-NOTCH IMPACT VALUES FOR PRESSURE-RETAINING COMPONENT MATERIALS

Specimen Orientation [Note (1)]	Number of Specimens [Note (2)]	Energy, ft-lbf (J) [Note (3)] for Specified Minimum Yield Strength, ksi (MPa) Up to 135 (930), Incl.	Over 135 (930)
Transverse [Note (4)]	Average for 3	30 (41)	35 (47)
	Minimum for 1	24 (33)	28 (38)
Longitudinal [Note (5)]	Average for 3	50 (68)	60 (81)
	Minimum for 1	40 (54)	48 (65)

GENERAL NOTE: This Table applies to all pressure-retaining materials, except protective liners (see KD-103), inner layers of shrink-fit layered vessels and wire-wound vessels [see KD-810(f) and KD-931, respectively], and bolting [see Table KM-234.2(b)].

NOTES:
(1) Specimen orientation is relative to the direction of maximum elongation during rolling or to the direction of major working during forging, as applicable. See KM-212.
(2) See KM-260 for permissible retests.
(3) Energy values in this Table are for standard size specimens. For subsize specimens, these values shall be multiplied by the ratio of the actual specimen width to that of a full-size specimen, 10 mm (0.394 in.).
(4) The acceptance criteria for all weld metal and heat-affected zone impact specimens shall be identical to those for transverse impact specimens.
(5) Except for components containing welds, longitudinal impact specimens may be tested only if component shape or size does not permit the removal of transverse specimens. See KM-212.

KM-241 Certification Test Procedure

(a) A sufficient number of test coupons to meet the requirements of KM-243 shall be provided from each lot of material in each vessel. These shall be quenched with the vessel or vessel component. If material from each lot is welded prior to heat treatment to material from the same or different lots in the part to be quenched, the test coupon shall be so proportioned that tensile and impact specimens may be taken from the same locations relative to thickness as are required by the applicable material specifications. Weld metal specimens shall be taken from the same locations relative to thickness as are required by the material specifications for plates used in the component to be treated. If desired, the effect of this distance may be achieved by temporary attachment of suitable thermal buffers. The effectiveness of such buffers shall be demonstrated by tests.

(b) In cases where the test coupon is not attached to the part being treated, it shall be quenched from the same heat treatment charge and under the same conditions as the part which it represents. It shall be so proportioned that test specimens may be taken from the locations prescribed in KM-241(a).

KM-242 Tempering

KM-242.1 Attached Test Coupons. The test coupons shall remain attached to the vessel or vessel component during tempering, except that any thermal buffers may be removed after quenching. After the tempering operation and after removal from the component, the coupon shall be subjected to the same thermal treatment(s), if

04 TABLE KM-234.2(b)
MINIMUM REQUIRED CHARPY V-NOTCH IMPACT VALUES FOR BOLTING MATERIALS

ASME Materials Specification	Specimen Orientation [Note (2)]	Nominal Bolt Size, in. (mm)	Number of Specimens	Energy, ft-lbf (J) [Note (1)] for Specified Minimum Yield Strength, ksi (MPa) Up to 135 (930), Incl.	Over 135 (930)
SA-320	Longitudinal	≤2 (50)	Note (3)	Note (3)	Not applicable
All others [Note (4)]	Longitudinal	All	Average for 3	30 (41)	35 (47)
			Minimum for 1 [Note (5)]	24 (33)	28 (38)

NOTES:
(1) Energy values in this Table are for standard size specimens. For subsize specimens, these values shall be multiplied by the ratio of the actual specimen width to that of a full-size specimen, 10 mm (0.394 in.).
(2) Specimen orientation is relative to the axis of the bolt.
(3) The requirements of ASME SA-320, including the temperature to be used for impact testing, shall apply.
(4) Charpy V-notch impact testing is not required for nuts and washers.
(5) See KM-260 for permissible retests.

any, to which the vessel or vessel component will be later subjected. The holding time at temperature shall not be less than that applied to the vessel or vessel component (except that the total time at each temperature may be applied in one heating cycle) and the cooling rate shall not be faster.

KM-242.2 Separate Test Coupons. The coupons that are quenched separately, as described in KM-241(b), shall be tempered similarly and simultaneously with the vessel or component which they represent. The conditions for subjecting the test coupons to subsequent thermal treatment(s) shall be as described in KM-242.1.

KM-243 Number of Tests

One tensile test and one impact test shall be made on material from coupons representing each lot of material in each vessel or vessel component heat treated. A lot is defined as material from the same heat, heat treated simultaneously and having thicknesses within ±20% or $\frac{1}{2}$ in. (13 mm) of nominal thickness, whichever is smaller.

(a) Coupons not containing welds shall meet the complete tensile requirements of the material specification and impact requirements of this Part.

(b) Coupons containing weld metal shall be tested across the weld and shall meet the required mechanical property requirements of the material specification; in addition, the minimum impact requirements shall be met by samples with notches in the weld metal. The form and dimension of the tensile test specimen shall conform to QW-462.1(a) or QW-462.1(d) of Section IX. Charpy impact testing shall be in accordance with the requirements of Article KT-2.

KM-250 SUPPLEMENTARY TOUGHNESS REQUIREMENTS FOR PRESSURE-RETAINING COMPONENT MATERIALS

Where a fracture mechanics evaluation in accordance with Article KD-4 is to be conducted, a value of K_{Ic} is required for the analysis. The designer shall specify the minimum value of K_{Ic} required, the number of tests to be performed, and shall indicate which of the following methods are to be used to verify that the material meets this value.

The orientation of the direction of crack propagation for all test coupons shall be the same as the direction of crack propagation expected in the fracture mechanics analysis conducted in accordance with Article KD-4.

KM-251 Charpy V-Notch Impact Testing

The designer may require that the pressure retaining component meet minimum Charpy V-notch absorbed energy values that are greater than those specified in KM-234.2 in order to verify compliance with the minimum K_{Ic} value. If supplemental impact testing is conducted, it shall be performed in accordance with SA-370 and be conducted at a temperature not exceeding the impact test temperature specified in KM-234.1. It shall be the designer's responsibility to determine and specify the appropriate K_{Ic}–CVN conversion equation to be used to ascertain the Charpy V-notch acceptance criterion (see Nonmandatory Appendix D).

KM-252 *CTOD* Fracture Toughness Testing

The designer may require that *CTOD* (crack tip opening displacement) testing of the high pressure retaining component be conducted to verify compliance with the minimum K_{Ic} value. If *CTOD* testing is required, it shall be performed in accordance with ASTM E 1290, and be conducted at a temperature not exceeding the impact test temperature specified in KM-234.1. The temperature reduction values given in Table KM-212 do not apply. It shall be the designer's responsibility to determine and specify the appropriate K_{Ic}–$CTOD$ conversion equation to be used to ascertain the *CTOD* acceptance criterion (see Nonmandatory Appendix D).

KM-253 J_{Ic} Fracture Toughness Testing

The designer may require that J_{Ic} testing of the pressure retaining component be conducted to verify compliance with the minimum K_{Ic} value. If J_{Ic} testing is required, it shall be performed in accordance with ASTM E 1820 and shall be conducted at a temperature not exceeding the impact test temperature specified in KM-234.1. The temperature reduction values given in Table KM-212 do not apply. It shall be the designer's responsibility to determine and specify the appropriate K_{Ic}–J_{Ic} conversion equation to be used to ascertain the J_{Ic} acceptance criterion (see Nonmandatory Appendix D).

KM-254 K_{Ic} Fracture Toughness Testing

The designer may, at his option, require that direct K_{Ic} testing of the pressure retaining component be conducted to verify compliance with the specified minimum K_{Ic} value. If such testing is required, it shall be performed in accordance with ASTM E 399 and shall be conducted at a temperature not exceeding the impact test temperature specified in KM-234.1. The temperature reduction values given in Table KM-212 do not apply.

KM-260 RETESTS

KM-261 General Retest Requirements

The following retest requirements apply to tension, Charpy V-notch impact, and *CTOD,* J_{Ic}, and K_{Ic} fracture toughness tests.

(a) If any test specimen fails to meet the applicable acceptance criteria for mechanical reasons, such as test equipment malfunction or improper specimen preparation, the results may be discarded and another representative specimen may be substituted.

(b) If any test specimen fails to meet the applicable acceptance criteria for nonmechanical reasons, two representative specimens as close to the original specimen location as possible may be selected for retesting without reheat treatment, provided the failure was not caused by preexisting material defects such as ruptures, flakes, or cracks. Both of these specimens shall meet the applicable acceptance criteria (see KM-262 for Charpy V-notch impact retests).

(c) Only one retesting is permitted. If the material fails the retest, it may be retempered or reheat treated, as necessary.

KM-262 Special Charpy V-Notch Impact Retest Requirements

(a) A Charpy V-notch impact retest is permitted if the average absorbed energy value meets the applicable acceptance criteria but the absorbed energy value for one specimen is below the specified minimum for individual specimens. The retesting shall consist of two representative impact specimens removed from a location adjacent to and on either side, if possible, of the original specimen location. Each of the retest specimens shall exhibit an absorbed energy value equal to or greater than the minimum average value.

(b) Only one retesting is permitted. If the material fails the retest, it may be retempered or reheat treated, as necessary.

ARTICLE KM-3
SUPPLEMENTARY REQUIREMENTS FOR BOLTING

KM-300 REQUIREMENTS FOR ALL BOLTING MATERIALS

KM-301 Scope

In this Division, bolting includes the following metallic fasteners: bolts, stud bolts, studs, cap screws, nuts, and washers.

KM-302 Material Specifications and Yield Strength Values

Specifications, supplementary rules, and yield strengths at temperature for acceptable bolting materials are specified in Table Y-3 in Subpart 1 of Section II, Part D.

KM-303 Examination of Bolts, Studs, and Nuts

Bolts, studs, and nuts shall be examined in accordance with KE-260.

KM-304 Threading and Machining of Studs

Threading and machining of studs shall meet the requirements of KD-621.

KM-305 Use of Washers

The use of washers is optional. When used, they shall be of wrought material.

KM-306 Materials for Nuts and Washers

Materials for steel nuts and washers shall conform to SA-194 or to the requirements for nuts in the specification for the bolting material with which they are to be used.

KM-307 Requirements for Nuts

Nuts shall be semifinished, chamfered, and trimmed. Nuts shall be threaded to Class 2B or finer tolerances according to ASME B1.1.

KM-307.1 Use With Flanges. For use with flanges, nuts shall conform at least to the dimensions specified in ASME/ANSI B18.2.2 for heavy series nuts.

KM-307.2 Use With Other Connections. For use with connections designed in accordance with the rules in Part KD, nuts may be of the American National Standard heavy series or they may be of other dimensions provided their static and fatigue strengths are sufficient to maintain the integrity of the connection. Due consideration shall be given to bolt hole clearance, bearing area, thread form, class of fit, thread shear, and radial thrust from threads.

KM-307.3 Depth of Engagement. Nuts shall engage the threads for the full depth of the nut.

KM-307.4 Special Design. Nuts of special design may be used provided their strength meets the requirements of KM-307.2.

ARTICLE KM-4
MATERIAL DESIGN DATA

KM-400 CONTENTS OF TABLES OF MATERIAL DESIGN DATA

(a) Vessels fabricated in accordance with the rules of this Division shall be built using the materials listed in the following tables unless specifically exempted by this Division:

(1) Table KCS-1

(2) Table KHA-1

(3) Table KNF-1

(b) Material property data for all materials that may be used under the rules of this Division are specified in the following tables in Section II, Part D:

(1) Yield Strengths, S_y, are specified in Table Y-3 in Subpart 1.

(2) Tensile Strengths, S_u, for SA-231 and SA-232 materials only are specified in Table U-2 in Subpart 1.

(3) Coefficients of thermal expansion are specified in Tables TE-1 and TE-4 in Subpart 2.

TABLE KCS-1
CARBON AND LOW ALLOY STEELS

Spec. No.	Type/Grade	Spec. No.	Type/Grade	Spec. No.	Type/Grade
SA-105	. . .	SA-372	E Cl. 70, F Cl. 70, J Cl. 110	SA-543	C Cl. 1 & 2; B Cl. 1 & 2
SA-106	A, B, C	SA-387	22 Cl. 2	SA-723	1 Cl. 1, 2, 3, 4, & 5; 2 Cl. 1, 2, 3, 4, & 5; 3 Cl. 1, 2, 3, 4, & 5
SA-193	B7, B16	SA-508	2 Cl. 1; 3 Cl. 1; 4N Cl. 1, 2, & 3	SA-724	A, B, C
SA-225	C	SA-516	60, 65, 70	SA-738	B
SA-231	. . .	SA-517	A, B, E, F, J, P	SA-832	21V
SA-232	. . .	SA-533	B Cl. 3, D Cl. 3	SA-905	Cl. 1 & 2
SA-320	L7, L7A, L7M, L43	SA-541	4N Cl. 2 & 3, 5 Cl. 1 & 2		
SA-333	6				
SA-335	P1, P11, P22				
SA-336	F3V, F22 Cl. 3				

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TABLE KHA-1
HIGH ALLOY STEELS

Spec. No.	Type/Grade	Spec. No.	Type/Grade	Spec. No.	Type/Grade
SA-276	316 Cond. B & S	SA-336	F316, F316H	SA-638	660 Type 1 & 2
SA-312	TP316, TP316H	SA-453	660 Cl. A & B	SA-705	XM-12 Cond. H900, H925, H1025, H1075, H1100, H1150, & H1150M; XM-13 Cond. H950, H1000, H1025, H1050, H1100, H1150, & H1150M; XM-16 Cond. H900, H950, & H1000; XM-25 Cond. H900, H950, H1000, H1025, H1050, H1100, & H1150; 630 Cond. H900, H925, H1025, H1075, H1100, H1150, & H1150M; 631 Cond. RH950 & TH1050
SA-320	B8 Cl. 1 & 2; B8A Cl. 1A; B8C Cl. 1 & 2; B8CA Cl. 1A; B8F Cl. 1, S & Se; B8FA Cl. 1A, S & Se; B8M Cl. 1 & 2; B8MA Cl. 1A; B8T Cl. 1 & 2; B8TA Cl. 1A	SA-479	316, 316H Cond. Ann.		
		SA-564	630 Cond. H1025, H1075, H1100, & H1150; XM-12 Cond. H900, H925, H1025, H1075, H1100, H1150, & H1150M; XM-13 Cond. H950, H1000, H1025, H1050, H1100, H1150, & H1150M; XM-16 Cond. H900, H950, & H1000; XM-25 Cond. H900, H950, H1000, H1025, H1050, H1100, & H1150		

TABLE KNF-1
NICKEL AND NICKEL ALLOYS

Spec. No.	UNS No.	Spec. No.	UNS No.	Spec. No.	UNS No.
SA-164	N04400 Cond. Ann.	SB-407	N08800 Cond. C.W. Ann.	SB-564	N04400, N06600, N06625, N08800, N08810 Cond. Ann.
SA-165	N04400 Cond. Ann. & S.R.	SB-408	N08800, N08810 Cond. Ann.		
SB-166	N06600 Cond. Ann.	SB-409	N08800, N08810 Cond. Ann.		
SB-167	N06600 Cond. Ann.	SB-444	N06625 Gr. 1	SB-574	N10276
		SB-446	N06625 Gr. 1		

(4) Moduli of elasticity are specified in Tables TM-1 and TM-4 in Subpart 2.

(5) Coefficients of thermal diffusivity are specified in Table TCD in Subpart 2.

04 *(c)* With the publication of the 2004 Edition, Section II Part D is published as two separate publications. One publication contains values only in U.S. Customary units and the other contains values only in SI units. The selection of the version to use is dependent on the set of units selected for construction.

PART KD
DESIGN REQUIREMENTS

ARTICLE KD-1
GENERAL

04 KD-100 SCOPE

(a) The requirements of this Part KD provide specific design criteria for some commonly used pressure vessel shapes under pressure loadings and, within specified limits, criteria or guidance for treatment of other loadings. This Part does not contain rules to cover all details of design.

(b) A complete analysis, including a fatigue or fracture mechanics analysis, of all structural parts of the vessel shall be performed in accordance with applicable Articles of this Part. All of the loadings specified in the User's Design Specification (see KG-311) and all stresses introduced by the fabrication processing, autofrettage, temperature gradients, etc., shall be considered. This analysis shall be documented in the Manufacturer's Design Report. See KG-324.

(c) Small vessels, which the User's Design Specification clearly states are for research laboratory service only, are exempt from the requirements of Articles KD-3 and KD-4, provided all the following are met:

(1) the volume does not exceed 75 in.^{3} (1.23 L)

(2) the required number of design cycles does not exceed 1,000

(3) all design limits of Article KD-2 are satisfied

(4) the vessel is intended to be operated at all times with supplementary protective devices to provide personnel safety

KD-101 Materials and Combinations of Materials

A vessel shall be designed for and constructed of materials permitted in Part KM. Any combination of those materials in Part KM may be used, provided the applicable rules are followed and the requirements of Section IX for welding dissimilar metals are met, when welding is involved.

Material design values such as moduli of elasticity, coefficients of thermal expansion, yield and tensile strength values, and other material properties are given in Section II, Part D. With the publication of the 2004 Edition, Section II Part D is published as two separate publications. One publication contains values only in U.S. Customary units and the other contains values only in SI units. The selection of the version to use is dependent on the set of units selected for construction.

NOTE: See ASME High Pressure Systems Standard Sections 2000, 5000, and 6000 for guidance in establishing supplementary protective device requirements.

KD-102 Types of Construction

Article KD-2 contains rules for the basic design of all pressure vessels within the scope of this Division. Article KD-2 also provides rules for designing nonwelded vessels that are constructed of forged or otherwise wrought material machined to its final configuration.

For openings, closures, and other types of construction, such as multiple-wall and layered, wire-wound, or welded, these rules shall be supplemented by those given in the appropriate Articles, i.e., KD-6, KD-8, KD-9, and KD-11.

KD-103 Protective Liners

A protective liner is the innermost layer of a pressure vessel, whose function is to protect the surface of load-carrying members against chemical and mechanical damage. It can be of any suitable material, and this material need not be listed in Part KM. Credit shall not be given for the thickness of a protective liner in the static strength and primary stress calculations, but the effects of a liner shall be considered in the secondary stress and number of design cyclic loading calculations. The designer shall consider the consequences of the liner failure in order to preserve the integrity of the pressure boundary.

KD-110 LOADINGS

Some of the loadings which shall be considered are as follows (see KG-311.8):

(a) internal and external pressure, at coincident temperature

(b) service temperature conditions that produce thermal stresses, such as those due to thermal gradients or differential thermal expansion

(c) weight of vessel and normal contents under operating or test conditions

(d) superimposed loads caused by other vessels, piping, or operating equipment

(e) wind loads and earthquake loads

(f) reactions of supporting lugs, rings, saddles, or other types of vessel supports

(g) impact loads, including rapidly fluctuating pressures and reaction forces from relief devices

(h) loadings resulting from expansion or contraction of attached piping or other parts

(i) residual stresses, introduced at fabrication, e.g., by autofrettage, hydrostatic test, shrink fit, prestressed wire or strip winding, rolling, forming, welding, thermal treatments, and surface treatment such as shot peening

(j) the effect of fluid flow rates, density, jet impingement streams, inlet and outlet temperatures, on loadings

KD-111 Limits of Test Pressure

The lower and upper limits on test pressure are specified in Article KT-3.

KD-112 Basis for Design Temperature

(a) When the occurrence of different metal temperatures during operation can be definitely predicted for different axial zones of the vessel, the design of the different zones may be based on their predicted temperatures.

When the vessel is expected to operate at more than one temperature and under different pressure conditions, all significant sets of temperature and coincident pressure shall be considered.

The metal temperature under steady operating conditions may vary significantly through the thickness. The temperature used in the design shall be not less than the mean temperature through the thickness of the part being examined under the set of conditions considered. If necessary, the metal temperature shall be determined by computations or by measurements from equipment in service under equivalent operating conditions. However, in no case shall the temperature at any point in the metal or the design temperature exceed the maximum temperature in the yield strength tables in Section II, Part D for the material in question or exceed the temperature limitations specified elsewhere in this Division, except as provided in KD-113.

In vessels exposed to repeated fluctuations of temperature in normal operation, the design shall be based on the highest fluid temperature, unless the designer can demonstrate by calculation or experiment that a lower temperature can be justified.

For determination of the fracture toughness to be used in the fracture mechanics evaluation, the minimum design metal temperature (MDMT) at the point of interest shall be used. See KG-311.4(d) for a definition of MDMT and for service restriction when the vessel temperature is below MDMT.

The lower limit of the metal temperature during the hydrostatic test is given in KT-320.

(b) It is the responsibility of the designer to specify the anticipated temperature of the overpressure relief device.

KD-113 Upset Conditions

Sudden process upsets, which occur infrequently, can cause local increases or decreases in metal surface temperature. For the purpose of the static pressure design requirements, no credit shall be taken for that portion of the wall thickness which is predicted to exceed the maximum temperature permitted in the material's yield strength table. The minimum metal surface temperature that occurs during sudden cooling shall be considered in the fracture toughness evaluations.

A complete stress and fracture mechanics analysis is required for any credible upset condition.

KD-114 Environmental Effects

The designer shall consider environmental effects, such as corrosion, erosion, and stress corrosion cracking, and their influence on the material thickness, fatigue, and fracture behavior.

KD-120 DESIGN BASIS

The design of the vessel parts is based on the requirement that the average and local stress intensities shall be limited to values which ensure an adequate safety margin against relevant failure modes under the stated conditions. The fulfillment of this requirement shall be demonstrated by a calculation based on the following:

(a) the results of a stress analysis (Article KD-2) giving the average stress intensity across section areas and the local stress intensity at critical points

(b) yield strength S_y (see Part KM and Section II, Part D)

(c) fracture toughness K_{Ic} (see Nonmandatory Appendix D)

(d) fatigue crack growth constants C and m (see Article KD-4)

(e) fatigue strength S_a (see Article KD-3)

(f) mill undertolerance on material thickness

(g) corrosion/erosion allowances [see KG-311.7(b)]

KD-121 Relevant Failure Modes

Some of the relevant failure modes are the following:

(a) through the thickness yielding as a consequence of too high an average stress intensity

(b) local yielding of a magnitude which could produce excessive distortion and unacceptable transfer of load to other portions of the structure, or leakage

(c) leak caused by stable fatigue crack propagation through the wall (leak-before-burst)

(d) unstable crack growth, i.e., fast fracture

(e) buckling (see KD-252)

KD-130 DESIGN CRITERIA

KD-131 Maximum Shear Stress Theory

In accordance with this theory, yielding at any point occurs when the difference between the algebraically largest and the algebraically smallest principal stress reaches the yield strength of the material.

KD-132 Residual Stress

Except as provided in KD-924, residual stresses are not considered in the static analysis, but shall be considered in the calculated number of design cycles in accordance with Article KD-3 or KD-4.

(a) The vessel may contain residual stresses of predetermined magnitudes and distributions. These residual stresses may be produced by assembling concentric cylinders with an interference in the dimensions of the mating surfaces (shrink fitting). Such vessels shall meet the requirements of Articles KD-8 and KF-8.

(b) Residual stresses also may be produced by autofrettage and wire winding, in which case the component shall meet the requirements of Articles KD-5, KD-9, KF-5, or KF-9, as appropriate.

(c) Residual stresses from fabrication operations such as welding and thermal heat treatments may also be present. See KD-110(i).

KD-133 Openings and Closures

Article KD-6 provides rules for the design of openings through vessel walls, connections made to these openings, and end closures and their attachment to cylindrical vessels. Additional guidance is provided in Nonmandatory Appendix H.

KD-140 FATIGUE EVALUATION

If it can be shown that the vessel will have a leak-before-burst mode of failure (see KD-141), the calculated number of design cycles may be determined using the rules of either Article KD-3 or Article KD-4. However, if the leak-before-burst mode of failure cannot be shown, then the Article KD-4 procedure shall be used.

KD-141 Leak-Before-Burst Mode of Failure

(a) For the purpose of this Code, it may be assumed that a leak-before-burst failure mode will occur if the critical crack depth in the appropriate plane is greater than the wall thickness at the location considered. Since many of the available methods for calculating stress intensity factors are not accurate for very deep cracks, it may not be possible to determine critical crack depths that are greater than 0.8 times the wall thickness. In such cases, leak-before-burst mode of failure may be assumed if both of the following conditions are met:

(1) the stress intensity factor at a crack depth equal to 0.8 times the wall thickness is less than the fracture toughness of the material

(2) the remaining ligament (distance from the crack tip to the free surface that the crack is approaching) is less than the quantity $(K_{Ic}/S_y)^2$

(b) For the case of failure due to a crack in the tangential-radial plane, such as a crack growing radially from an end closure thread or a blind end, it may not be possible to ensure a leak-before-burst mode of failure. In such cases the number of design cycles shall be calculated using Article KD-4.

04 *(c)* For additional leak-before-burst criteria for shrink-fit layered vessels, see KD-810(f). For wire-wound vessels, see KD-931.

(d) Alternately, leak-before-burst mode of failure can be established by the User based on documented experience within the industry with vessels of similar design, size, material properties, and operating conditions (see KG-311.10).

ARTICLE KD-2
BASIC DESIGN REQUIREMENTS

KD-200 SCOPE

This Article provides basic design rules and definitions for vessels constructed in accordance with this Code. Additional rules for fatigue life and special construction techniques are given in later Articles of this Part.

If construction details do not satisfy the various configurations contained herein, or if no applicable equations are presented, a detailed stress analysis shall be made to show conformance with this Part.

KD-210 TERMS RELATING TO STRESS ANALYSIS

Terms used relating to stress analysis are defined below.

(a) Autofrettage. Autofrettage is a process for producing a system of favorable residual stresses in a thick walled vessel by pressurizing to produce plastic deformation in part or all of the wall thickness.

(b) Deformation. Deformation of a component part is alteration of its shape or size due to stress or temperature changes.

(c) Fatigue Strength Reduction Factor. This is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. Values for some specific cases, based on experiment, are given elsewhere in this Division. In the absence of experimental data, the theoretical stress concentration factor may be used.

(d) Gross Structural Discontinuity. A gross structural discontinuity is a source of stress or strain intensification which affects a relatively large portion of a structure and has a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

(e) Inelasticity. Inelasticity is a general characteristic of material behavior in which the material does not return to its original (undeformed) shape and size after removal of all applied loads. Plasticity and creep are special cases of inelasticity.

(1) Plasticity. Plasticity is the special case of inelasticity in which the material undergoes time-independent nonrecoverable deformation.

(2) Plastic Analysis. Plastic analysis is that method which computes the structural behavior under given loads considering the plasticity characteristics of the materials including strain hardening and the stress redistribution occurring in the structure. (Strain rate effects may also be significant where impact or other dynamic loads are involved.)

(3) Plastic Instability Load. The plastic instability load for members under predominantly tensile or compressive loading is defined as that load at which unbounded plastic deformation can occur without an increase in load. At the plastic tensile instability load, the true stress in the material increases faster than strain hardening can accommodate.

(4) Strain Limiting Load. When a limit is placed upon a strain, the load associated with the strain limit is called the strain limiting load.

(5) Limit Analysis. Limit analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (nonstrain-hardening). In limit analysis, the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. Two bounding methods are used in limit analysis: the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field. For beams and frames, the term *mechanism* is commonly used in lieu of *kinematically admissible velocity field.*

(6) Collapse Load — Limit Analysis. The methods of limit analysis are used to compute the maximum load a structure made of ideally plastic material can carry. The deformations of an ideally plastic structure increase without bound at this load, which is termed collapse load.

(7) Plastic Hinge. A plastic hinge is an idealized concept used in limit analysis. In a beam or frame, a plastic hinge is formed at the point where the moment, shear, and axial force lie on the yield interaction surface. In plates and shells, a plastic hinge is formed where the generalized stresses lie on the yield surface.

(8) Creep. Creep is the special case of inelasticity that relates to the stress-induced time-dependent deformation under load. Small time-dependent deformations may occur after the removal of all applied loads.

(9) Ratcheting. Ratcheting is a progressive incremental inelastic deformation or strain which can occur in a component that is subjected to variations of mechanical stress, thermal stress, or both (thermal stress ratcheting is partly or wholly caused by thermal stress).

(10) Shakedown. Shakedown of a structure occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic–plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic.

(11) Free End Displacement. Free end displacement consists of the relative motions that would occur between an attachment and connected structure or equipment if the two members were separated. Examples of such motions are those that would occur because of relative thermal expansion of piping, equipment, and equipment supports, or because of rotations imposed upon the equipment by sources other than the piping.

(12) Expansion Stresses. Expansion stresses are those stresses resulting from restraint of free end displacement.

(f) Load Stress. The stress resulting from the application of a load, such as internal pressure or the effects of gravity, as distinguished from thermal stress.

(g) Local Primary Membrane Stress, P_L. Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a primary loading, discontinuity, or both effects would, if not limited, produce excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress. An example of a local primary membrane stress is the membrane stress in a shell produced by external load and moment at a permanent support or at a nozzle connection.

(h) Local Structural Discontinuity. A local structural discontinuity is a source of stress or strain intensification that affects a relatively small volume of material and does not have a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples are small fillet radii and small attachments.

(i) Membrane Stress. Membrane stress is the component of normal stress that is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

(j) Normal Stress, σ. The component of stress normal to the plane of reference (this is also referred to as *direct stress*). Usually, the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration, and the other of which varies with the location across the thickness.

(k) Operational Cycle. An operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. Three types of operational cycles are considered:

(1) start-up/shutdown cycle, defined as any cycle that has atmospheric temperature, pressure, or both as its extremes and normal operation conditions as its other extreme

(2) the initiation of and recovery from any emergency or upset condition that shall be considered in the design

(3) normal operating cycle, defined as any cycle between start-up and shutdown which is required for the vessel to perform its intended purpose

(l) Peak Stress, F. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress that is not highly localized falls into this category if it is of a type which cannot cause progressive deformation (ratcheting). Examples of peak stress are:

(1) the thermal stress which occurs when a relatively thin inner shell material is dissimilar from a relatively thick outer shell material

(2) the thermal stress in the wall of a vessel or pipe caused by a rapid change in temperature of the contained fluid

(3) the stress at a local structural discontinuity

(m) Primary Stress. A normal stress or a shear stress developed by the imposed loading which is necessary to satisfy the simple laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or at least in gross distortion. A thermal stress is not classified as a primary stress. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are:

(1) average through-wall longitudinal stress and the average through-wall circumferential stress in a closed cylinder under internal pressure, remote from discontinuities

(2) bending stress in the central portion of a flat head due to pressure

(n) Secondary Stress. A secondary stress is a normal stress or a shear stress developed by the constraint of adjacent parts or by self-constraint of a structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are:

(1) general thermal stress [see KD-210(l)(1)]

(2) bending stress at a gross structural discontinuity

(o) Shape Factor. The shape factor, α, is defined as the ratio of the moment that produces a full plastic section (no strain hardening) to the bending moment that produces initial yielding at the extreme fibers of the section. $\alpha = 1.5$ for a rectangular section.

(p) Shear Stress, τ. The shear stress is the component of stress tangent to the plane of reference.

(q) Stress Intensity, S. The stress intensity is defined as twice the maximum shear stress. In other words, the stress intensity is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tension stresses are considered positive and compression stresses are considered negative.

(r) Thermal Stress. A self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as follows:

(1) general thermal stress, which is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting local stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore, this type is classified as secondary stress in Fig. KD-230. Examples of general thermal stress are:

(a) stress produced by an axial temperature gradient in a cylindrical shell.

(b) stress produced by temperature differences between a nozzle and the shell to which it is attached.

(c) the equivalent linear stress produced by the radial temperature gradient in a cylindrical shell. Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

(2) local thermal stress, which is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses in Fig. KD-230. Examples of local thermal stress are:

(a) the stress in a small hot spot in a vessel wall

(b) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell

(c) the thermal stress in a liner material that has a coefficient of expansion different from that of the base metal

(s) Stress Cycle. A stress cycle is a condition in which the alternating stress difference (see Article KD-3) goes from an initial value through an algebraic maximum value and an algebraic minimum value, and then returns to the initial value. A single operational cycle may result in one or more stress cycles.

KD-220 DERIVATION OF STRESS INTENSITIES

This paragraph describes the procedure for the linear elastic calculation of the stress intensities that are subject to specified limits. The steps in the procedure are given in the following subparagraphs. The Designer shall use the elastic–plastic analysis method (see KD-240) for cylindrical and spherical shells that have diameter ratios greater than 1.5 (see KD-251).

(a) At the point on the vessel that is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them the subscripts *t, l,* and *r.* The stress components in these directions are then designated σ_t, σ_l, and σ_r for direct (normal) stresses, and τ_{tl}, τ_{tr}, and τ_{rl} for shear stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the categories below (see Fig. KD-230):

(1) general primary membrane stress, P_m

(2) local primary membrane stress, P_L

(3) primary bending stress, P_b

(4) secondary stress, Q

(5) peak stress, F

(c) Use Fig. KD-230 to provide assistance in assigning the stress values to the appropriate category. Consider

each box in Fig. KD-230. For each of the three normal stress components and each of the three shear components, calculate the algebraic sum of the values which results from the different types of loadings. The result is a set of six stress components in each box.

(d) Translate the stress components in the *t, l,* and *r* directions into principal stresses σ_1, σ_2, and σ_3. (In many pressure vessel calculations, the *t, l,* and *r* directions may be so chosen that the shearing stress components are zero and σ_1, σ_2, and σ_3 are identical to σ_t, σ_l, and σ_r, respectively.)

(e) Calculate the stress differences S_{12}, S_{23}, and S_{31} from Eqs. (1) through (3):

$$S_{12} = \sigma_1 - \sigma_2 \tag{1}$$

$$S_{23} = \sigma_2 - \sigma_3 \tag{2}$$

$$S_{31} = \sigma_3 - \sigma_1 \tag{3}$$

The stress intensity, S, is the largest absolute value of S_{12}, S_{23}, and S_{31}.

Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the stress component level in KD-220(b) or (c).

KD-230 STRESS LIMITS

Designs shall satisfy applicable requirements for the most severe combination of loadings and limits of stress intensities. For all components except spherical and cylindrical monobloc shells remote from discontinuities, those requirements are as specific in Fig. KD-230 and the subparagraphs that follow. The stress intensity calculated per KD-220(e) from the stress components in any box in Fig. KD-230 shall not exceed the stress limits that are shown in the circle adjacent to each stress intensity category in Fig. KD-230. Designs shall include the load combinations and maximum stress limits under the conditions of design and operation.

The yield strength values, S_y, used in the calculations shall be taken from the tables in Section II, Part D for the design temperature, except as indicated in Note (3) of Fig. KD-230.

04 KD-231 Primary Membrane and Bending Stresses

(a) The general primary membrane stress intensity, P_m, across the thickness of the section under consideration, due to any specified combination of design pressure and mechanical loading, shall not exceed the design stress intensity value $S_y/1.5$.

(b) The local primary membrane stress intensity, P_L, (see Fig. KD-230) due to any specified combination of design pressure and mechanical loadings shall not exceed S_y. The distance over which this stress intensity exceeds $0.73(S_y)$ shall not extend in the meridional direction more than $\sqrt{R_m t}$, where R_m is the radius at the midsurface of the shell or head at the location of the highest local primary membrane stress intensity measured normal to the surface from the axis of revolution in the meridional plane, and t is the nominal thickness of the shell or head under consideration.

(c) The primary bending, P_b, plus local primary membrane stress intensity, P_L, due to any specified combination of design pressure and mechanical loadings expected to occur simultaneously shall not exceed $\alpha S_y/1.5$. (See Fig. KD-230 when the design of components involves combinations of calculated stresses.)

KD-232 Pure Shear Stress

The average primary shear stress across a section loaded in pure shear (for example, keys, shear rings, pins) shall be limited to $0.4S_y$. For screw threads, see KD-611. The maximum primary shear under design conditions, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.57S_y$.

KD-233 Bearing Stress

(a) The average bearing stress for resistance to crushing under the maximum design load shall be limited to the yield strength S_y at temperature, except that when the distance to a free edge is greater than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted.

(b) When bearing loads are applied on parts having free edges, such as at a protruding edge, the possibility of a shear failure shall be considered. In the case of primary stress only, the average shear stress shall be limited to $0.4S_y$. In the case of primary stress plus secondary stress, the average stress shall not exceed $0.5S_y$.

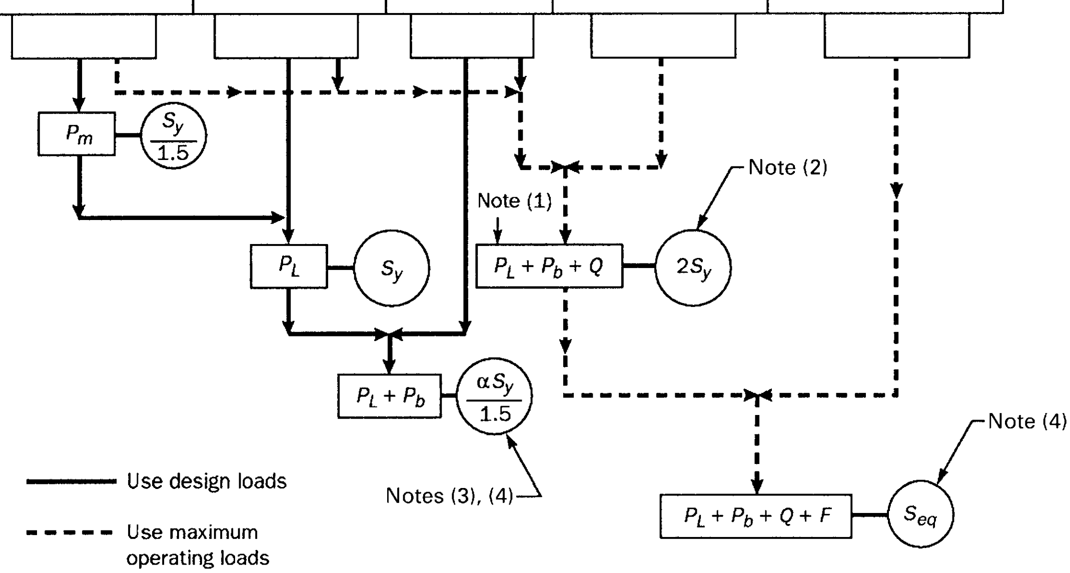
(c) When considering bearing stresses from pins in supporting members, the S_y at temperature value is applicable, except that a value of $1.5S_y$ may be used if the pin is at least three pin diameters from the edge.

KD-234 Secondary Stresses

The magnitude of the primary-plus-secondary stresses is limited to $2S_y$ per Fig. KD-230.

Stress Category	Primary			Secondary Membrane Plus Bending [Note (1)]	Peak
	General Membrane	Local Membrane	Bending		
Description	Average primary stress across solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Average primary stress across any solid section. Considers discontinuities but not concentrations. Produced only by mechanical loads.	Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations. Produced by mechanical loads.	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical load or by differential thermal expansion. Excludes local stress concentrations.	(1) Increment added to primary or secondary stress by a concentration (notch). (2) Certain thermal stresses which may cause fatigue but not distortion of vessel shape.
Symbol	P_m	P_L	P_b	Q	F

Combination of stress components and allowable limits of stress intensities



[Notes to figure follow on next page]

04 FIG. KD-230 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY

GENERAL NOTE: The stress limits permitted in these design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary-plus-secondary stress intensity of $2S_y$ has been placed at a level that ensures shakedown to elastic action after a few repetitions of the stress cycle, except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation.

NOTES:

(1) The stresses in Category Q are those parts of the total stress that are produced by thermal gradients, structural discontinuities, etc., and do not include primary stresses, which may also exist at the same point. It should be noted, however, that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of P_m (or P_L) + P_b + Q and not Q alone. Similarly, if the stress in Category F is produced by a stress concentration, the quantity F is the additional stress produced by the notch, over and above the nominal stress. For example, if a plate has a nominal stress intensity S and has a notch with a stress concentration factor K, then $P_m = S$, $P_b = 0$, $Q = 0$, $F = P_m(K - 1)$, and the peak stress intensity equals $P_m + P_m(K - 1) = KP_m$.

(2) This limitation applies to the range of stress intensity. When the secondary stress is due to a temperature excursion at the point at which the stresses are being analyzed, the value of S_y shall be taken as the average of the S_y values tabulated in Section II, Part D for the highest and the lowest temperatures of the metal during the transient. When part or all of the secondary stress is due to mechanical load, the value of S_y shall be taken as the S_y value for the highest temperature of the metal during the transient.

(3) α is the shape factor [see KD-210(o)].

(4) This applies only if a fatigue analysis is performed in accordance with Article KD-3. See KD-140.

FIG. KD-230 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY (CONT'D)

KD-235 Triaxial Stresses

The algebraic sum of the three principal stresses, including the primary, secondary, and peak stresses, shall not exceed $2.5S_y$.

04 KD-240 ELASTIC–PLASTIC ANALYSIS

The limits on general membrane stress intensity, local membrane stress intensity, primary membrane plus primary bending stress intensity, and primary-plus-secondary membrane plus bending stress intensity from KD-230, need not be satisfied and the equations for cylindrical and spherical shells in KD-250 need not be used, if an analysis is conducted using numerical methods such as elastic–plastic finite element or finite difference analysis, and the results satisfy the requirements in KD-240(a) through (f). The material shall be assumed to be ideal elastic, perfectly plastic (nonstrain-hardening[1]) with a yield strength equal to the value at temperature from the appropriate table in Section II, Part D.

(a) The design margin against collapse load [see KD-210(e)(6)] shall be at least 1.732 in the case of the most severe combination of specified loading.

(b) In addition, a design margin of at least 1.732 shall be applied to the higher of the following:

(1) the load that causes the strain to exceed 5% at any point in the structure. The designer shall consider the need to reduce this strain limit for confined liners made from materials which are not permitted for the primary pressure boundary in Part KM, and for areas of high triaxial tension.

(2) the load that causes yielding through the entire thickness of a cross section.

(c) Application of no more than two cycles of the maximum operating load, after application of the expected hydrotest or autofrettage load, shall result in shakedown to elastic conditions, except in small areas associated with local stress (strain) concentrations. These small areas shall exhibit a stable hysteresis loop [see KD-210(e)(9)], with no indication of progressive distortion.

(d) A fatigue analysis shall be conducted in accordance with Article KD-3, or a fracture mechanics evaluation in accordance with Article KD-4, whichever is applicable. The stress and strain values used in these fatigue analyses shall be obtained from the numerical analysis.

(e) The designer shall consider the effect of component displacements on the performance of vessel components and sealing elements, under design, hydrotest, and autofrettage loads as appropriate.

(f) The algebraic sum of the principal stresses shall not exceed $2.5S_y$.

KD-250 EQUATIONS FOR CYLINDRICAL AND SPHERICAL SHELLS

Below are equations for the limits of the design pressure. The purpose of these requirements is to ensure adequate safety against collapse. These equations are only appropriate for spherical and cylindrical shells remote from discontinuities.

[1] A small amount of strain hardening may be used if necessary to achieve stability in the numerical solution. This strain hardening shall not result in a calculated value of stress at any point, at the maximum load applied during the analysis, which is more than 5% above the yield strength.

04 KD-251 Shells Under Internal Pressure

The shell shall have a diameter ratio Y (see KD-260) which meets the requirements of KD-251.1, KD-251.2, KD-251.3, or KD-251.4, as applicable.

KD-251.1 Cylindrical Monobloc Shells. The design pressure P_D shall not exceed the limit set by the equation:

$$P_D = \frac{2}{3}(S_y)\ln(Y)$$

KD-251.2 Cylindrical Layered Shells. For shells consisting of n layers with different yield strengths, the equation in KD-251.1 is replaced by:

$$P_D = \sum_{j=1}^{n} \frac{2}{3}(S_{yj})\ln(Y_j)$$

where S_{yj} and Y_j are the yield strength and diameter ratio for each layer.

KD-251.3 Spherical Monobloc Shells. The design pressure P_D shall not exceed the limit set by the equation:

$$P_D = \frac{4}{3}(S_y)\ln(Y)$$

KD-251.4 Spherical Layered Shells. For shells consisting of n layers with different yield strengths, the equation in KD-251.3 is replaced by:

$$P_D = \sum_{j=1}^{n} \frac{4}{3}(S_{yj})\ln(Y_j)$$

KD-251.5 Additional Loads. If the shell is subject to loading in addition to the internal pressure, the design shall be modified as necessary so that the collapse pressure in the presence of the additional load is greater than or equal to 1.732 times the design pressure.

KD-252 Shells Under External Pressure

The shells shall have a diameter ratio that shall ensure the same safety against collapse as in KD-251. This means that the same equations are applicable for controlling the diameter ratios for shells under external pressure as those given in KD-251 for shells under internal pressure, provided that all loadings are considered and the longitudinal stress remains the intermediate principal stress (i.e., closed end case). Shells under external pressure shall also be checked for safety against buckling. For the special case of cylindrical monobloc shells, the following equation shall be used:

$$P_D = \frac{E(Y-1)^3}{40(1-\nu^2)Y^3}$$

but in no case shall exceed the value of P_D given by the equation in KD-251.1.

KD-260 PRINCIPAL STRESSES IN MONOBLOC VESSELS

For a vessel consisting of a hollow, circular cylinder of uniform wall thickness, the stresses in the cylinder wall remote from the ends of the cylinder or other discontinuities shall be calculated as follows if no residual stresses exist:

$$\sigma_t = \frac{P}{Y^2-1}(1+Z^2) \quad (1)$$

$$\sigma_r = \frac{P}{Y^2-1}(1-Z^2) \quad (2)$$

If the cylinder is a closed end, then:

$$\sigma_l = \frac{P}{Y^2-1} \quad (3)$$

where

D = diameter corresponding to any point in the wall
P = internal pressure
Y = diameter ratio D_O/D_I
Z = diameter ratio D_O/D

If the longitudinal stress is the intermediate principal stress, the maximum value of stress intensity S calculated from Eqs. (1), (2), and (3) is at the bore surface and is given by

$$S = P\frac{2Y^2}{Y^2-1} \quad (4)$$

When the longitudinal stress is not the intermediate principal stress, S shall be suitably calculated.

ARTICLE KD-3
FATIGUE EVALUATION

KD-300 SCOPE

This Article presents a traditional fatigue analysis design approach. In accordance with KD-140, if it can be shown that the vessel will fail in a leak-before-burst mode, then the number of design cycles shall be calculated in accordance with either Article KD-3 or Article KD-4. If a leak-before-burst mode of failure cannot be shown, then the number of design cycles shall be calculated in accordance with Article KD-4.

04 KD-301 General

Cyclic operation may cause fatigue failure of pressure vessels and components. While cracks often initiate at the bore, cracks may initiate at outside surfaces or at layer interfaces for autofrettaged and layered vessels. In all cases, areas of stress concentrations are a particular concern. Fatigue-sensitive points shall be identified and a fatigue analysis made for each point. The result of the fatigue analysis will be a calculated number of design cycles N_f for each type of operating cycle, and a calculated cumulative effect number of design cycles when more than one type of operating cycle exists.

The resistance to fatigue of a component shall be based on the design fatigue curves for the materials used.

In some cases it may be convenient or necessary to obtain experimental fatigue data for a component itself rather than for small specimens of the material (see KD-1260). If there are two or more types of stress cycles which produce significant stresses, their cumulative effect shall be evaluated by calculating for each type of stress cycle the usage factors U_1, U_2, U_3, etc., and the cumulative usage factor U per KD-330. The cumulative usage factor U shall not exceed 1.0.

KD-302 Theory

The theory used in this Article postulates that fatigue at any point is controlled by the alternating stress intensity S_{alt} and the associated mean stress σ_{nm} normal to the plane of S_{alt}. They are combined to define the equivalent alternating stress intensity S_{eq}, which is used with the design fatigue curves to establish the number of design cycles N_f.

KD-302.1 Alternating Stress Intensity. The alternating stress intensity S_{alt} represents the maximum range of shear stress.

KD-302.2 Associated Mean Stress. The associated mean stress σ_{nm} is the mean value of stress normal to the plane subjected to the maximum alternating stress intensity.

For welded construction, the associated mean stress shall not be combined with the alternating stress intensity [see KD-312.4(a)].

KD-310 STRESS ANALYSIS FOR FATIGUE EVALUATION

The calculation of the number of design cycles shall be based on a stress analysis of all fatigue-sensitive points.

KD-311 Loading Conditions and Residual Stresses

In this analysis, consideration shall be taken of the following loadings and stresses.

KD-311.1 Residual Stresses Due to Manufacturing

(a) Some manufacturing processes such as forming, etc., introduce residual tensile stresses of unknown magnitude. Unless these stresses are controlled by some method, such as postfabrication heat treatment or mechanical overstrain processes like autofrettage, these initial residual stresses shall be assumed to have a peak magnitude corresponding to the yield strength of the material.

(b) Manufacturing processes such as welding, heat treatment, forming, autofrettage, shrink fitting, and wire wrapping introduce residual stresses. Tensile residual stresses shall be included in the calculation of associated mean stresses. Compressive residual stresses may also be included. When calculating the residual stresses introduced by autofrettage, due account shall be taken of the influence of the Bauschinger effect (see Article KD-5).

If any combination of operational or hydrotest loadings will produce yielding at any point, any resulting change in the residual stress values shall be taken into account.

(c) In welded construction, no credit shall be taken for beneficial residual stresses within the weld metal or the heat-affected zone.

(d) In austenitic stainless steel construction, no credit shall be taken for beneficial residual stresses.

KD-311.2 Operating Stresses. Mean and alternating stresses shall be calculated for all loading conditions specified in the User's Design Specification. Stress concentration factors shall be determined by analytical or experimental techniques.

Ranges of stress intensities due to cyclic loadings and associated mean stresses (residual plus operational) shall be calculated on the assumption of elastic behavior. If these calculations show that yielding occurs, a correction shall be made. See KD-312.3.

KD-312 Calculation of Fatigue Stresses When Principal Stress Directions Do Not Change

For any case in which the directions of the principal stresses at the point being considered do not change during the operating cycle, the methods stated in KD-312.1 through KD-312.4 shall be used to determine the fatigue controlling stress components.

KD-312.1 Principal Stresses. Determine the values of the three principal stresses at the point being investigated for the complete operating cycle assuming the loading and conditions described in KD-311. These stresses are designated σ_1, σ_2, and σ_3.

KD-312.2 Alternating Stress Intensities. Determine the stress differences (maintain the proper algebraic sign for the complete operating cycle):

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

In the following, the symbol S_{ij} is used to represent any one of these three differences.

Identify the algebraic largest stress difference $S_{ij\,\max}$ and the algebraic smallest difference $S_{ij\,\min}$ of each S_{ij} during the complete operating cycle. Then the alternating stress intensity $S_{alt\,ij}$ is determined by:

$$S_{alt\,ij} = 0.5(S_{ij\,\max} - S_{ij\,\min})$$

These three alternating stress intensities ($S_{alt\,12}$, $S_{alt\,23}$, and $S_{alt\,31}$) are the three ranges of shear stress that shall be considered in a fatigue analysis. Each will have an associated mean stress (determined below), which also influences the fatigue behavior.

KD-312.3 Associated Mean Stress

(a) For welded construction, see KD-312.4(a).

(b) For nonwelded construction, the associated mean stresses $\sigma_{nm\,ij}$ shall be calculated in accordance with the following method.

The stresses σ_n normal to the plane of the maximum shear stress, associated with the three $S_{alt\,ij}$, are given by:

$$\sigma_{n\,12} = 0.5(\sigma_1 + \sigma_2)$$

$$\sigma_{n\,23} = 0.5(\sigma_2 + \sigma_3)$$

$$\sigma_{n\,31} = 0.5(\sigma_3 + \sigma_1)$$

In the following, the symbol $\sigma_{n\,ij}$ is used to represent any one of these normal stresses.

Identify the maximum $\sigma_{n\,ij\,\max}$ and the minimum $\sigma_{n\,ij\,\min}$ value of each $\sigma_{n\,ij}$ during the complete operating cycle. Then the mean normal stresses $\sigma_{nm\,ij}$ shall be calculated by:

(1) when $S_{ij\,\max} < S_y$ and $S_{ij\,\min} > -S_y$, then

$$\sigma_{nm\,ij} = 0.5\,(\sigma_{n\,ij\,\max} + \sigma_{n\,ij\,\min})$$

(2) when $S_{alt\,ij} \geq S_y$, then

$$\sigma_{nm\,ij} = 0$$

If neither KD-312.3(b)(1) nor (b)(2) applies, then the stress values used in this analysis shall be determined from an elastic–plastic analysis (see KD-240). Alternatively, $\sigma_{nm\,ij}$ may be calculated as equal to $0.5(\sigma_{n\,ij\,\max} + \sigma_{n\,ij\,\min})$ but not less than zero.

KD-312.4 Equivalent Alternating Stress Intensity

(a) For austenitic stainless steel construction, and for welded construction within the weld metal and the heat-affected zone, effects of associated mean stresses (see Fig. KD-320.2) are incorporated in the design fatigue curve. Therefore:

$$S_{eq\,ij} = S_{alt\,ij}$$

(b) For nonwelded construction, the equivalent alternating stress intensity S_{eq}, which is assumed to have the same effect on fatigue as the combination of the alternating stress intensity S_{alt} and its associated mean stress σ_{nm}, shall be calculated in accordance with the equation: 04

$$S_{eq\,ij} = S_{alt\,ij}\,\frac{1}{1 - \beta\sigma_{nm\,ij}/S'_a}$$

where S'_a is the allowable amplitude of the alternating stress component when $\sigma_{nm} = 0$ and $N = 10^6$ cycles (see KD-321). The value of β shall be 0.2 for carbon or low alloy steel forged nonwelded construction (see Fig. KD-320.1). The value of β shall be 0.2 for $\sigma_{nm\,ij} < 0$ and 0.5 for $\sigma_{nm\,ij} > 0$ for 17-4PH or 15-5PH stainless steel nonwelded construction using forgings or bar (see Fig. KD-320.4). Other values of β may be used if justified by experimental evidence. If the values of $\beta\sigma_{nm\,ij}/S'_a$ exceeds 0.9, limit its value to 0.9.

Using this equation, three values of $S_{eq\,ij}$ are obtained. The largest of these three shall be used in combination with the design fatigue curve to establish the number of design cycles in accordance with KD-322(a) or KD-322(d).

KD-313 Calculation of Fatigue Stresses When Principal Stress Axes Change

When the directions of the principal stresses change during the loading cycle, the plane carrying the maximum range of shear stress cannot be easily identified using equations based on principal stresses. The position of each plane at the point of interest can be defined by two angles and a convenient set of Cartesian axes. By varying this combination of angles in increments, it is possible to determine the range of shear stress on each plane. The largest of these shear stress ranges shall be considered to be the alternating stress intensity, S_{alt}, used in the calculation of design cycles.

KD-320 CALCULATED NUMBER OF DESIGN CYCLES

The calculation of the number of design cycles N_f shall be based either on design fatigue curves described in KD-321 or on results of experimental fatigue tests on components as stated in KD-1260.

KD-321 Basis for Design Fatigue Curves

(a) The conditions and procedures of this paragraph are based on a comparison between the calculated equivalent alternating stress intensity S_{eq} and strain cycling fatigue data. The strain cycling fatigue data have been used to derive design fatigue curves. These curves show the allowable amplitude S_a of the alternating stress component (one-half of the alternating stress range) plotted against the number of design cycles N_f, which the component is assumed to safely endure without failure.

(b) The design fatigue curves have been derived from strain-controlled push–pull tests with zero mean stress (i.e., $\sigma_{nm} = 0$) on polished unnotched specimens in dry air. The imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated equivalent stress intensity amplitude and the allowable stress amplitude directly comparable. S_{eq} and S_a have the dimensions of stress, but they do not represent a real stress when the elastic range is exceeded.

(c) The design fatigue curves for forged nonwelded construction presented in this Article have been developed from fatigue tests in dry air with polished specimens of steels having an ultimate tensile strength in the range of 90 ksi to 180 ksi (620 MPa to 1 242 MPa). Fatigue tests with small cylinders pressurized from the inside by oil and made of low alloy steels having an ultimate tensile strength in the range of 130 ksi to 180 ksi (896 MPa to 1 242 MPa) have been used to confirm the validity of these curves for carbon or low alloy forgings with machined surfaces. For design fatigue curves, see Fig. KD-320.1 (and Table KD-320.1) for forged carbon or low alloy steel construction, Fig. KD-320.2 for welded construction, Fig. KD-320.3 for austenitic stainless steel construction, and Fig. KD-320.4 for 17-4PH or 15-5PH stainless steel construction. 04

(d) The design fatigue curves are not applicable in the presence of aggressive environments. For conditions not covered by these design fatigue curves, the Manufacturer shall provide supplementary fatigue data.

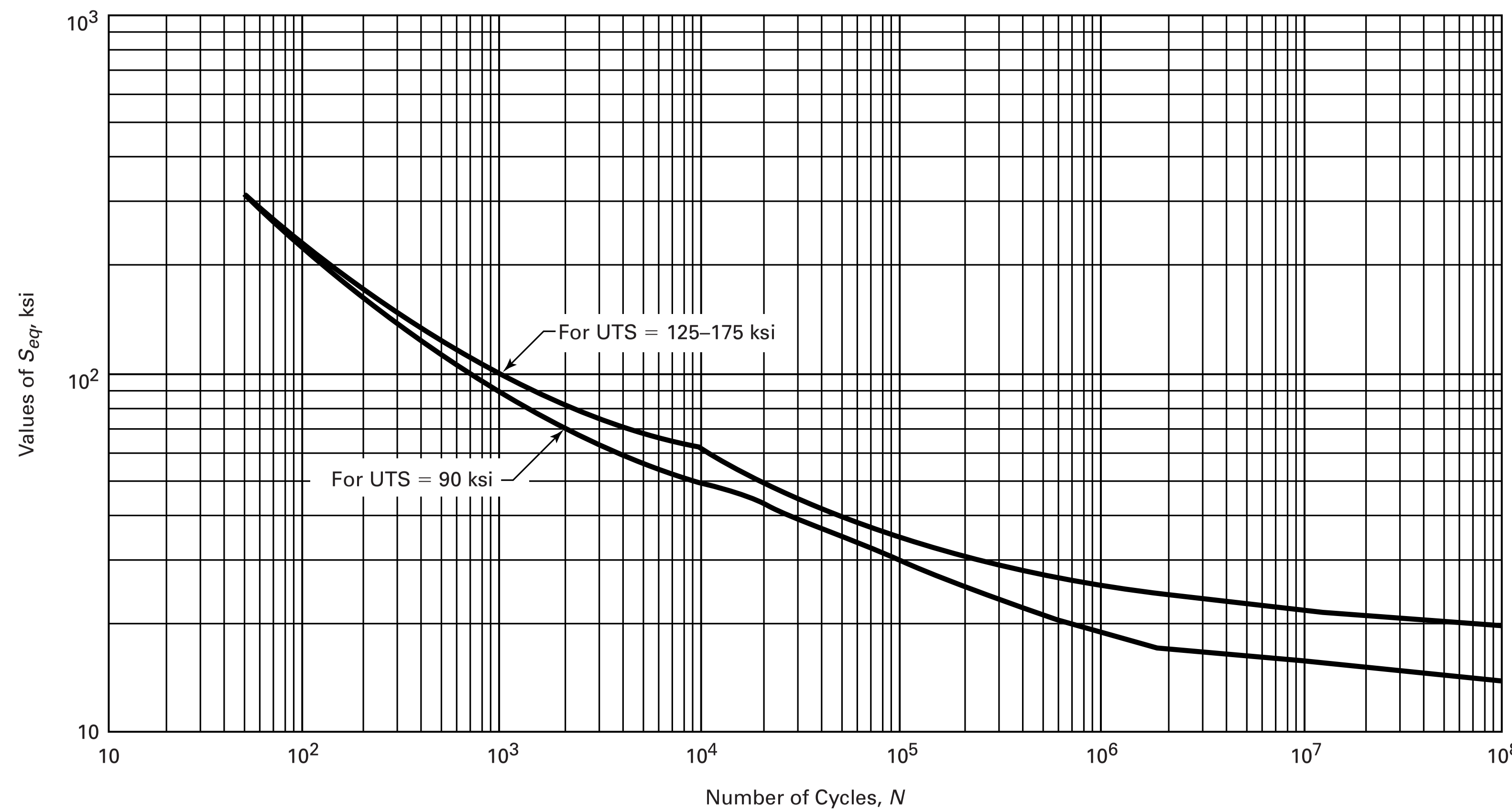
KD-322 Use of Design Fatigue Curve

(a) Figure KD-320.1 shall be used for forged nonwelded parts with machined surfaces made of carbon or low alloy steels having a specified minimum value of the ultimate tensile strength S_u greater than 90 ksi (621 MPa). The curves are applicable for an average surface roughness of 19 R_a μin. or a maximum surface roughness of 59 μin. R_{max} (peak-to-valley height) in fatigue-sensitive areas. Lower quality surface finish will influence fatigue. This influence is considered by a factor K_r [see Fig. KD-320.5(a) or Fig. KD-320.5(b)], which shall be combined with S_{eq} as specified in KD-322(e) when determining the calculated number of design cycles N_f.

(b) Figure KD-320.2 shall be used for those areas of the vessel that contain butt welded joints ground flush. The influence of the surface roughness is included in the curve, i.e., $K_r = 1.0$; therefore, a surface roughness factor need not be applied. For other types of welded joints, not ground flush but permitted by this Division, appropriate stress concentration factors shall be determined and used.

(c) Figure KD-320.3 shall be used for forged nonwelded parts with machined surfaces made of austenitic stainless steels. The influence of the surface roughness is included in the curve, i.e., $K_r = 1.0$; therefore, a surface roughness factor need not be applied.

(d) Figure KD-320.4 shall be used for forged nonwelded parts with machined surfaces made of 17-4PH 04



GENERAL NOTES:

(a) $E = 28.3 \times 10^6$ psi

(b) Interpolate for UTS = 90–125 ksi

(c) Table KD-320.1 contains tabulated values and equations for these curves, and a formula for an accurate interpolation of these curves.

(d) For UTS < 90 ksi, use curve in Fig. KD-320.2.

04 **FIG. KD-320.1 DESIGN FATIGUE CURVES $S_{eq} = f(N_f)$ FOR NONWELDED MACHINED PARTS MADE OF FORGED CARBON OR LOW ALLOY STEELS**

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TABLE KD-320.1
TABULATED VALUES OF S_{eq}, ksi, FROM FIGURES INDICATED

		Number of Design Operating Cycles, N_f																			
Figure	Curve	5E1	1E2	2E2	5E2	1E3	2E3	5E3	1E4	2E4	5E4	1E5	2E5	5E5	1E6	2E6	5E6	1E7	2E7	5E7	1E8
320.1	UTS 90 ksi	311	226	164	113	89	72	57	49	43	34	29	25	21	19	17	16.2	15.7	15.2	14.5	14
320.1	UTS 125 ksi	317	233	171	121	98	82	68	61	49	39	34	31	28	26	24	22.9	22.1	21.4	20.4	19.7
320.2	Welded	275	205	155	105	83	64	48	38	31	24	20	16.5	13.5	12.5	12.1	11.5	11.1	10.8	10.3	9.9
320.3	Austenitic stainless steel	345	261	201	148	119	97	76	64	56	46	41	36	31	28	...	...	...	...	...	...
320.4	17-4PH/ 15-5PH stainless steel	205	171	149	129	103	86.1	72.0	65.1	60.0	54.8	51.6	48.7	45.2	42.8	40.6	37.8	35.9	...	...	...

GENERAL NOTES:

(a) All notes on the referenced figures apply to these data.

(b) Number of design cycles indicated shall be read as follows: 1EJ = 1×10^J, e.g., 5E2 = 5×10^2 or 500 cycles.

(c) Interpolation between tabular values is permissible based upon data representation by straight lines on a log–log plot. Accordingly, for $S_i > S > S_j$,

$$\frac{N}{N_i} = \left(\frac{N_j}{N_i}\right)^{[\log(S_i/S)/\log(S_i/S_j)]}$$

where

S, S_i, S_j = values of S_a
N, N_i, N_j = corresponding calculated number of design cycles from design fatigue data

For example, from the data above, use the interpolation formula above to find the calculated number of design cycles N for $S_{eq} = 50.0$ ksi when UTS ≥ 125 ksi on Fig. KD-320.1:

$$\frac{N}{10{,}000} = \left(\frac{20{,}000}{10{,}000}\right)^{[\log(61/50)/\log(61/49)]}$$
$$N = 18{,}800 \text{ cycles}$$

(d) Equations for number of design operating cycles:

(1) Fig. KD-320.1, UTS = 90 ksi

$S_{eq} \geq 42.6$ ksi: $N = \mathrm{EXP}[15.433 - 2.0301 \ln(S_{eq}) + 1036.035 \ln(S_{eq})/S_{eq}^2]$

17 ksi $< S_{eq} <$ 42.6 ksi: $N = [(2.127\mathrm{E}{-05}) + (7.259\mathrm{E}{-10})S_{eq}^3 - (8.636\mathrm{E}{-06})\ln(S_{eq})]^{-1}$

$S_{eq} \leq 17$ ksi: $N = \mathrm{EXP}[-20.0 \ln(S_{eq}/35.12)]$

(2) Fig. KD-320.1, UTS = 125–175 ksi

$S_{eq} \geq 60.6$ ksi: $N = [0.00122 - (7.852\mathrm{E}{-05})S_{eq} + (7.703\mathrm{E}{-06})S_{eq}^{1.5}]^{-1}$

24 ksi $< S_{eq} <$ 60.6 ksi: $N = [((7.8628\mathrm{E}{-05}) + (3.212\mathrm{E}{-03})S_{eq} + (9.36\mathrm{E}{-02})S_{eq}^2)/(1 - (8.599\mathrm{E}{-02})S_{eq} + (1.816\mathrm{E}{-03})S_{eq}^2 + (4.05774\mathrm{E}{-06})S_{eq}^3)]^2$

$S_{eq} \leq 24$ ksi: $N = \mathrm{EXP}[-20.0 \ln(S_{eq}/49.58)]$

(3) Fig. KD-320.2, welded

$S_{eq} \geq 38$ ksi: $N = [-(7.125\mathrm{E}{-04}) + (4.4692\mathrm{E}{-08})(S_{eq}^2)\ln(S_{eq}) + (3.561\mathrm{E}{-03})/S_{eq}^{0.5}]^{-1}$

12.5 ksi $< S_{eq} <$ 38 ksi: $N = \mathrm{EXP}[(18.0353 - 1.3663 S_{eq} - (1.549\mathrm{E}{-02})S_{eq}^2)/(1 - (4.031\mathrm{E}{-02})S_{eq} - (3.854\mathrm{E}{-02})S_{eq}^2)]$

$S_{eq} < 12.5$ ksi: $N = \mathrm{EXP}[-20.0 \ln(S_{eq}/24.94)]$

(4) Fig. KD-320.3, austenitic stainless steel

$S_{eq} \geq 55.7$ ksi: $N = \mathrm{EXP}[((3.03\mathrm{E}{-02}) - 0.7531 S_{eq} - (1.968\mathrm{E}{-04})S_{eq}^2)/(1 - (7.23\mathrm{E}{-02})S_{eq} - (4.075\mathrm{E}{-04})S_{eq}^2)]$

$S_{eq} < 55.7$ ksi: $N = \mathrm{EXP}[((2.445\mathrm{E}{-04}) + (1.656\mathrm{E}{-03})S_{eq} - (3.416\mathrm{E}{-02})S_{eq}^2)/(1 - (6.062\mathrm{E}{-02})S_{eq} - (4.29\mathrm{E}{-04})S_{eq}^2 - (4.049\mathrm{E}{-05})S_{eq}^3)]$

(5) Fig. KD-320.4, 17-4PH/15-5PH stainless steel

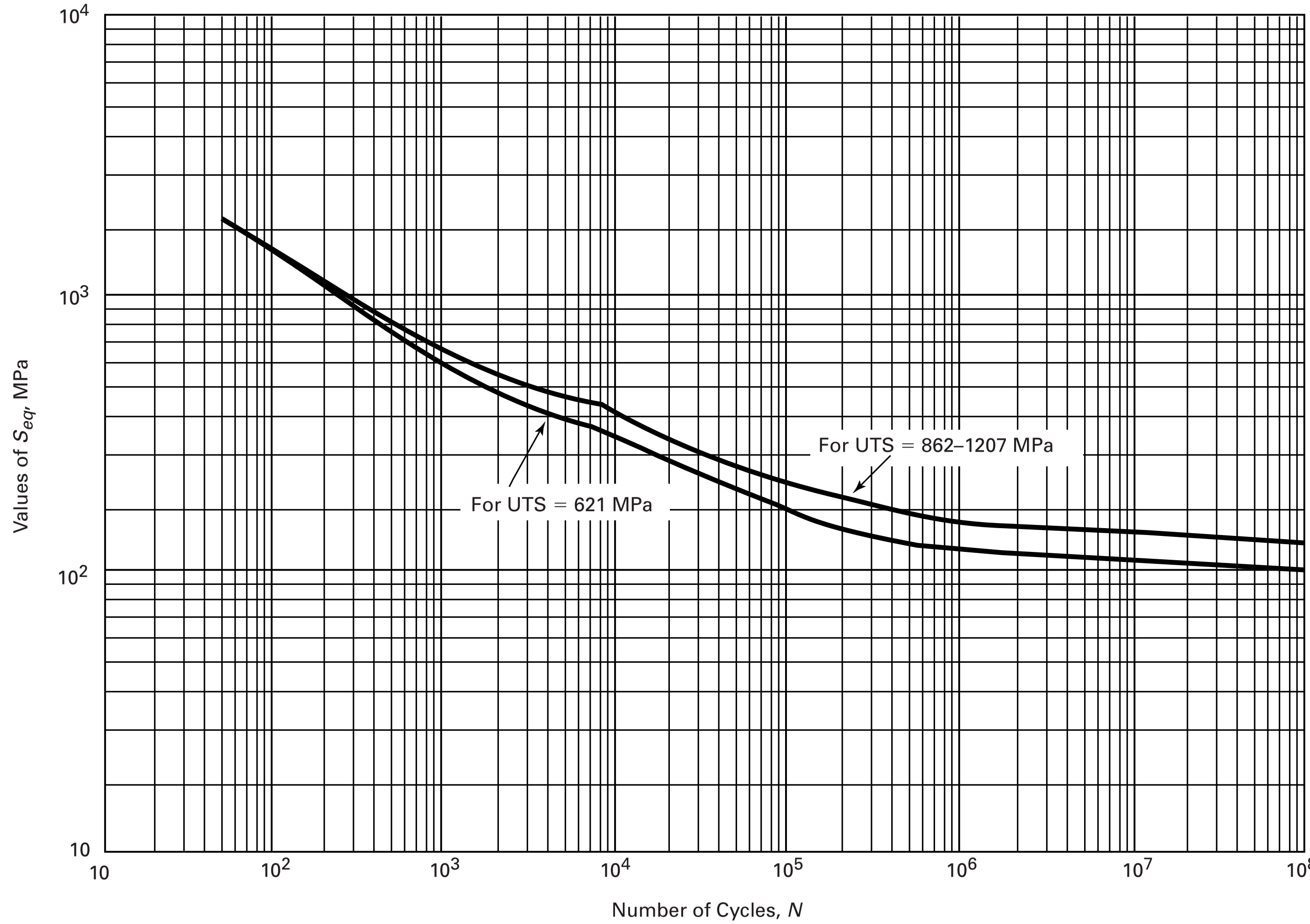
129 ksi $\leq S_{eq} <$ 207 ksi: $N = 10^{(-10.600[\log(S_{eq})]^3 + 80.024[\log(S_{eq})]^2 - 203.37[\log(S_{eq})] + 175.13)}$

103 ksi $\leq S_{eq} <$ 129 ksi: $N = 10^{(56.735[\log(S_{eq})]^3 - 347.76[\log(S_{eq})]^2 + 707.66[\log(S_{eq})] - 475.12)}$

71 ksi $\leq S_{eq} <$ 103 ksi: $N = 10^{(-29.577[\log(S_{eq})]^3 + 180.59[\log(S_{eq})]^2 - 370.92[\log(S_{eq})] + 259.15)}$

$S_{eq} < 71$ ksi: $N = 10^{(41.740[\log(S_{eq})]^3 - 201.51[\log(S_{eq})]^2 + 311.25[\log(S_{eq})] - 146.68)}$

(e) Equations shall not be used outside of the cycle range given in the Table.



GENERAL NOTES:
(a) E = 195 × 10^3 MPa
(b) Interpolate for UTS = 621–862 MPa
(c) Table KD-320.1M contains tabulated values and equations for these curves, and a formula for an accurate interpolation of these curves.
(d) For UTS < 621 MPa, use curve in Fig. KD-320.2M.

04 FIG. KD-320.1M DESIGN FATIGUE CURVES $S_{eq} = f(N_f)$ FOR NONWELDED MACHINED PARTS MADE OF FORGED CARBON OR LOW ALLOY STEELS

TABLE KD-320.1M TABULATED VALUES OF S_{eq}, MPa, FROM FIGURES INDICATED

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Figure	Curve	Number of Design Operating Cycles, N_f																			
		5E1	1E2	2E2	5E2	1E3	2E3	5E3	1E4	2E4	5E4	1E5	2E5	5E5	1E6	2E6	5E6	1E7	2E7	5E7	1E8
320.1M	UTS 621 MPa	2144	1558	1131	779	614	496	393	338	297	234	200	172	145	131	117.2	111.8	108.2	104.8	100	96.5
320.1M	UTS 862 MPa	2186	1607	1197	834	675	565	469	421	338	269	234	214	193	179	165	157.9	152.4	147.6	140.7	135.8
320.2M	Welded	1896	1413	1069	724	572	441	331	262	214	165	138	114	93	86	83	79	77	74	71	68
320.3M	Austenitic stainless steel	2379	1800	1386	1020	821	669	524	441	386	317	283	248	214	193	...	...	...	...	...	...
320.4M	17-4PH/ 15-5PH stainless steel	1410	1180	1030	889	710	594	496	449	414	378	356	336	312	295	280	261	248	...	...	...

GENERAL NOTES:

(a) All notes on the referenced figures apply to these data.

(b) Number of design cycles indicated shall be read as follows: $1EJ = 1 \times 10^J$, e.g., $5E2 = 5 \times 10^2$ or 500 cycles.

(c) Interpolation between tabular values is permissible based upon data representation by straight lines on a log–log plot. Accordingly, for $S_i > S > S_j$,

$$\frac{N}{N_i} = \left(\frac{N_j}{N_i}\right)^{[\log(S_i/S)/\log(S_i/S_j)]}$$

where

S, S_i, S_j = values of S_a

N, N_i, N_j = corresponding calculated number of design cycles from design fatigue data

For example, from the data above, use the interpolation formula above to find the calculated number of design cycles N for $S_{eq} = 50.0$ ksi when UTS ≥ 125 ksi on Fig. KD-320.1:

$$\frac{N}{10{,}000} = \left(\frac{20{,}000}{10{,}000}\right)^{[\log(61/50)/\log(61/49)]}$$

$$N = 18{,}800 \text{ cycles}$$

(d) Equations for number of design operating cycles:

(1) Fig. KD-320.1M, UTS = 621 MPa

$S_{eq} \geq 294$ MPa — $N = \mathrm{EXP}[19.353 - 2.0301 \ln(S_{eq}) + (49254.16 \ln(S_{eq}) - 95099.7)/S_{eq}^2]$

117 MPa < S_{eq} < 294 MPa — $N = [(3.794E{-}05) + (2.297E{-}12)S_{eq}^3 - (8.636E{-}06)\ln(S_{eq})]^{-1}$

$S_{eq} \leq 117$ MPa — $N = \mathrm{EXP}[-20.0 \ln(S_{eq}/242.11)]$

(2) Fig. KD-320.1M, UTS = 862–1207 MPa

$S_{eq} \geq 418$ MPa — $N = [0.00122 - (1.139E{-}05)S_{eq} + (4.255E{-}07)S_{eq}^{1.5}]^{-1}$

166 MPa < S_{eq} < 418 MPa — $N = [((7.8628E{-}05) + (4.659E{-}04)S_{eq} + (1.97E{-}03)S_{eq}^2)/(1 - (1.247E{-}02)S_{eq} + (3.820E{-}05)S_{eq}^2 + (1.238E{-}08)S_{eq}^3)]^2$

$S_{eq} \leq 166$ MPa — $N = \mathrm{EXP}[-20.0 \ln(S_{eq}/341.81)]$

(3) Fig. KD-320.2M, welded

$S_{eq} \geq 262$ MPa — $N = [-(7.125E{-}04) + (9.401E{-}10)(S_{eq}^2)\ln(S_{eq}) - (1.8512E{-}09)S^2{}_{eq} + (9.35E{-}03)/S_{eq}^{0.5}]^{-1}$

86 MPa < S_{eq} < 262 MPa — $N = \mathrm{EXP}[(18.0353 - 0.19617S_{eq} - (3.258E{-}04)S_{eq}^2)/(1 - (5.846E{-}03)S_{eq} - (8.107E{-}05)S_{eq}^2)]$

$S_{eq} \leq 86$ MPa — $N = \mathrm{EXP}[-20.0 \ln(S_{eq}/171.96)]$

(4) Fig. KD-320.3M, austenitic stainless steel

$S_{eq} \geq 384$ MPa — $N = \mathrm{EXP}[(0.0303 - 0.1092S_{eq} - (4.140E{-}06)S_{eq}^2)/(1 - (1.05E{-}02)S_{eq} - (8.572E{-}06)S_{eq}^2)]$

$S_{eq} < 384$ MPa — $N = \mathrm{EXP}[((2.445E{-}04) + (2.402E{-}04)S_{eq} - (7.186E{-}04)S_{eq}^2)/(1 - (8.789E{-}03)S_{eq} - (9.02E{-}06)S_{eq}^2 - (1.235E{-}07)S_{eq}^3)]$

(5) Fig. KD-320.4M, 17-4PH/15-5PH stainless steel

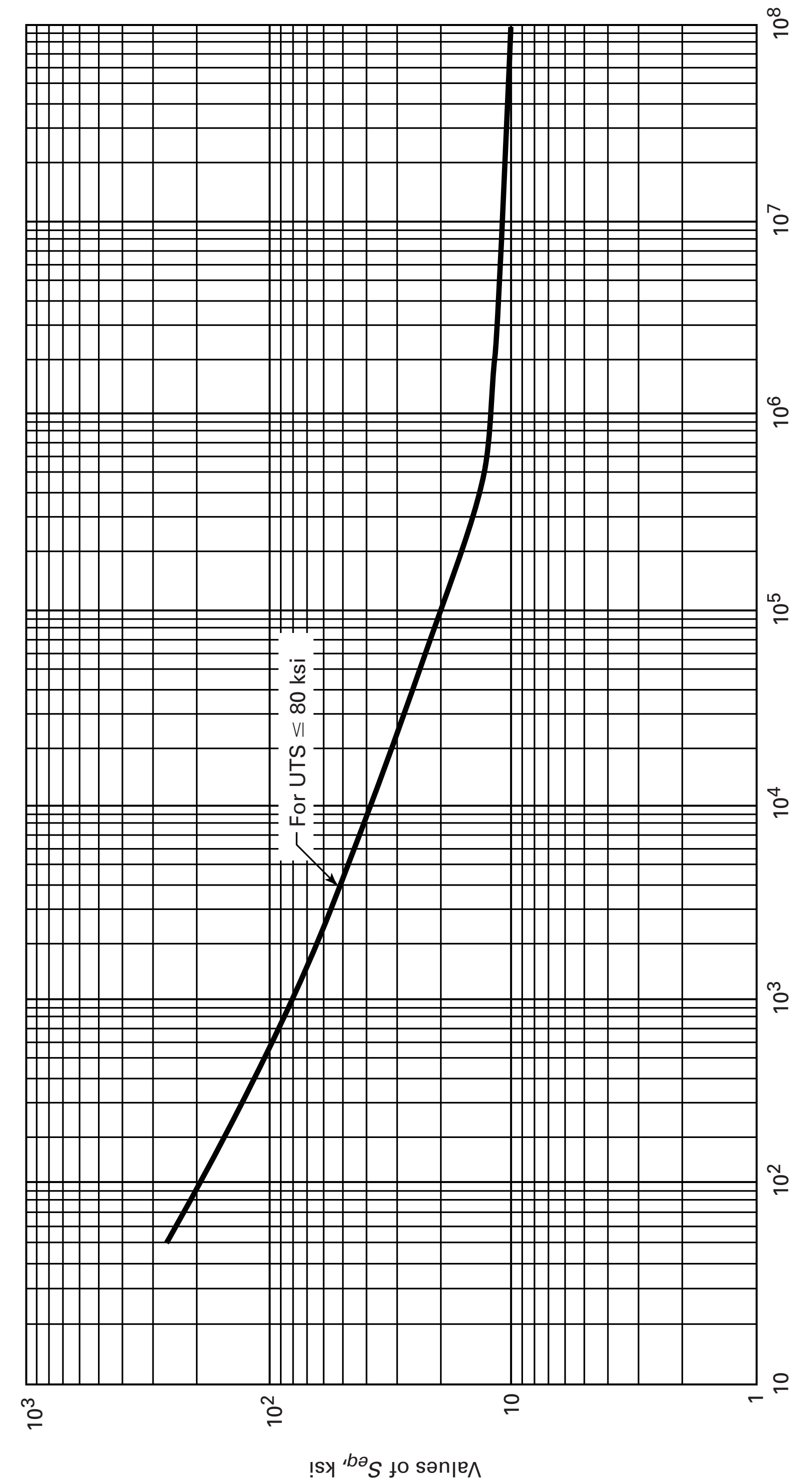
889MPa ≤ S_{eq} < 1413MPa — $N = 10^{\{-10.600[\log(S_{eq})]^3 + 106.689[\log(S_{eq})]^2 - 359.932[\log(S_{eq})] + 408.175\}}$

710MPa ≤ S_{eq} < 889 MPa — $N = 10^{\{56.735[\log(S_{eq})]^3 - 490.48[\log(S_{eq})]^2 + 1410.54[\log(S_{eq})] - 1346.471\}}$

490MPa ≤ S_{eq} < 710 MPa — $N = 10^{\{-29.577[\log(S_{eq})]^3 + 254.993[\log(S_{eq})]^2 - 736.164[\log(S_{eq})] + 714.587\}}$

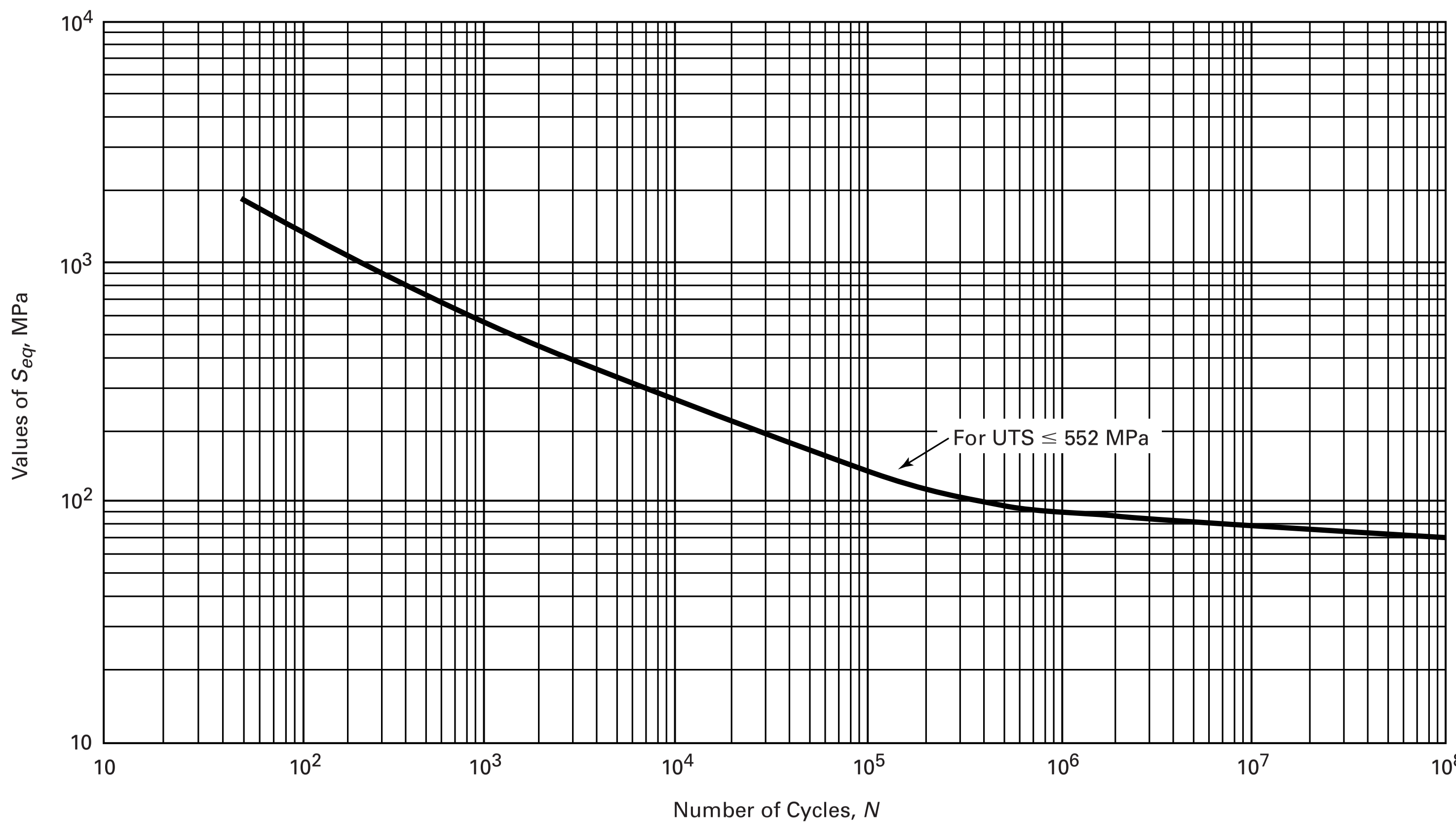
S_{eq} < 490 MPa — $N = 10^{\{41.740[\log(S_{eq})]^3 - 306.509[\log(S_{eq})]^2 + 737.234[\log(S_{eq})] - 573.962\}}$

(e) Equations shall not be used outside of the cycle range given in the Table.



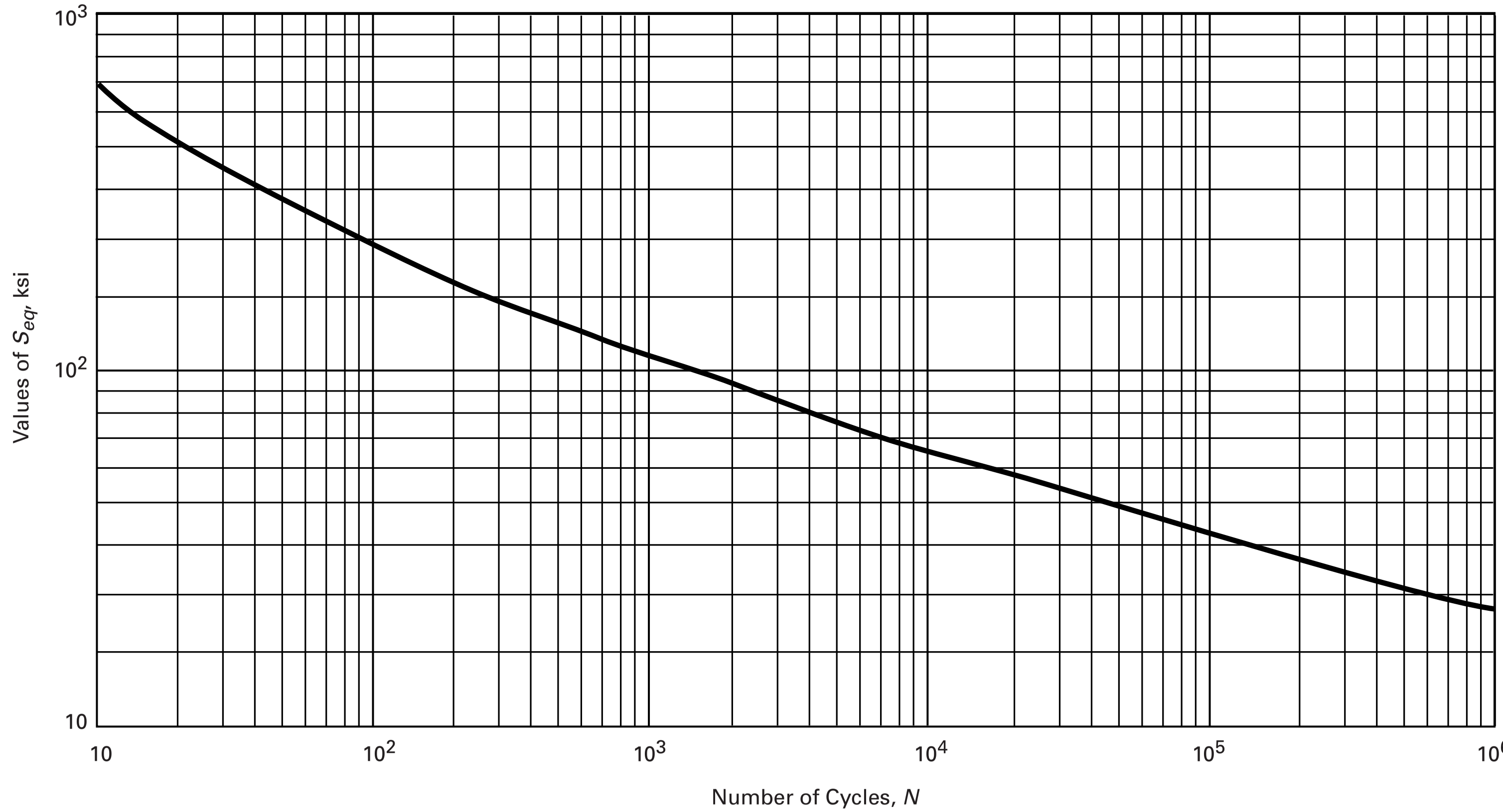
GENERAL NOTES:
(a) $E = 30 \times 10^6$ psi
(b) Table KD-320.1 contains tabulated values and an equation for this curve, and a formula for an accurate interpolation of this curve.

04 **FIG. KD-320.2 DESIGN FATIGUE CURVE $S_{eq} = f(N_f)$ FOR WELDED PARTS MADE OF CARBON OR LOW ALLOY STEELS**



GENERAL NOTES:
(a) $E = 207 \times 10^3$ MPa
(b) Table KD-320.1M contains tabulated values and an equation for this curve, and a formula for an accurate interpolation of this curve.

04 FIG. KD-320.2M DESIGN FATIGUE CURVE $S_{eq} = f(N_f)$ FOR WELDED PARTS MADE OF CARBON OR LOW ALLOY STEELS

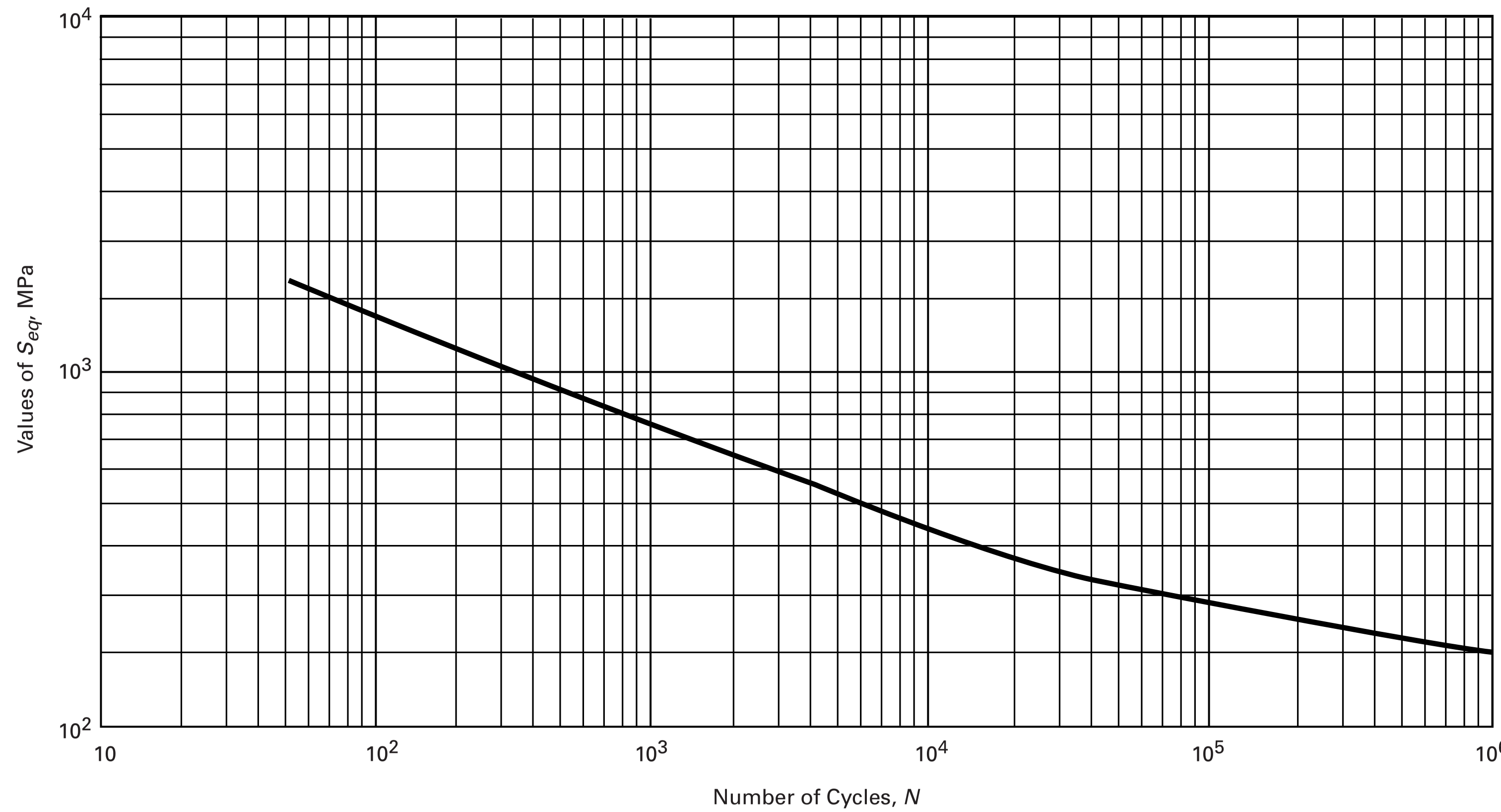


GENERAL NOTES:

(a) $E = 28.3 \times 10^6$ psi

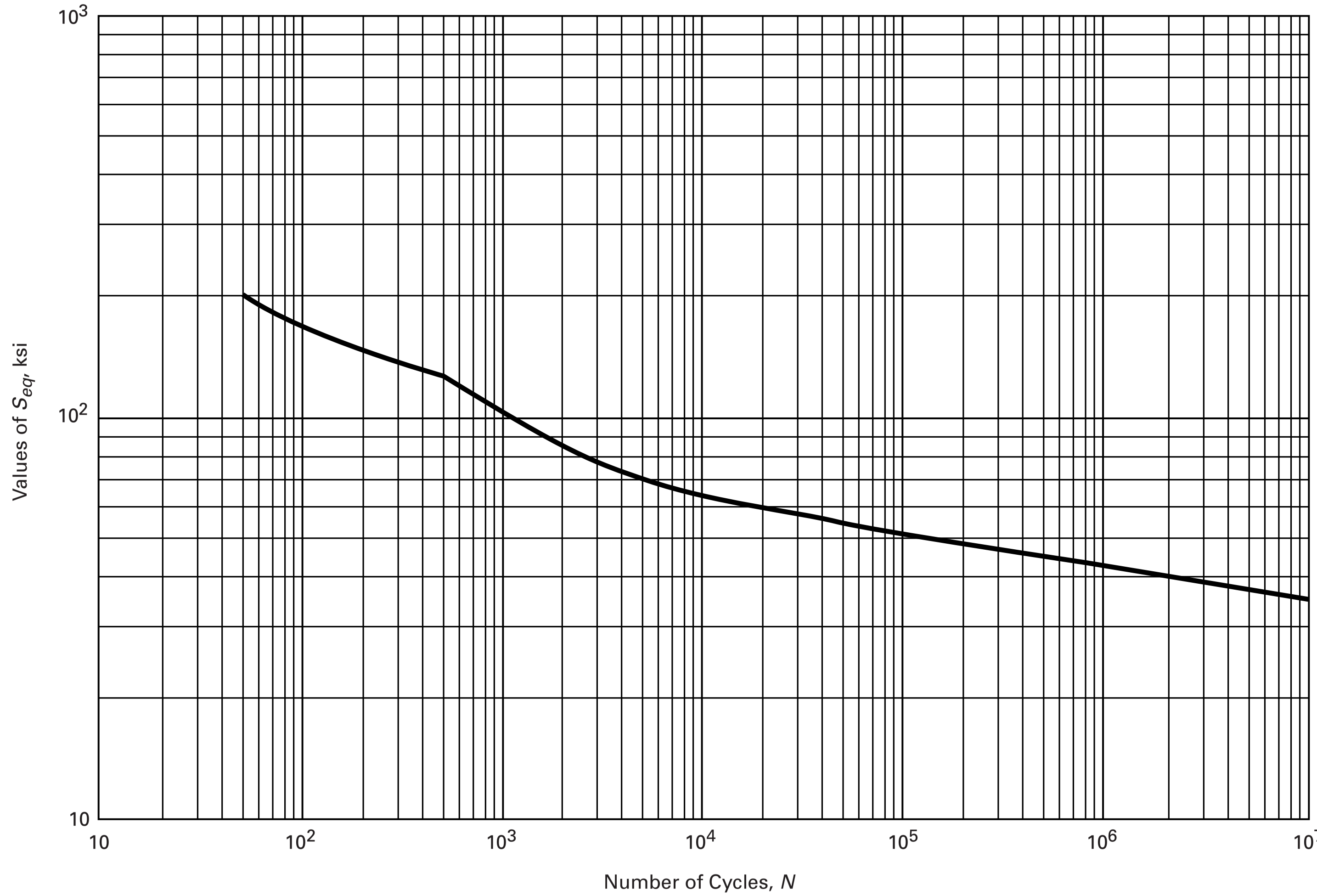
(b) Table KD-320.1 contains tabulated values and an equation for this curve, and a formula for an accurate interpolation of this curve.

04 **FIG. KD-320.3 DESIGN FATIGUE CURVE FOR AUSTENITIC STAINLESS STEELS FOR TEMPERATURES NOT EXCEEDING 800°F**



GENERAL NOTES:
(a) $E = 195 \times 10^3$ MPa
(b) Table KD-320.1M contains tabulated values and an equation for this curve, and a formula for an accurate interpolation of this curve.

04 FIG. KD-320.3M DESIGN FATIGUE CURVE FOR AUSTENITIC STAINLESS STEELS FOR TEMPERATURES NOT EXCEEDING 427°C



GENERAL NOTES:

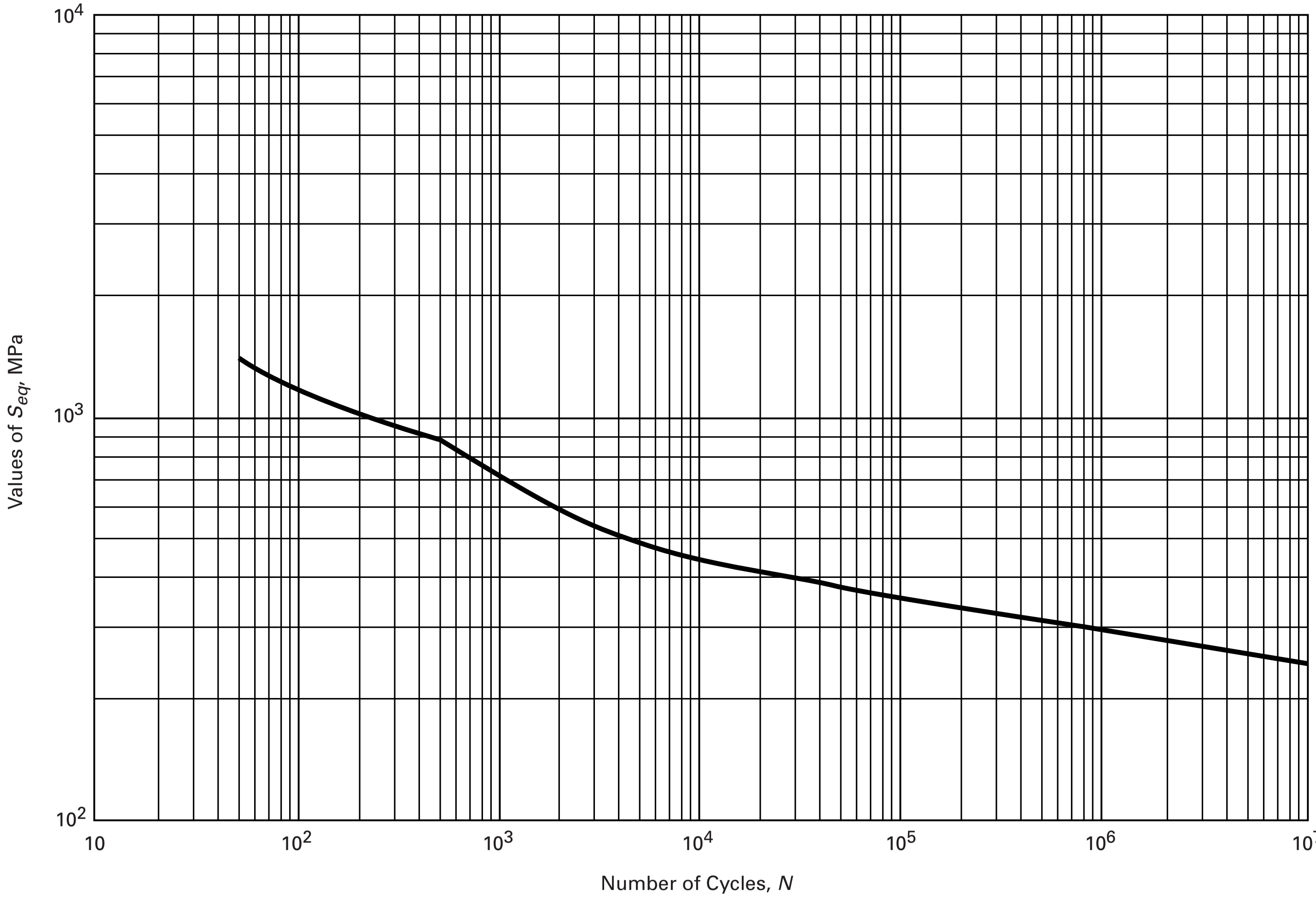
(a) $E = 29.0 \times 10^6$ psi

(b) Table KD-320.1 contains tabulated values and an equation for this curve, and a formula for the accurate interpolation of this curve.

(c) When the 17-4PH/15-5PH heat treat condition is H1025 or stronger, this curve may be used only for analysis of either protective liners or inner layers in vessels demonstrated to be leak-before-burst (see KD-103 and KD-141).

(d) Use of this curve is limited to cases where the peak Tresca strain range from mechanical loading is less than 1%.

04 **FIG. KD-320.4 DESIGN FATIGUE CURVE $S_{eq} = f(N_f)$ FOR NONWELDED MACHINED PARTS MADE OF 17-4PH/15-5PH STAINLESS STEEL BAR OR FORGINGS, FOR TEMPERATURES NOT EXCEEDING 550°F**



GENERAL NOTES:

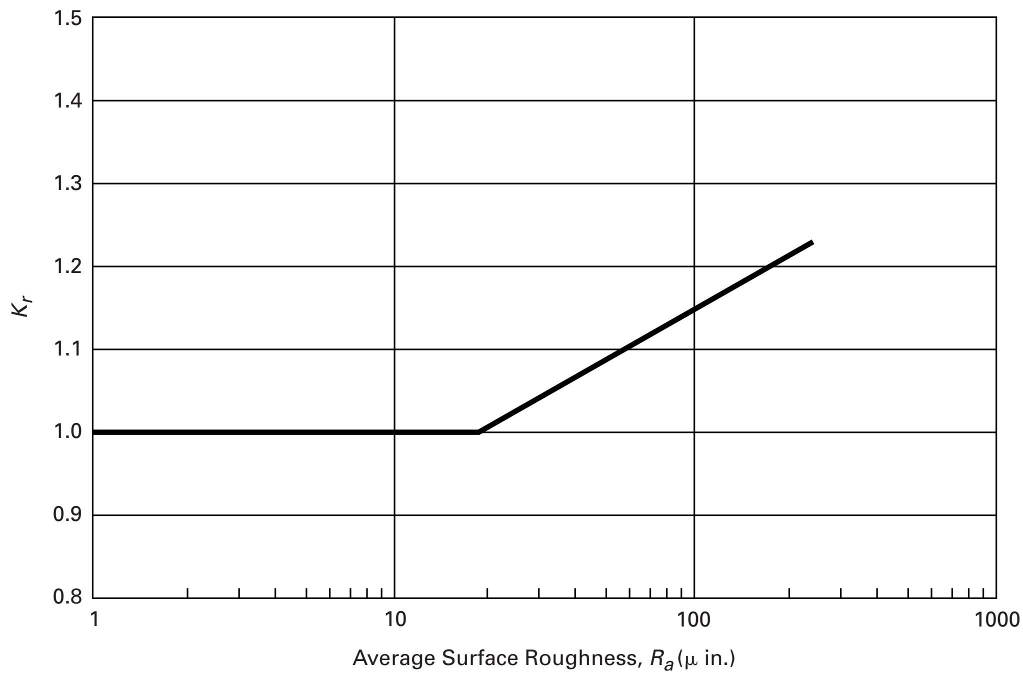
(a) E = 200 × 10^3 MPa

(b) Table KD-320.1 contains tabulated values and an equation for this curve, and a formula for the accurate interpolation of this curve.

(c) When the 17-4PH/15-5PH heat treat condition is H1025 or stronger, this curve may be used only for analysis of either protective liners or inner layers in vessels demonstrated to be leak-before-burst (see KD-103 and KD-141).

(d) Use of this curve is limited to cases where the peak Tresca strain range from mechanical loading is less than 1%.

04 **FIG. KD-320.4M DESIGN FATIGUE CURVE $S_{eq} = f(N_f)$ FOR NONWELDED MACHINED PARTS MADE OF 17-4PH/15-5PH STAINLESS STEEL BAR OR FORGINGS, FOR TEMPERATURES NOT EXCEEDING 290°C**



GENERAL NOTES:
(a) See ASME B46.1 for definition of arithmatic average surface roughness, R_a.
(b) Curve Equations:
$R_a \leqq 19$ μin.
$K_r = 1.0$
$19 < R_a \leqq 250$ μin.
$K_r = 1/\{-0.16998 \log [R_a \text{ (μin.)}] + 1.2166\}$

04 FIG. KD-320.5(a) ROUGHNESS FACTOR K_r VERSUS AVERAGE SURFACE ROUGHNESS R_a μin. AA

stainless steel having ultimate tensile strength S_u of 115 ksi (793 MPa) or greater. The curve is applicable for an average surface roughness of 19 R_a μin. (0.48 μm) or a maximum surface roughness of 59 μin. (1.5 μm) R_{max} in fatigue-sensitive areas. Lower quality surface finish will influence fatigue. This influence is considered by a factor K_r [see Fig. KD-320.5(a) or Fig. KD-320.5(b)], which shall be combined with S_{eq} as specified in KD-322(e) when determining the calculated number of design cycles N_f.

(e) When the operational cycle being considered is the only one that produces significant fluctuating stresses, the calculated number of design cycles N_f is determined as follows.

(1) Identify the applicable fatigue curve for the material as explained in KD-322(a) and (b).

(2) Multiply S_{eq} by the ratio of the modulus of elasticity given on the design fatigue curve to the value used in the analysis.

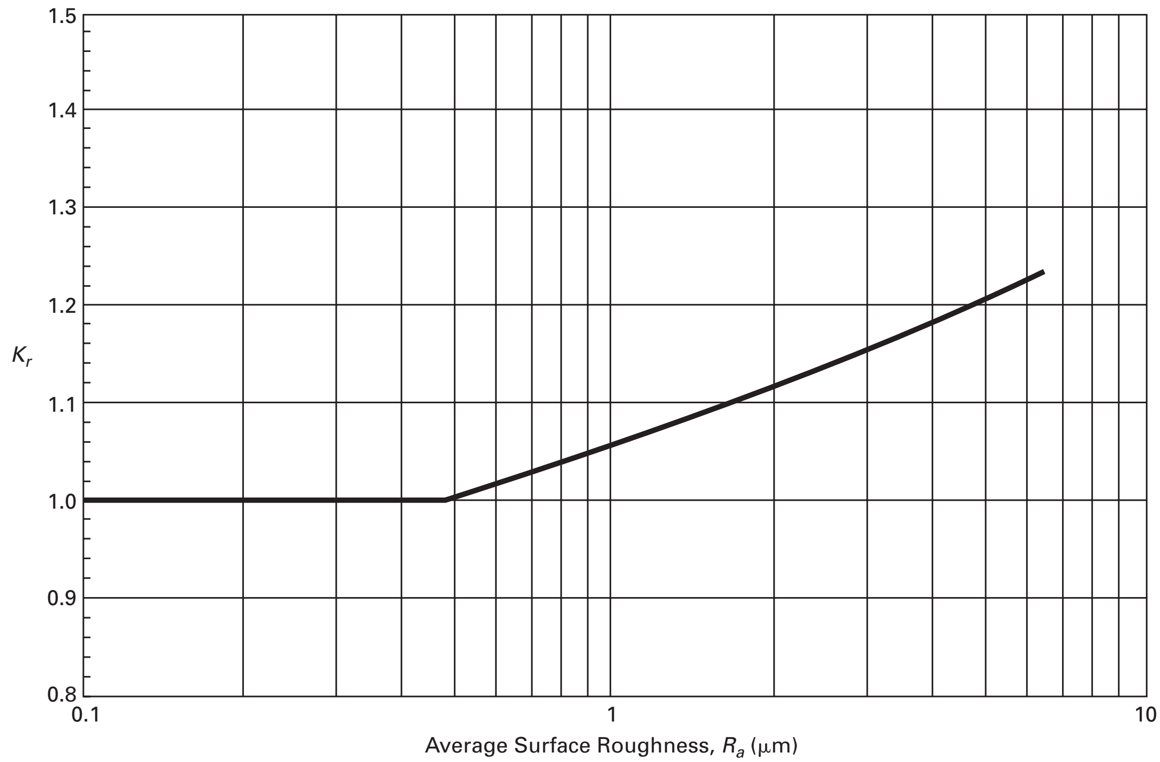
(3) Enter the curve from the ordinate axis at the value:

$$S_a = K_r S_{eq}$$

(4) Read the corresponding number of cycles on the abscissa. This is the calculated number of design cycles N_f.

KD-330 CALCULATED CUMULATIVE EFFECT NUMBER OF DESIGN CYCLES

If there are two or more types of stress cycles which produce significant stresses, the alternating stress intensity and the associated mean stress shall be calculated for each type of stress cycle. The cumulative effect of all of the stress cycles shall be evaluated using a linear damage relationship as specified in KD-330(a) through (f).



GENERAL NOTES:
(a) See ASME B46.1 for definition of arithmatic average surface roughness, R_a.
(b) Curve Equations:
$R_a \leqq 0.48$ μm
$K_r = 1.0$
$0.48 < R_a \leqq 6.35$ μm
$K_r = 1/\{-0.16998 \log [R_a (\mu m)] + 0.94545\}$

FIG. KD-320.5M(a) ROUGHNESS FACTOR K_r VERSUS AVERAGE SURFACE ROUGHNESS R_a μm AA 04

(a) Calculate the number of times each type of stress cycle of type 1, 2, 3, etc., will be repeated during a specific design service life period L. It is recommended that L be based on the design service L_d as specified in the User's Design Specification; designate these numbers n_1, n_2, n_3, etc., or generally n_i.

(b) For each type of stress cycle, determine S_{eq} by the procedures given in KD-312.4. Designate these quantities $S_{eq\ 1}$, $S_{eq\ 2}$, $S_{eq\ 3}$, etc., or generally $S_{eq\ i}$.

(c) For each value $S_{eq\ i}$, use the applicable design fatigue curve to determine the maximum number of design repetitions N_i if this type of cycle were the only one acting. Designate these as N_1, N_2, N_3, etc., or generally N_i.

(d) For each type of stress cycle, calculate the usage factor $U_i = n_i/N_i$.

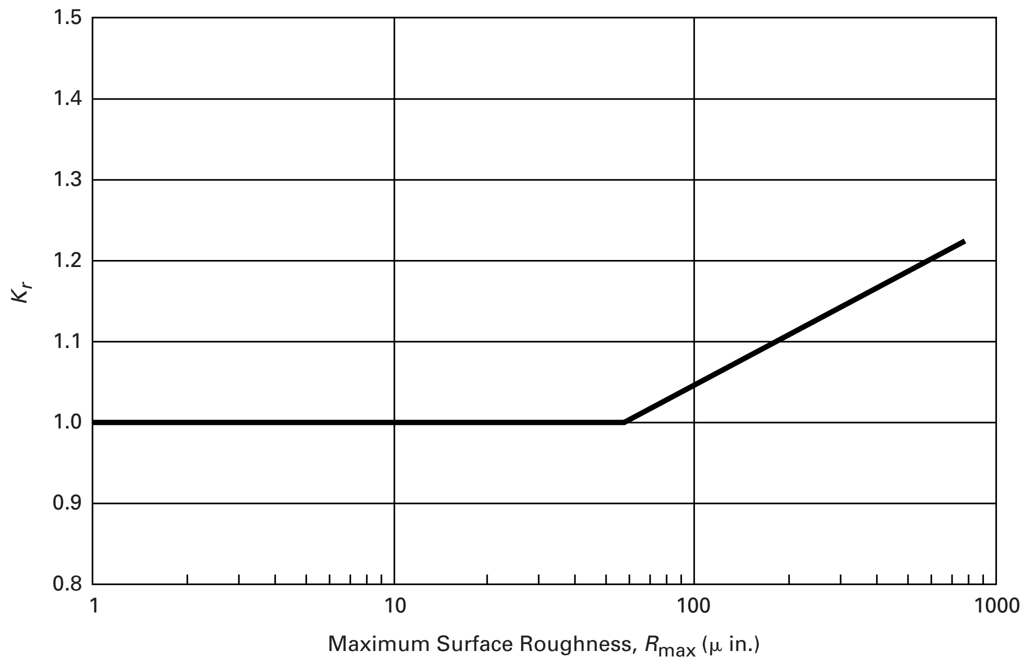
(e) Calculate the cumulative usage factor from:

$$U = \sum_{i=1}^{i} \frac{n_i}{N_i}, \text{ or } = U_1 + U_2 \ldots$$

The cumulative usage factor U shall not exceed 1.0.

(f) Calculate the design service L_d using the equation:

$$L_d = L/U$$



GENERAL NOTES:
(a) See ASME B46.1 for definition of arithmatic average surface roughness, R_a.
(b) Curve Equations:

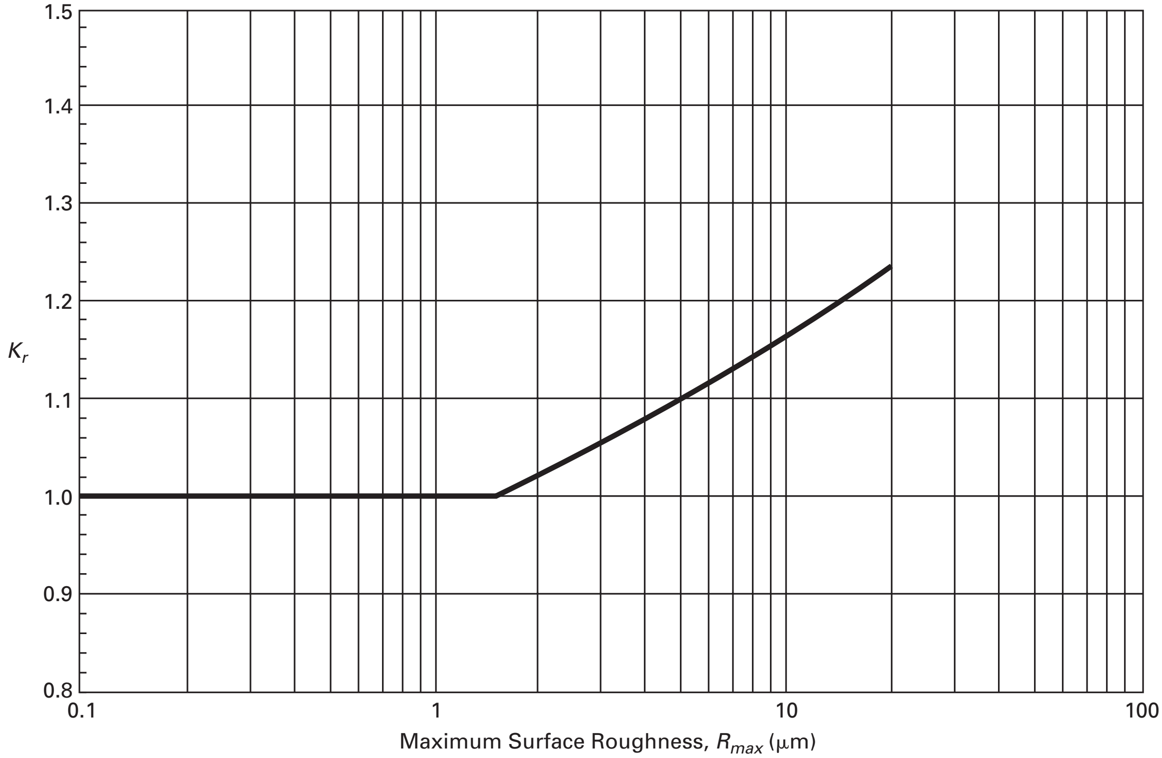
$R_{max} \leqq 59$ μin.

$K_r = 1.0$

$59 < R_{max} \leqq 785$ μin.

$K_r = 1/\{-0.16998 \log [R_{max}\ (\mu\text{in.})] + 1.3011\}$

04 **FIG. KD-320.5(b) ROUGHNESS FACTOR K_r VERSUS MAXIMUM SURFACE ROUGHNESS R_{max} μin.**



GENERAL NOTES:

(a) See ASME B46.1 for definition of arithmatic average surface roughness, R_a.

(b) Curve Equations:

$R_{max} \leqq 1.50$ μm

$K_r = 1.0$

$1.50 < R_{max} \leqq 19.9$ μm

$K_r = 1/\{-0.16998 \log [R_{max} (\mu m)] + 1.02995\}$

FIG. KD-320.5M(b) ROUGHNESS FACTOR K_r VERSUS MAXIMUM SURFACE ROUGHNESS R_{max} μm 04

ARTICLE KD-4
FRACTURE MECHANICS EVALUATION

KD-400 SCOPE

This Article presents a fracture mechanics design approach. In accordance with KD-140, if it can be shown that the vessel will fail in a leak-before-burst mode, then the number of design cycles shall be calculated in accordance with either Article KD-3 or Article KD-4. If a leak-before-burst mode of failure cannot be shown, then the number of design cycles shall be calculated in accordance with this Article.

KD-401 General

(a) This Article is based on the assumption that the crack initiation stage is complete and that cracks exist at highly stressed points in the pressure vessel. The principles of linear elastic fracture mechanics were used to develop the criteria in this Article for calculating the number of design cycles to propagate these cracks to the critical crack depth and the maximum allowable depth. See also Nonmandatory Appendix D.

(b) Manufacturing processes such as welding, heat treatment, forming, autofrettage, shrink fitting, and wire wrapping introduce residual stresses. Some cracks may propagate through the resulting residual stress field due to cyclic loading. A method for accounting for these residual stresses is given in KD-420.

(c) The critical crack depth for a given loading condition is defined to be the crack depth at which the stress intensity factor equals K_{Ic}. The critical crack depth shall be calculated for the most severe combination of loading conditions. When calculating the critical crack depth, appropriate plastic zone corrections shall be included in the calculation of the stress intensity factor. Methods for making this correction are given in Nonmandatory Appendix D for some crack configurations. If the critical crack depth is less than the wall thickness, it may not be possible to assume a leak-before-burst mode of failure. However, see KD-141.

KD-410 CRACK SIZE CRITERIA

KD-411 Assumed Initial Crack Size

(a) The initial crack size to be used for the calculation of the crack propagation design cycles shall be based on the nondestructive examination method to be used. If the nondestructive examination method to be used measures the length of a surface indication, an assumption shall be made as to the depth and shape of an assumed initial crack.

(b) A surface crack not associated with a stress concentration shall be assumed to be semielliptical with a ratio of depth to surface length of 1:3. The assumed surface length shall not be less than the maximum acceptable nondestructive examination indication as given in Part KE unless a smaller length is specified in the User's Design Specification [see KG-311.12(a)]. If a smaller length is specified, it must be clearly demonstrated that the nondestructive examination method used will reliably detect indications of that size.

(c) For a thread root or circumferential groove, the crack shall be assumed to be annular. The initial crack depth shall be assumed to be not less than one-third of the maximum acceptable length of a surface nondestructive examination indication as defined above.

KD-412 Allowable Final Crack Depth

To calculate the number of design cycles N_p based on crack propagation, it is necessary to determine an allowable final crack depth. The allowable final crack depth shall be calculated in accordance with KD-412.1 and KD-412.2. The calculated number of design cycles is the number of cycles required to propagate a crack of the assumed initial flaw size to that allowable final crack depth. The calculated number of design cycles is defined as the lesser of:

(a) the number of cycles corresponding to one-half of the number of cycles required to propagate a crack from the initial assumed flaw size to the critical crack length [see KD-401(c)]; or

(b) the number of cycles required to propagate a crack from the initial assumed flaw size to the depth as defined in KD-412.1 and KD-412.2.

KD-412.1 Monobloc Vessels. For monobloc vessels, the allowable final crack depth shall be the lesser of 25%

of the section thickness being considered or 25% of the critical crack depth.

KD-412.2 Vessels With Two or More Layers

(a) For vessels with two or more layers, the final crack depth in the inner layer may be equal to the layer thickness, provided the theoretical collapse pressure (two times the value calculated in KD-251.2) of the combined remaining layers is at least 20% higher than the design pressure of the unflawed vessel.

Otherwise, the allowable final crack depth shall not exceed 25% of the inner layer thickness.

The theoretical collapse pressure of the combined remaining layers shall be calculated using the inside diameter of the innermost of the remaining layers as the pressure loading diameter.

(b) For all other layers, the allowable final crack depth shall not exceed 25% of the layer thickness except as in KD-412.2(c).

(c) The allowable final crack depth of the outermost layer also shall not exceed 25% of the theoretical critical crack depth.

KD-420 STRESS INTENSITY FACTOR K_I CALCULATION

(a) Methods for calculating the fracture mechanics stress intensity factor for several critical locations in a typical high pressure vessel are given in Nonmandatory Appendix D.

(b) All forms of loading shall be considered, including pressure stresses, thermal stresses, discontinuity stresses, and residual stresses. In some cases, the stresses produced by the action of the fluid pressure in the crack shall be considered. Guidelines are given in Nonmandatory Appendix D.

(c) The K_I values for all loadings except residual stresses shall be assessed by considering their minimum and maximum values and their chronological relationship. The combined effects of these loadings shall be reported as minimum $K^*_{I\,\min}$ and maximum $K^*_{I\,\max}$ stress intensity factors. The effects of intentionally introduced residual stresses, such as those due to autofrettage, shrink fitting, or wire winding, shall be assessed separately by calculating an equivalent positive or negative stress intensity factor due to these residual stresses $K_{I\,\mathrm{res}}$. KD-430 specifies how $K_{I\,\mathrm{res}}$, $K^*_{I\,\min}$, and $K^*_{I\,\max}$ are combined to calculate a crack growth rate which shall be integrated to solve for a calculated number of design cycles N_p based on crack propagation.

KD-430 CALCULATION OF CRACK GROWTH RATES

(a) The crack growth rate da/dN, in./cycle (m/cycle), is assumed to be a function of the range of stress intensity factor ΔK, ksi-in.$^{1/2}$ (MPa-m$^{1/2}$), and the stress intensity factor ratio R_K where

$$\frac{da}{dN} = C\,[f(R_K)]\,(\Delta K)^m \tag{1}$$

$$\Delta K = K^*_{I\,\max} - K^*_{I\,\min}$$

and

$$R_K = \frac{K^*_{I\,\min} + K_{I\,\mathrm{res}}}{K^*_{I\,\max} + K_{I\,\mathrm{res}}}$$

When calculating crack growth rates, the plastic zone correction to the stress intensity factor may be neglected. If $(K^*_{I\max} + K^*_{I\mathrm{res}}) \le 0$, da/dN may be assumed to be equal to zero. The values of C and m to be used for some materials are given in Table KD-430 for the case of $f(R_K) = 1$. If $R_K = 0$, then $f(R_K) = 1$. The relationship $f(R_K)$, which may be used for some materials, is given in Nonmandatory Appendix D.

(b) If the value of ΔK is less than the value of the threshold ΔK (ΔK_{th}) as given by the following equation, the value of da/dN may be assumed to be zero.

ΔK_{th} = the lesser of $G\,(1 - HR_K)$ or I, but is not less than 2 ksi-in.$^{1/2}$ (2.2 MPa-m$^{1/2}$)

Values of G, H, and I for some common pressure vessel materials are given in Table KD-430.

KD-440 CALCULATED NUMBER OF DESIGN CYCLES

Crack growth is dependent on both cyclic stress and the crack length when the cycle occurs. Thus, the calculated number of design cycles N_p is highly dependent on the sequence of loadings. The designer shall provide a summary of the sequence and magnitude of all loadings and a projection of the calculated crack growth associated with each point in the loading sequence. This summary shall be documented in the Manufacturer's Design Report. See Nonmandatory Appendix B for recalculation of fatigue life based on the actual sequence and magnitude of loading.

The number of design cycles may be calculated by numerical integration of the crack growth rate [KD-430(a) Eq. (1)]. It shall be assumed that K_I values are constant over an interval of crack growth Δa that is small relative

TABLE KD-430
CRACK GROWTH RATE FACTORS (U.S. Customary Units)

Material	*C*, in./cycle (ksi-in.$^{1/2}$)$^{-m}$	*m*	*G*, ksi-in.$^{1/2}$	H	I, ksi-in.$^{1/2}$
High strength low alloy steels, $S_y > 90$ ksi	1.95E−10	3.26	6.4	0.85	5.5
Martensitic precipitation-hardened steels	2.38E−10	3.15	6.4	0.85	5.5
Austenitic stainless steels	1.1E−10	3.30	NA (1)	NA (1)	NA (1)

NOTE:
(1) Threshold values for austenitic stainless steels have not yet been established.

TABLE KD-430M
CRACK GROWTH RATE FACTORS (SI Units)

Material	*C*, m/cycle (MPa-m$^{1/2}$)$^{-m}$	m	*G*, MPa-m$^{1/2}$	*H*	*I*, MPa-m$^{1/2}$
High strength low alloy steels, $S_y > 90$ ksi	3.64E−12	3.26	7.03	0.85	6.04
Martensitic precipitation-hardened steels	4.49E-12	3.15	7.03	0.85	6.04
Austenitic stainless steels	2.05E-12	3.30	NA (1)	NA (1)	NA (1)

NOTE:
(1) Threshold values for austenitic stainless steels have not yet been established.

to the crack depth. To ensure that the interval of crack depth is sufficiently small, the calculation shall be repeated using intervals of decreasing size until no significant change in the calculated number of design cycles N_p is obtained.

ARTICLE KD-5
DESIGN USING AUTOFRETTAGE

KD-500 SCOPE

This Article provides means to calculate residual stress distribution after autofrettage has been performed, in straight single wall cylinders with no crossholes or discontinuities. Numerical elastic–plastic analyses or experimental techniques may be used for more complex geometries. Other approaches may be used if they can be shown to be conservative.

Autofrettage is one of several processes that can be used to produce favorable residual stresses in thick-walled pressure vessels. Autofrettage may be used alone or combined with other processes such as shrink fitting or wrapping to produce a more favorable residual stress distribution than can be conveniently produced by autofrettage alone. See Article KD-8 for rules on combining these residual stresses.

The method for vessel fatigue design accounting for the residual stresses produced by autofrettage is given in Articles KD-3 and KD-4. The guidelines for accomplishing the autofrettage operation are given in Article KF-5.

KD-501 Theory

(a) The theory of autofrettage is based on the fact that the stress in a thick-walled cylindrical vessel is higher at the bore than at the outside surface for a given internal pressure. If such a vessel is subjected to a continuously increasing pressure, the entire vessel will deform elastically until some pressure is reached at which the material at the bore begins to plastically deform. As the pressure continues to increase, the boundary at which material begins to yield moves from the bore through the vessel wall until it reaches the outer wall, causing plastic collapse [see KD-210(e)(6)]. In the process of autofrettage, the pressure is increased from the point of first yielding at the bore to a pressure that will place the elastic–plastic interface at the desired radius. The removal of this pressure then produces compressive residual tangential stress at the bore and tensile residual tangential stress at the outer wall.

(b) The effects of these residual compressive tangential stresses are to

(1) increase the value of any subsequent application of internal pressure which will cause the onset of additional permanent deformation of the cylinder

(2) reduce the effective mean stress value of the cyclic bore stresses and thus increase the fatigue life

(3) reduce the effective fracture mechanics stress intensity factor at the tip of a crack or cracklike flaw near the bore due to internal pressure. This will retard the growth of fatigue or stress corrosion cracks near the bore surface.

KD-502 Nomenclature

A_{cs} = cross-sectional area normal to the longitudinal axis, in.^{2} (mm^2)

D = diameter of the cylindrical vessel at any point in the wall, in. (mm)

D_I = inside diameter, in. (mm)

D_O = outside diameter, in. (mm)

D_P = diameter of the plastic–elastic interface before unloading the autofrettage pressure, in. (mm)

D_Z = diameter where $\sigma_{tRA} = \sigma_{rRA}$, in. (mm)

E = elastic modulus, ksi (MPa)

F_b = correction factor for the Bauschinger effect for $D_Z \leq D \leq D_P$

P_A = maximum pressure applied during the autofrettage operation, ksi (MPa)

S_y = actual measured yield strength of the material being autofrettaged at the temperature at which the autofrettage is performed, ksi (MPa)

Y = ratio of D_O/D_I

ϵ_m = average value of the maximum tangential strain on the outside surface of the vessel, taken at a minimum of three axial locations and measured at the maximum pressure used for the autofrettage operation P_A

ϵ_p = average value of the permanent tangential strain on the inside surface of the vessel, taken at a minimum of three axial locations and measured after the release of the autofrettage pressure

σ_{AD} = value of σ_{tRA} at $D = D_I$, ksi (MPa)

σ_{CD} = value of the residual tangential stress at $D = D_I$ corrected for the Bauschinger effect, ksi (MPa)
σ_{rR} = residual radial stress corrected for the Bauschinger effect, ksi (MPa)
σ_{rRA} = first approximation of the residual radial stress after autofrettage for $D_I \leq D \leq D_P$, ksi (MPa)
σ_{tR} = residual tangential stress corrected for the Bauschinger effect, ksi (MPa)
σ_{tRA} = first approximation of the residual tangential stress after autofrettage for $D_I \leq D \leq D_P$, ksi (MPa)
ν = Poisson's ratio

KD-510 LIMITS ON AUTOFRETTAGE PRESSURE

There is no specified upper limit on autofrettage pressure. However, the permanent tangential strain at the bore surface resulting from the autofrettage operation shall not exceed 2%.

KD-520 CALCULATION OF RESIDUAL STRESSES

(a) In order to evaluate the design of a vessel utilizing autofrettage, a calculation of the residual stress distribution produced by autofrettage shall first be performed. This calculation requires knowledge of the actual extent of autofrettage obtained during the process. This is defined by the diameter of the elastic–plastic interface D_P or by the overstrain ratio $(D_P - D_I)/(D_O - D_I)$. Possible methods for determining D_P are given below. Other methods may be used if they can be shown to be more accurate or conservative.

(b) Machining after autofrettage is permitted. The resulting extent of autofrettage (overstrain ratio) for this condition is calculated using the final dimensions of the vessel and the assumption that D_P remains as determined above. However, any residual tensile stresses introduced by the machining shall be considered.

(c) The theoretical residual stresses calculated in this Article are based on the maximum shear criterion and the assumption that the longitudinal stress is the intermediate principal stress. Therefore, the residual longitudinal stress distribution cannot be determined by this theory. In most pressure vessel applications, the longitudinal stress in the cylinder wall, remote from discontinuities, is the intermediate principal stress and therefore need not be considered in design calculations. However, when longitudinal stresses must be considered near discontinuities, the longitudinal residual stress due to autofrettage shall be neglected.

KD-521 Calculation of the Elastic–Plastic Interface Diameter

The diameter of the elastic–plastic interface D_P may be determined from one or more of the following measurements:

(a) ϵ_m.

(b) ϵ_p.

(c) P_A. This shall only be used to determine D_P if the value of the resulting overstrain ratio so determined is less than 0.4.

KD-521.1 When Outside Strain Is Known. If ϵ_m is measured, calculate D_P/D_O as follows.

(a) For vessels supporting end load during autofrettage,

$$(D_P/D_O)^2 = \left[E\epsilon_m + \nu\left(\frac{P_A D_I^2}{D_O^2 - D_I^2}\right)\right] \Big/ 1.15S_y$$

(b) For all other cases,

$$(D_P/D_O)^2 = [E\epsilon_m + \nu\,(F_1/A_{cs})]/1.15S_y$$

KD-521.2 When Residual Inside Strain Is Known. If ϵ_p is measured, calculate D_P from the following equation using an iterative procedure:

$$\begin{aligned}2E\epsilon_p/1.15S_y = {} & (1 - 2\nu)[\ln(D_I{}^2/D_P{}^2) - 1] + (2 - \nu)(D_P/D_I)^2 \\ & + (1 - \nu)(D_P/D_O)^2 \\ & - \frac{[\ln(D_P{}^2/D_I{}^2) + (D_O^2 - D_P^2)/D_O^2]\,[1 - \nu + (1 + \nu)Y^2]}{Y^2 - 1}\end{aligned}$$

KD-521.3 When Autofrettage Pressure Is Known. If P_A is measured and the requirements of KD-521(c) are met, then D_P can be determined from the following equation using an iterative procedure:

$$P_A = 1.15S_y\,[\ln(D_P/D_I) + (D_O^2 - D_P^2)/2D_O^2]$$

KD-522 Residual Stresses Between Bore and Elastic–Plastic Interface

The general method for calculating the autofrettage residual stresses is given below for a monobloc cylinder.

KD-522.1 When No Reverse Yielding Occurs. Calculate the first approximation of the tangential and radial residual stress distributions (σ_{tRA} and σ_{rRA}) using Eqs. (1) and (2) for $D_I < D < D_P$.

$$\begin{aligned}\frac{\sigma_{tRA}}{S_y} = {} & \frac{D_P^2 + D_O^2}{2D_O^2} + \ln\left(\frac{D}{D_P}\right) \\ & - \left[\frac{D_I^2}{D_O^2 - D_I^2}\right]\left[\frac{D_O^2 - D_P^2}{2D_O^2} + \ln\left(\frac{D_P}{D_I}\right)\right]\left(1 + \frac{D_O^2}{D^2}\right) \qquad (1)\end{aligned}$$

$$\frac{\sigma_{rRA}}{S_y} = \frac{D_P^2 - D_O^2}{2D_O^2} + \ln\left(\frac{D}{D_P}\right)$$

$$- \left[\frac{D_I^2}{D_O^2 - D_I^2}\right]\left[\frac{D_O^2 - D_P^2}{2D_O^2} + \ln\left(\frac{D_P}{D_I}\right)\right]\left(1 - \frac{D_O^2}{D^2}\right) \qquad (2)$$

04 **KD-522.2 Correction for Reverse Yielding (Bauschinger Effect).** The residual stresses shall be corrected for the fact that reverse yielding may occur on unloading from the autofrettage pressure due to the reduction of the compressive yield strength of the material resulting from tensile plastic deformation. This is known as the *Bauschinger Effect.* This correction shall be accomplished as follows:

(a) Using Eqs. (1) and (2) in KD-522.1, calculate the value of D at which $(\sigma_{tRA} - \sigma_{rRA}) = 0$ using an iterative procedure, and define this as D_Z.

(b) Calculate the value of σ_{tRA} at $D = D_I$ from Eq. (1) in KD-522.1 and define this as σ_{AD}. Calculate the corrected value of the residual stress at $D = D_I$ (defined as σ_{CD}), from both Eqs. (1) and (2) below.

$$\sigma_{CD}/\sigma_{AD} = 1.0388 - 0.1651Y + 0.6307 - 1.8871M + 1.9837M^2 - 0.7296M^3 \qquad (1)$$

where M is the overstrain ratio, $(D_p - D_I)/(D_O - D_I)$ and Y is diameter ratio.

If the end load on the closures is not supported by the cylinder wall during autofrettage (open end)

$$\sigma_{CD}/\sigma_{AD} = -0.5484 + 1.8141Y - 0.6502Y^2 + 0.0791Y^3 \qquad (2)$$

If the end load on the closures is supported by the cylinder wall during autofrettage (closed end), replace Eq. (2) with $\sigma_{CD}/\sigma_{AD} = 1.15$.

The value of σ_{CD} to be used is the least negative value of those determined from Eq. (1) or (2) above.

(c) If $\sigma_{CD}/S_y < -0.7$, then let $\sigma_{CD}/S_y = -0.7$.

(d) For $D_I < D < D_Z$, calculate the residual stress distribution from Eqs. (3) and (4):

$$\frac{\sigma_{tR}}{\sigma_{CD}} = \frac{D_Z\,[\ln(D/D_I) + 1] + D_I - 2D}{D_Z - D_I} \qquad (3)$$

$$\frac{\sigma_{rR}}{\sigma_{CD}} = \frac{D_Z \ln(D/D_I) + D_I - D}{D_Z - D_I} \qquad (4)$$

(e) For $D > D_Z$, the residual stresses shall be corrected to ensure that continuity and equilibrium conditions are met. This shall be accomplished by calculating a correction factor F_b as follows:

(1) Calculate σ_{rR} at $D = D_Z$ using Eq. (4) above.

(2) Calculate σ_{rRA} at $D = D_Z$ using Eq. (2) in KD-522.1.

(3) Divide the results of subparagraph (1) by the results of subparagraph (2) and this equals F_b.

(f) For $D_Z < D < D_P$, calculate the residual stresses using Eqs. (1) and (2) in KD-522.1 and multiply the results at each value of D by F_b.

KD-523 Residual Stresses Between Elastic–Plastic Interface and Outside Diameter 04

For $D_P < D < D_O$, calculate the residual stresses using Eqs. (1) and (2):

$$\frac{\sigma_{tR}}{S_y} = F_b\left(1 + \frac{D_O^2}{D^2}\right)\left\{\frac{D_P^2}{2D_O^2} + \frac{D_I^2}{D_O^2 - D_I^2} \times \left[\frac{D_P^2 - D_O^2}{2D_O^2} - \ln\left(\frac{D_P}{D_I}\right)\right]\right\} \qquad (1)$$

$$\frac{\sigma_{rR}}{S_y} = F_b\left(1 - \frac{D_O^2}{D^2}\right)\left\{\frac{D_P^2}{2D_O^2} + \frac{D_I^2}{D_O^2 - D_I^2} \times \left[\frac{D_P^2 - D_O^2}{2D_O^2} - \ln\left(\frac{D_P}{D_I}\right)\right]\right\} \qquad (2)$$

KD-530 DESIGN CALCULATIONS

These residual stress values are used in the fatigue analysis as described in Article KD-3 and in the fracture mechanics analysis as described in Article KD-4.

ARTICLE KD-6
DESIGN REQUIREMENTS FOR OPENINGS, CLOSURES, HEADS, BOLTING, AND SEALS

KD-600 SCOPE

The requirements in this Article apply to heads, closures, bolting, and seals. These requirements are additional to the general requirements given in Articles KD-2, KD-3, and KD-4.

KD-601 Openings

The Designer shall consider the influence of cross bores and other openings on the static strength integrity of the vessel. Additional guidance is provided in Nonmandatory Appendix H.

KD-610 THREADED CONNECTIONS

(a) Straight threaded connections are permitted as provided for in this Article.[1] Tapered pipe threads are not permitted.

(b) Where tapped holes are provided in pressure boundaries, the effect of such holes (e.g., stress riser, material loss) shall be considered in the vessel design.

(c) Thread load distribution shall be considered in design cyclic analysis per KD-616.

KD-611 Standard Bolt and Nut Pairs

If a standard bolt and nut pair conforming to material specifications in Section II Part D is used and both members are of the same material, the thread shear and bearing capability need not be qualified further.

KD-612 Average Thread Shear Stress

The average shear stress in the threads, calculated by dividing the design load by the appropriate thread shear area, shall be limited to $0.25S_y$ at the design temperature.

[1] The Designer is cautioned that fine threads may cause assembly problems and possible loss of engagement because of thermal expansion and dilation due to loading.

KD-613 Average Thread Bearing Stress

The average bearing stress in the threads due to the maximum design loading shall be limited to $0.75S_y$.

KD-614 Limitations on Thread Displacements

Relative radial displacement between mating threads shall be calculated considering the combination of applied loads and thermal effects. No credit shall be taken for thread friction. The results of this analysis shall demonstrate that the threads having relative radial displacement less than 10% of the minimum thread overlap meet the requirements of KD-612 and KD-613. No credit shall be taken for threads whose relative radial displacement exceeds 10%.

KD-615 Length of Engagement

The length of engagement is to be taken as the minimum which can occur within the drawing tolerances with no credit for partial threads.

(a) Connections which have imposed loads on threads in tapped holes shall comply with the requirements of KD-615(b). The vessel or an integral weld buildup shall have a flat surface machined on the shell to receive the connection.

(b) Where tapped holes are provided, the threads shall be full and clean and the engaged length shall not be less than the larger of d_s or

$$0.75d_s\left(\frac{S_y \text{ of stud material at design temperature}}{S_y \text{ of tapped material at design temperature}}\right)$$

in which d_s is the root diameter of the stud.

KD-616 Fatigue and Fracture Mechanics Analysis

(a) Except as permitted in KD-100(c), a fatigue analysis in accordance with Article KD-3 or a fracture mechanics analysis in accordance with Article KD-4 is required for all threaded connections.

(b) The fatigue evaluation of a threaded joint is made by the same methods as are applied to any other structure that is subjected to cyclic loading.

(c) The stresses developed by the expected service shall be analyzed. Unless it can be shown by analysis or test that a lower value is appropriate, the fatigue strength reduction factor for threads shall not be less than 4.0.

(d) ANSI standard nuts of materials permitted by this Division do not require fatigue analysis. Internal threads mating with a stud or bolt do not require fatigue analysis for bolting loads. However, the effects of the internally threaded penetration on the nominal primary-plus-secondary stresses in the internally threaded member shall be considered.

KD-617 Special Threads, Sleeve Coupled Joints, and Other Proprietary Joints

Flared, flareless, and compression type joints for tubing are not permitted.

Mechanical joints for which no standards exist and other proprietary joints may be used provided the requirements of KD-617(a), (b), and (c) are met.

(a) Provision is made to prevent separation of the joints under all service loadings.

(b) A prototype joint shall be subjected to performance tests to determine the safety of the joint under simulated service loadings per Article KD-12. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock is anticipated, the applicable loads shall be incorporated in the tests.

(c) Vent passages shall be provided to prevent pressure buildup caused by accidental or incidental development of any secondary sealing areas exterior to the designated sealing surface (e.g., threads).

KD-620 BOLTING

The number and cross-sectional area of bolts required to resist primary loads shall be determined. The yield strength values to be used are the values given in Section II Part D for bolting materials.

(a) The average primary stress intensity S shall be based on the thread root diameter and shall not exceed the following limit:

$$S = \frac{1}{1.8} S_y$$

(b) For bolts with a reduced shank, which has a diameter less than 0.9 times the thread root diameter, the above equation shall be replaced by:

$$S = \frac{1}{1.5} S_y$$

provided the actual shank diameter is used.

(c) Primary-plus-secondary membrane stress intensity in bolts shall not exceed $0.75S_y$. Primary-plus-secondary membrane plus bending stress intensity in bolts shall not exceed S_y due to the combination of both the design loads and preloads. Stress intensification due to the threads shall not be considered in the above analysis.

KD-621 Threading and Machining of Studs

Studs shall be threaded full length, or shall be machined down to the root diameter of the thread in the unthreaded portion. The threaded portions shall have a length of at least $1\frac{1}{2}$ times the nominal diameter, unless analysis (see KD-612 through KD-616) using the most unfavorable combination of tolerances at assembly demonstrates adequate thread engagement is achieved with a shorter thread length.

Studs greater than eight times the nominal diameter in length may have an unthreaded portion which has the nominal diameter of the stud, provided the following requirements are met.

(a) The stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion.

(b) A suitable transition shall be provided between the root diameter portion and the full diameter portion.

(c) Threads shall be of a "V" type, having a minimum thread root radius no smaller than 0.08 times the pitch.

(d) Fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060 in. (1.5 mm).

KD-630 LOAD-CARRYING SHELL WITH SINGLE THREADED END CLOSURES

Because of the many variables involved, and in order not to restrict innovative designs, detailed rules are kept to a minimum. The effects of the total load to be resisted, the number of threads, the thread form, the relative stiffness of mating parts, and friction shall be considered in both the static and fatigue analyses of the closure. Stresses can be minimized by providing generous undercuts ahead of the first threads and providing flexibility in mating parts to promote equalization of the thread loads.

KD-631 Stresses in Vessel at Threads

The Designer shall identify the area of the threaded closure where the maximum stress intensity occurs. This is generally the area at the root of the most highly loaded thread, which is usually the first or second thread. Calculation of this stress intensity requires consideration of the actual thread load, stress concentration factor due to thread form (in particular, the thread root radius), thread bending stress, and the membrane and bending stresses in the vessel at the thread.

KD-631.1 Longitudinal Bending Stresses. Unless it can be shown by analysis or test that a lower value is appropriate, the primary longitudinal bending stress in the vessel at the first thread shall be considered to be 3.0 times the primary longitudinal membrane stress.

KD-631.2 Circumferential Stresses. The circumferential stresses are significantly affected by the distance to the pressure seal. Unless shown by analysis or test that a lower value is appropriate, the circumferential stresses in the vessel at the first thread shall be considered to be those in the cylinder derived with the equations in Article KD-2. In addition, circumferential stresses due to resultant radial loading of the threads shall be included.

KD-631.3 Thread Load Distribution. In general, the threads do not carry the end load uniformly. The Designer shall determine thread load distribution. See E-200.

KD-631.4 Fracture Mechanics Analysis. Fracture mechanics analysis shall be made in accordance with Article KD-4. This analysis shall include as a minimum the combined effects of bending of the thread, and the shell membrane and bending stresses.

KD-631.5 Progressive Distortion. Screwed-on caps and screwed-in plugs are examples of nonintegral connections which are subject to failure by bell mouthing or other types of progressive deformation. Such joints may be subject to ratcheting, causing the mating members to progressively disengage. See KD-210(e)(9).

KD-631.6 Interrupted Threads. Closures utilizing interrupted threads may be analyzed as closures with continuous threads provided that a multiplier is applied to the resultant stresses. The multiplier is the ratio of the continuous thread circumferential length to that of the interrupted thread. The contact length used when calculating the stress distribution for an interrupted thread may be less than the thread length because of the profiling of the thread ends.

KD-632 Special Closures and Materials

Threaded closures for which no standards exist may be used, provided the requirements of KD-632(a), (b), and (c) are met.

(a) The design shall prevent separation of the closure parts under all service conditions stated in the User's Design Specification.

(b) The closure is analyzed in accordance with the rules of Articles KD-2, KD-3, and KD-4, or a prototype has been evaluated in accordance with the rules of Article KD-12.

(c) For parts for which it is impossible or impractical to measure the yield strength after final processing, the maximum allowable tensile stress at design pressure shall be one-third the ultimate strength at design temperature, so long as the final processing does not adversely affect the ultimate strength.

KD-640 FLAT INTEGRAL HEADS

Except as provided in KD-240, flat heads shall meet the design criteria in KD-230.

For guidance on the design of integral heads (blind heads), see E-100.

KD-650 QUICK-ACTUATING CLOSURES

KD-651 General Design Requirements

Quick-actuating closures shall be so designed and installed that it can be determined by visual external observation that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement. Alternatively, other means may be provided to ensure full engagement.

KD-652 Specific Design Requirements

Quick-actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limited movement of the closure itself or the locking mechanism, and any automated closure, shall be designed to meet the following conditions:

(a) The closure and its holding elements are fully engaged in their intended operating position before the vessel can be pressurized.

(b) Pressure tending to open the closure shall be released before the locking mechanism is disengaged.

(c) A coefficient of friction less than or equal to 0.02 shall be used in the design analysis.

KD-652.1 Permissible Design Deviations for Manually Operated Closures. Quick-actuating closures that are held in position by a locking device or mechanism that requires manual operation and are so designed that there shall be leakage of the contents of the vessel prior to disengagement of the locking elements and release of closure need not satisfy KD-652(a), (b), and (c). However, such closures shall be equipped with an audible or visible warning device that shall serve to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged in their intended position and, further, will serve to warn the operator if an attempt is made to operate the locking mechanism or device before the pressure within the vessel is released.

KD-652.2 Yokes. Yokes or frames shall comply with all requirements of this Division.

KD-653 Required Pressure-Indicating Devices

All vessels having quick-actuating closures shall be provided with a pressure-indicating device visible from the operating station.

KD-660 REQUIREMENTS FOR CLOSURES AND SEALS

The requirement of a leak-tight seal is of primary importance in closures for high pressure vessels. This is because even small leaks produce a damaging (cutting) effect through the sealing surfaces, which may progress rapidly to increasingly hazardous conditions.

KD-661 Requirements for Closures

(a) The seal closure shall have the capability to contain pressure with the same assurance against failure as the vessel for which it will be used.

(b) Adequate venting shall be provided in the closure design in the event of seal failure.

(c) The effects of dilation, distortion, or both on the closure components under all expected conditions of pressure and temperature shall not result in an increase in the seal clearances greater than the values required to retain the sealing element.

(d) A complete stress analysis shall be made of all components that contribute to the strength and sealing capability of the closure.

(e) For applications involving cyclic loads, the requirements of Articles KD-3 or KD-4, as applicable, shall be met for all parts except the sealing element.

KD-662 Requirements for Sealing Elements

The material selected shall be compatible with all normally expected process and environmental conditions, such as pressure, temperature, corrosion, solubility, chemical reaction, etc., as specified in the User's Design Specification.

KD-662.1 Contained Sealing Elements. The materials of construction for sealing elements are generally not covered in Part KM. The User's Design Specification shall either specify the required material or furnish enough information to enable the Designer to make an appropriate selection.

KD-662.2 Unsupported Metallic Sealing Elements. Sealing elements which themselves provide the strength required to contain the pressure (i.e., cone joint, lapped joint, etc.) shall satisfy the requirements of this Division.

ARTICLE KD-7
DESIGN REQUIREMENTS FOR ATTACHMENTS, SUPPORTS, AND EXTERNAL HEATING AND COOLING JACKETS

KD-700 GENERAL REQUIREMENTS

The requirements of this Article are in addition to the requirements given in Articles KD-2, KD-3, and KD-4.

(a) Supports, lugs, brackets, stiffeners, and other attachments may be welded or bolted to the vessel wall. A detailed fatigue and fracture mechanics analysis in accordance with the requirements of Article KD-3 or KD-4, as applicable, of the effect of all attachments on the pressure boundary is required.

(b) Attachments shall approximately conform to the curvature of the shell to which they are to be attached.

(c) Attachments may be welded to a pressure vessel only as permitted by the rules of this Division.

(1) Resistance welded studs, clips, etc., shall not be used.

(2) Some acceptable types of welds are shown in Fig. KD-700.

(3) All welds joining nonpressure parts to pressure parts shall be continuous full-penetration welds; see KF-220(c).

(d) Attachments may be welded directly to weld deposit cladding, in which case the following requirements shall apply.

(1) For clad construction, attachments may be made directly to the cladding only if loadings producing primary stresses in the attachment weld do not exceed 10% of the design stress intensity value of the attachment or the cladding material, whichever is less. For higher loadings, there shall be sufficient attachment welding either directly to the base metal or to weld overlay cladding to develop the strength for the primary stress loadings (portions of weld not required for strength, e.g., for weld continuity or sealing, may be welded directly to the cladding).

(2) For linings, attachments should be made directly to the base metal or to weld overlay cladding. Analysis and tests shall be made to establish the adequacy and reliability of attachment before making any attachments directly to the lining (successful experience with similar linings in comparable service may provide a basis for judgment).

KD-710 MATERIALS FOR ATTACHMENTS

KD-711 Attachments to Pressure Parts

Those attachments welded directly to pressure parts shall be of a material listed in Part KM. The material and the weld metal shall be compatible with that of the pressure part. The designer is cautioned to consider the effects of differences in coefficients of expansion modulus of elasticity and yield strength between materials at the design temperature.

KD-712 Minor Attachments

Minor attachments are defined as parts of small size [not over $^3\!/_8$ in. (10 mm) thick or 5 in.^{3} (0.082 L) volume] carrying no load or insignificant load requiring no load calculation in the Designer's judgment, such as nameplates, insulation supports, and locating lugs.

Except as limited by Parts KF or KM, where no welding is permitted, minor attachments may be of material not listed in Section II Part D and may be welded directly to the pressure part, provided

(a) the material is identified as complying with an ASTM specification and is suitable for welding

(b) the material of the attachment and the pressure part are compatible insofar as welding is concerned

(c) the welds are postweld heat treated when required in Part KF

KD-720 WELDS ATTACHING NONPRESSURE PARTS TO PRESSURE PARTS

KD-721 Location Restrictions

Welds attaching nonpressure parts to pressure parts shall be no closer than $(R_m t_s)^{0.5}$ to a gross structural discontinuity, where

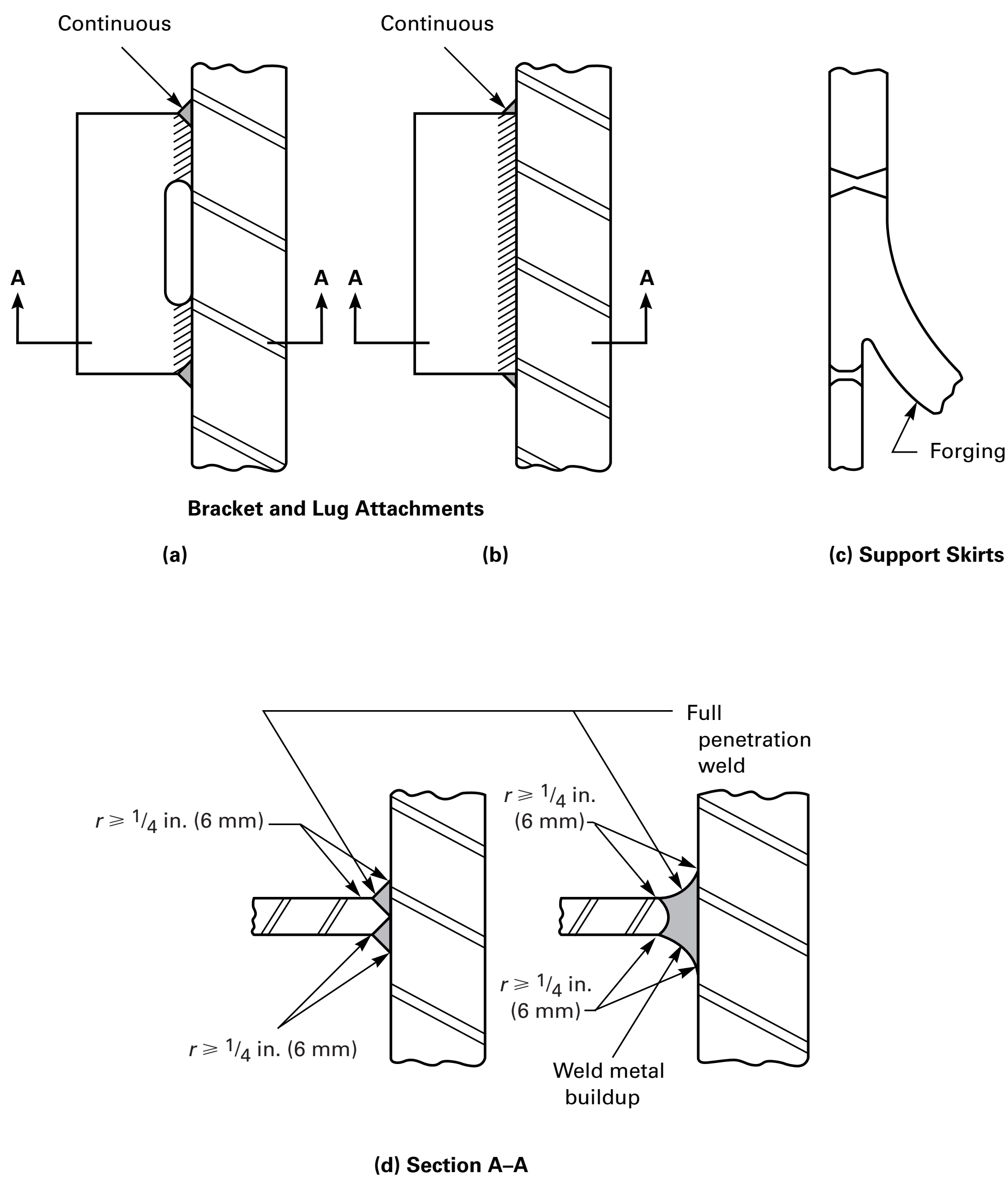


FIG. KD-700 SOME ILLUSTRATIVE WELD ATTACHMENT DETAILS

R_m = mean radius of curvature of shell at the discontinuity
t_s = shell thickness

KD-722 Types of Attachment Welds

Attachment of nonpressure parts to pressure parts shall be one of the following types:

(a) full-penetration weld[1] [see Fig. KD-700, sketch (c)]

(b) full-penetration weld plus fillet weld on one or both sides, in accordance with Fig. KD-700, sketches (a) and (b)

KD-723 Stress Values for Weld Materials

Attachment weld strength shall be based on the minimum weld area and the design stress intensity value in Section II Part D and stress criteria in Article KD-2 for the weaker of the two materials joined.

KD-724 Attachment Welds — Fatigue Analysis

The fatigue analysis evaluations of Article KD-3 or KD-4, as applicable, shall apply.

KD-730 DESIGN OF ATTACHMENTS

The effects of attachments, including external and internal piping connections, shall be taken into account in checking for compliance with the other requirements of this Division.

KD-740 DESIGN OF SUPPORTS

(a) Vessel supports shall accommodate the maximum imposed loadings. The imposed loadings include those due to pressure, weight of the vessel and its contents, machinery and piping loads, wind, earthquake, etc. (see Article KD-2). Wind and earthquake loads need not be assumed to occur simultaneously.

(b) The membrane stress intensity in that part of the support within the jurisdiction of this Division shall not exceed the limits established in Fig. KD-230.

(c) Supports of vertical vessels provided with removable bottom closures shall be designed so as to allow the bottom closure to be periodically removed for service and inspection.

KD-750 JACKETED VESSELS

When a vessel constructed to this Division is to be fitted with a jacket for heating or cooling purposes, the jacket shall meet the following rules:

(a) The portion of a jacket welded directly to a Division 3 vessel shall meet the rules of Division 3 for the direct attachment weldment (actual attachment weld and attachment material) as covered by Parts KF and KM. The remainder of the jacket shall meet the design rules of this Division, Division 2, or Division 1, in accordance with the User's Design Specification.

(b) A jacket attached by means other than direct welding to the vessel shall meet the design rules of this Division, Division 2, or Division 1. Spacer bars and jacket closures shall meet the materials and fabrication requirements of the same Division.

[1] The prior deposition of weld metal to provide a boss for the butt weld is permissible provided it is examined for soundness by suitable nondestructive examination. The Manufacturer shall also give consideration to heat treatment of the buildup.

ARTICLE KD-8
SPECIAL DESIGN REQUIREMENTS FOR LAYERED VESSELS

KD-800 GENERAL

(a) For the purposes of this Division, a *layered vessel* is defined as any cylindrical or spherical vessel that is constructed of two or more concentric, hollow cylinders or spheres assembled in such a way that the outer surface of each cylinder or sphere is in contact with the inner surface of the next larger cylinder or sphere. Each individual cylinder or sphere is referred to as a *layer.*

(b) There are three types of layered vessel constructions considered in this Article:

(1) vessels made of forged, machined layers that are shrink-fitted together

(2) vessels made of rolled, welded, and machined layers that are shrink-fitted together

(3) vessels made of concentrically wrapped and welded layers

(c) This Article addresses layers and inner shells (see KD-104) that are considered in the static strength of the vessels. Liners are not considered in the static strength of vessels and shall meet the requirements of KD-103.

KD-801 Design Criteria

(a) The static strength of layered vessels with no significant gaps between the layers, those that meet the requirements of KD-810, or those for which $Q_c = 1$ (see KD-822 and KD-824) shall be determined in accordance with Articles KD-1 and KD-2.

(b) The equations given in this Article are based on elastic analysis. However, in the case of shrunk fit vessels, if additional prestressing is obtained from autofrettage, the residual stress distribution from the local plastic deformation shall be calculated in accordance with the rules of Article KD-5. In determining the final residual stress distribution using an autofrettaged liner, the nonlinear effects of the Bauschinger effect shall be considered.

(c) The beneficial residual stress distribution in vessels assembled by shrink fitting shall be calculated according to the rules given in KD-810. For welded layer shrink-fit vessel construction, the beneficial effects from the residual stress shall only be considered in the Article KD-3 and KD-4 analysis in areas of the vessel not located in a weld or a heat-affected zone of a weld.

(d) Concentrically wrapped, welded, layered vessels shall be treated as monobloc vessels except that the radial and circumferential stresses shall be calculated with corrections for the effects of the gaps between the layers. Rules for calculating these stresses are given in KD-820. No beneficial effects from compressive residual stresses shall be considered in the fatigue analysis of these types of vessels.

KD-802 Nomenclature

D = diameter at any point in the wall, in. (mm)
D_I = diameter of inside surface of innermost layer, in. (mm)
D_{if} = diameter of the interface between layers, in. (mm)
D_n = diameter of outside surface of layer *n,* in. (mm)
D_O = diameter of outside surface of outermost layer, in. (mm)
E = elastic modulus, ksi (MPa)
E_I = elastic modulus of inner layer, ksi (MPa)
E_n = elastic modulus of the *n*th layer, ksi (MPa)
E_O = elastic modulus of outer layer, ksi (MPa)
F_c = calculated factor for circumferential expansion of permissible layer gaps
K = layer number that diameter D is within
N = total number of layers
P = pressure, ksi (MPa)
P_{if} = interface pressure between shrunk fit layers, ksi (MPa)
P_n = pressure between layers n and $n + 1$, caused by layer interference, ksi (MPa)
P_t = internal test pressure, ksi (MPa)
Q_c = ratio of the measured circumferential displacement at hydrotest to the calculated value of a vessel with zero gaps
Y = D_O/D_I

Y_i = ratio of outside diameter to inside diameter of inner layer

Y_o = ratio of outside diameter to inside diameter of outer layer

e_m = actual circumferential growth, in. (mm), to be measured at the hydrotest pressure as specified in KD-822 and KD-824

e_{th} = theoretical circumferential growth, in. (mm)

n = layer number in which stresses are to be calculated

t = total thickness, in. (mm)

t_n = thickness of layer *n,* in. (mm)

δ = diametrical interference between inner and outer layers, for two-piece shrink-fit vessels only, in. (mm)

δ_n = diametrical interference between layers n and $n + 1$, in. (mm)

ν = Poisson's ratio

ν_i = Poisson's ratio for inner layer

ν_o = Poisson's ratio for outer layer

σ_r = radial stress component at radius *r,* ksi (MPa)

σ_{rr} = radial residual stresses, ksi (MPa)

σ_t = tangential stress component at radius *r,* ksi (MPa)

σ_{tr} = tangential residual stresses, ksi (MPa)

KD-810 RULES FOR SHRINK-FIT LAYERED VESSELS

(a) This type of construction differs from concentrically wrapped and welded layers in that each layer is fabricated individually and machined to cause an interference pressure to exist in the assembled layered vessel. The manufacture and assembly of the cylindrical layers shall be accomplished so that the interference stress distribution in all layers can be determined within ±10%. Documentation of the manufacturing and assembly process shall be reviewed by the Professional Engineer who signs the Manufacturer's Design Report so that the actual stress distribution in the completed vessel can be verified.

(b) The final residual stress shall be calculated and shall not exceed the yield strength in any layer at any diameter for the interference fit condition except in the case of autofrettaged liners [see KD-810(c)].

(c) Residual stresses from the interference fitting operation shall be combined with other residual stresses from other manufacturing or assembly operations in the layers or completed vessel. See KD-801(a) and (b). Plastic analysis in accordance with KD-240 may also be used.

(d) Any reduction in yield strength or relaxation in the residual stress distribution due to elevated temperatures during the shrink fitting operation or as a result of welding shall be considered.

(e) Rules for vessels constructed from two layers are given in KD-811 and rules for vessels constructed of more than two layers are given in KD-812.

(f) For shrink-fit vessels of two or more layers, the Designer may assume a leak-before-burst failure mode for the vessel if all the following conditions are met: 04

(1) A fast fracture failure of one or more inner layers causes no parts or fragments to be ejected, and one or more outer layers remain intact.

(2) The end closures remain intact and in place.

(3) The calculated collapse pressure of the remaining intact vessel's pressure boundary shall be greater than 120% of the design pressure of the entire vessel.

The materials used in the construction of the inner layers that are assumed to fail in a fast fracture mode must meet the Charpy V-notch impact energy requirements stated in their applicable material specification in Section II, but do not have to meet the additional Charpy V-notch impact energy requirements given in Table KM-234.2(a). All of the pressure boundary components that are assumed to remain intact shall meet the requirements given in Table KM-234.2(a).

Some plastic deformation is permitted in this type of failure. It is also recognized that some leakage from the vessel may occur and the Designer is cautioned that this type of analysis may not be appropriate if the vessel contains harmful or lethal substances, see KG-311.10(d).

KD-811 Construction With Only Two Layers

KD-811.1 Interference Pressure. The interference pressure between the inner and outer layers is calculated as follows:

$$P_{if} = \frac{\delta}{D_{if} A}$$

where

$$A = \frac{1}{E_i}\left(\frac{D_I^2 + D_{if}^2}{D_{if}^2 - D_I^2} - \nu_i\right) + \frac{1}{E_O}\left(\frac{D_{if}^2 + D_O^2}{D_O^2 - D_{if}^2} + \nu_O\right)$$

This analysis assumes that there is no longitudinal force transmitted between the inner and outer cylinder due to friction at the interface. In some cases of shrink fit, longitudinal stresses can be developed which will affect the interface pressure obtained due to the Poisson effect. For such cases, a more detailed analysis is required to determine the residual stresses.

KD-811.2 Residual Shrink-Fit Stresses. The residual stresses at any point removed from discontinuities in the inner layer, $D_I \le D \le D_{if}$, are then calculated from Eqs. (1) and (2):

$$\sigma_{tr} = -\frac{P_{if} Y_i^2}{Y_i^2 - 1}\left(1 + \frac{D_I^2}{D^2}\right) \tag{1}$$

$$\sigma_{rr} = -\frac{P_{if} Y_i^2}{Y_i^2 - 1}\left(1 - \frac{D_I^2}{D^2}\right) \tag{2}$$

and in the outer layer, $D_{if} \le D \le D_O$, from Eqs. (3) and (4):

$$\sigma_{tr} = \frac{P_{if}}{Y_o^2 - 1}\left(1 + \frac{D_O^2}{D^2}\right) \tag{3}$$

$$\sigma_{rr} = \frac{P_{if}}{Y_o^2 - 1}\left(1 - \frac{D_O^2}{D^2}\right) \tag{4}$$

where

$$Y_i = D_{if}/D_I$$

$$Y_o = D_O/D_{if}$$

KD-811.3 Final Distribution of Residual Stresses. If the vessel components contain known residual stresses produced by autofrettage prior to assembly, these residual stresses shall be combined with the stresses determined from Eqs. (1) through (4) above to determine the final distribution of residual stresses after assembly; see KD-801(a) and (b).

KD-812 Construction With More Than Two Layers

For the case of vessels composed of more than two layers assembled with interference, the following procedure shall be used.

(a) Assemble the first two layers and calculate the residual stresses as in KD-811.

(b) Determine the interference between this assembly and the next layer and calculate the resulting residual stresses as if the first two layers were a single layer. If the first two layers do not have the same elastic modulus, then an appropriate composite value shall be used.

(c) Add the stresses calculated in KD-812(b) to those calculated in KD-812(a) and determine the total residual stress distribution in the resulting assembly. This procedure may be repeated for any number of successive layers.

(d) Equations for calculating the linear elastic stress distribution in a layered cylindrical vessel are given below (see Fig. KD-812).

(1) Layer interference pressure:

$$P_n = \frac{\delta_n E}{2D_n^3}\,\frac{(D_n^2 - D_I^2)(D_{n+1}^2 - D_n^2)}{D_{n+1}^2 - D_I^2}$$

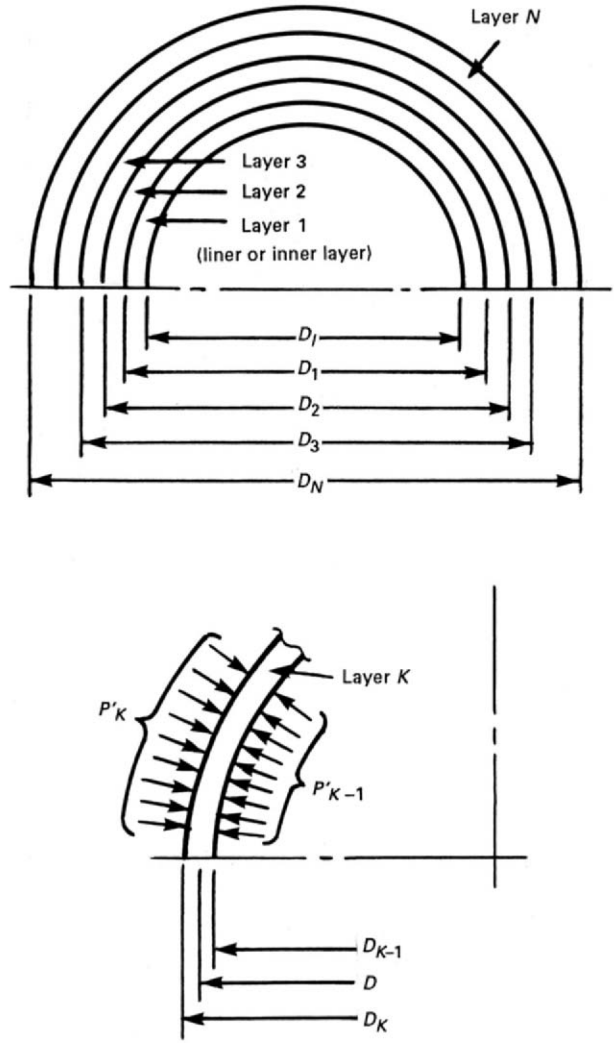


FIG. KD-812 DIAMETERS AND LAYER NUMBERS FOR CONCENTRIC SHRINK-FIT LAYERED CYLINDER

(2) Tangential layer stress component due to prestress:

(a) for $D > D_I$, $K > 1$,

$$\sigma_{tr} = \frac{P_{K-1}\, D_{K-1}^2}{D_K^2 - D_{K-1}^2}\left(\frac{D_K^2}{D^2} + 1\right) - \left(1 + \frac{D_I^2}{D^2}\right)\sum_{n=K}^{N} \frac{P_n D_n^2}{D_n^2 - D_I^2}$$

(b) for $K = 1$, $D > D_I$, $P_{K-1} = P_I = 0$,

$$\sigma_{tr} = -\left(1 + \frac{D_I^2}{D^2}\right)\sum_{n=1}^{N} \frac{P_n D_n^2}{D_n^2 - D_I^2}$$

(3) Radial layer stress component due to prestress:

(a) for $D > D_I$, $K > 1$,

$$\sigma_{rr} = -\frac{P_{K-1} D_{K-1}^2}{D_K^2 - D_{K-1}^2}\left(\frac{D_K^2}{D^2} - 1\right) - \left(1 - \frac{D_I^2}{D^2}\right)\sum_{n=K}^{N} \frac{P_n D_n^2}{D_n^2 - D_I^2}$$

(b) for $K = 1$, $D > D_I$, $P_{K-1} = P_I = 0$,

$$\sigma_{rr} = -\left(1 - \frac{D_I^2}{D^2}\right) \sum_{n=1}^{N} \frac{P_n D_n^2}{D_n^2 - D_I^2}$$

KD-820 RULES FOR CONCENTRICALLY WRAPPED AND WELDED LAYERED VESSELS

KD-821 Welded Layers

The rules given in KD-820 are valid only if KD-821(a) through (d) are met.

(a) Each layer shall have an outer diameter to inner diameter ratio no greater than 1.10 and a minimum layer thickness of $\frac{1}{4}$ in. (6 mm).

(b) All layers in a vessel shall have the same modulus of elasticity and Poisson's ratio over the design temperature range.

(c) No beneficial effects from prestress can be taken into account in the fatigue analysis of the vessel.

(d) The effects of gaps between layers on the stress developed in the layers shall be considered in the stress analysis of the vessel; see KD-822 through KD-825.

KD-822 Circumferential Expansion of Cylindrical Layers

When a layered cylindrical shell is pressurized, the outside circumference will not expand as much as a monobloc vessel of the same dimensions unless all layers are in intimate contact with each other. A measure of the extent of the gaps between layers is to calculate the circumferential expansion e_{th} [see Eq. (1)] of a monobloc cylindrical shell of the same dimensions and compare that to the actual measured circumferential expansion e_m of the layered vessel. This is done at the hydrotest pressure. The ratio of the actual expansion during hydrotest, divided by the theoretical elastic expansion during hydrotest is denoted as Q_c [see Eq. (2)].

$$e_{th} = \frac{P_t\,(2 - \nu)\pi D_O}{E(Y^2 - 1)} \tag{1}$$

The designer may perform a more rigorous analysis to calculate e_{th}, considering end effects and constraint.

$$Q_c = \frac{e_m}{e_{th}} \tag{2}$$

Q_c shall be between 0.5 and 1.0; see KF-827.

KD-823 Calculation of Stresses in Cylindrical Shells

The designer shall assume a value of Q_c between 0.5 and 1.0 to determine the stress distribution in the vessel. The actual value of Q_c measured at hydrotest shall be reported to the designer to verify that the vessel meets the rules of this Division. Assuming a value of Q_c, or using the measured value of Q_c, the value of F_c, the gap correction factor, is calculated using Eq. (1):

$$F_c = \frac{2PD_I^2(1.0 - Q_c)}{D_O^2 - D_I^2} \tag{1}$$

Once the value of F_c is known for a particular vessel, the three principal stresses due to internal pressure are calculated according to Eqs. (2), (3), and (4). These calculated stresses are primary membrane stresses used in KD-220, and in place of those calculated in KD-260 for a monobloc vessel, and must meet the requirements of KD-230.

$$\sigma_t = \frac{PD_I^2(D_O^2 + D^2)}{D^2(D_O^2 - D_I^2)} + F_c\frac{D_O + D_I - 2D}{D_O - D_I} \tag{2}$$

$$\sigma_r = \frac{1}{D}\left\{-PD_I + \frac{PD_I^2}{D_O^2 - D_I^2}\left[D - D_I - D_O^2\left(\frac{1}{D} - \frac{1}{D_I}\right)\right] + \frac{F_c}{D_O - D_I}\left[D(D_I + D_O) - D^2 - D_O D_I\right]\right\} \tag{3}$$

$$\sigma_L = \frac{PD_I^2}{D_O^2 - D_I^2} \tag{4}$$

KD-824 Circumferential Expansion of Welded Layered Spherical Shells and Hemispherical Heads

The theoretical circumferential expansion of a spherical shell at a given pressure e_{th} is given by Eq. (1). The ratio of the actual circumferential expansion in a layered spherical vessel measured at the hydrotest pressure e_m to the theoretical expansion at the same pressure Q_c is given by Eq. (2):

$$e_{th} = \frac{3P_t(1 - \nu)\pi D_O}{2E(Y^3 - 1)} \tag{1}$$

$$Q_c = \frac{e_m}{e_{th}} \tag{2}$$

Q_c shall be between 0.5 and 1.0; see KF-827.

KD-825 Calculated Layer Stress in Spherical Shells and Hemispherical Heads Due to Internal Pressure

(a) Tangential layer stress component due to internal pressure

$$\sigma_t = \frac{PD_I^3(D_O^3 + 2D^3)}{2D^3(D_O^3 - D_I^3)} + F_c\,\frac{D_I + D_O - 2D}{D_O - D_I}$$

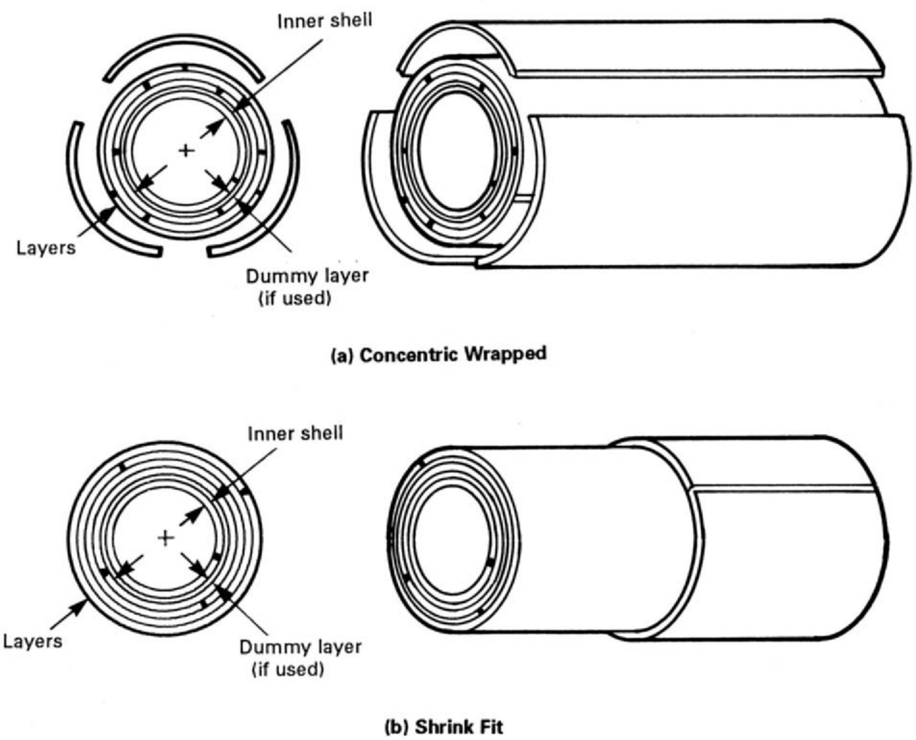


FIG. KD-830.1 ACCEPTABLE LAYERED SHELL TYPES

where

$$F_c = \frac{1.5 D_I^3 P (1.0 - Q_c)}{D_O^3 - D_I^3}$$

(b) Radial layer stress component due to internal pressure

$$\sigma_r = \frac{1}{D^2}\left\{ - P D_I^2 + \frac{P D_I^3}{D_O^3 - D_I^3}\left[D^2 - D_I^2 - D_O^3\left(\frac{1}{D} - \frac{1}{D_I}\right)\right] + \frac{F_c}{D_O - D_I}\left[D^2 (D_I + D_O) - \frac{4D^3 - D_I^3}{3} - D_O D_I^2 \right]\right\}$$

KD-830 DESIGN OF WELDED JOINTS

(a) For vessels assembled by shrink fitting cylindrical shells, all welds in the individual layers shall be Type No. 1 butt welds in accordance with the requirements of Article KD-11, Article KF-2, and Article KF-4. These welds shall be ground flush to provide smooth continuous surfaces at all layer interfaces so that the requirements of KD-810(a) are met.

(b) For vessels assembled by the concentrically wrapped, welded layer technique, the weld in the innermost layer shall be a Type No. 1 butt weld, and the welds in all other layers shall be Type No. 2 butt welds. Additional welding requirements to those in KD-830(a) are given in Article KF-8.

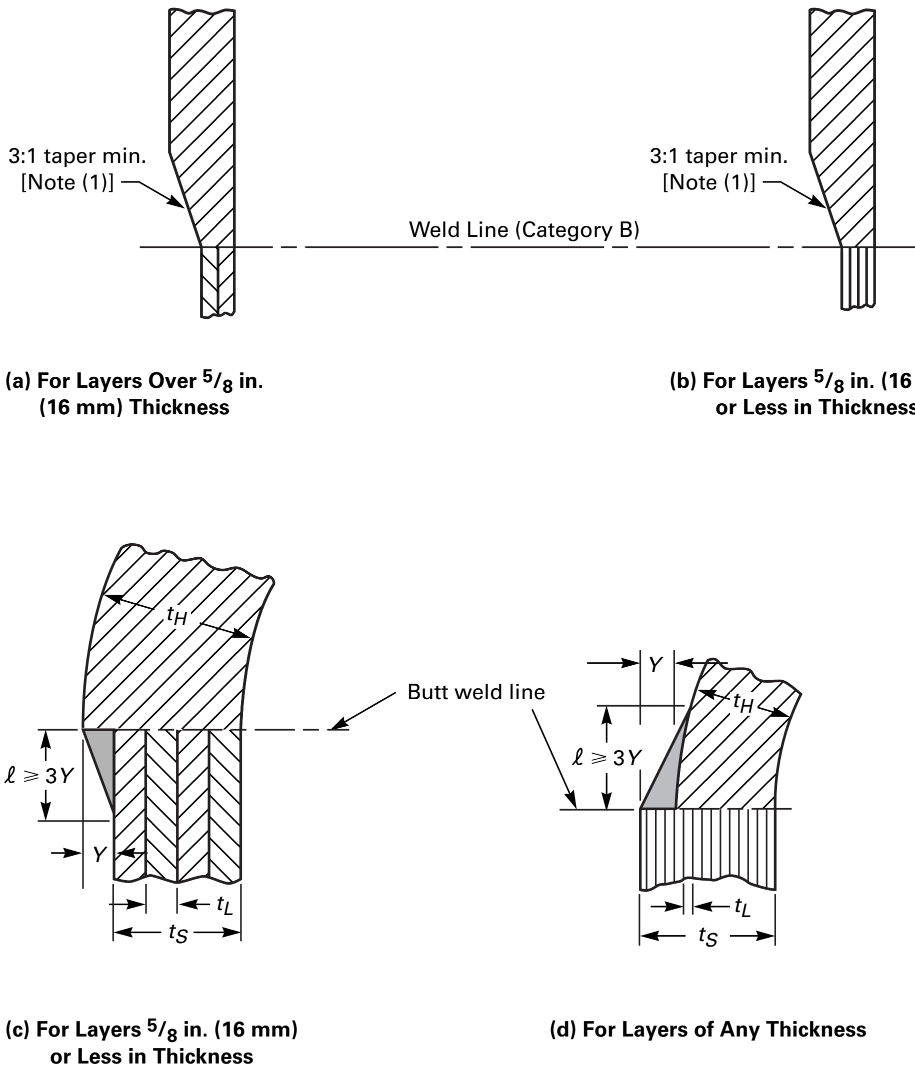
(c) Some acceptable examples of welded construction are shown in Figs. KD-830.1 through KD-830.6.

KD-840 OPENINGS AND THEIR REINFORCEMENT

All reinforcements required for openings shall be integral with the nozzles or provided in the layered section or both. Additional complete full circumferential layers may be included for required reinforcement. Pad type reinforcements are not permitted. See Nonmandatory Appendix H.

KD-850 SUPPORTS

Some acceptable support details are shown in Fig. KD-850. Local loadings imposed on the outer wraps by the supports shall be considered.



t_S = thickness of layered shell
t_L = thickness of one layer
t_H = thickness of head at joint
Y = offset

GENERAL NOTES:

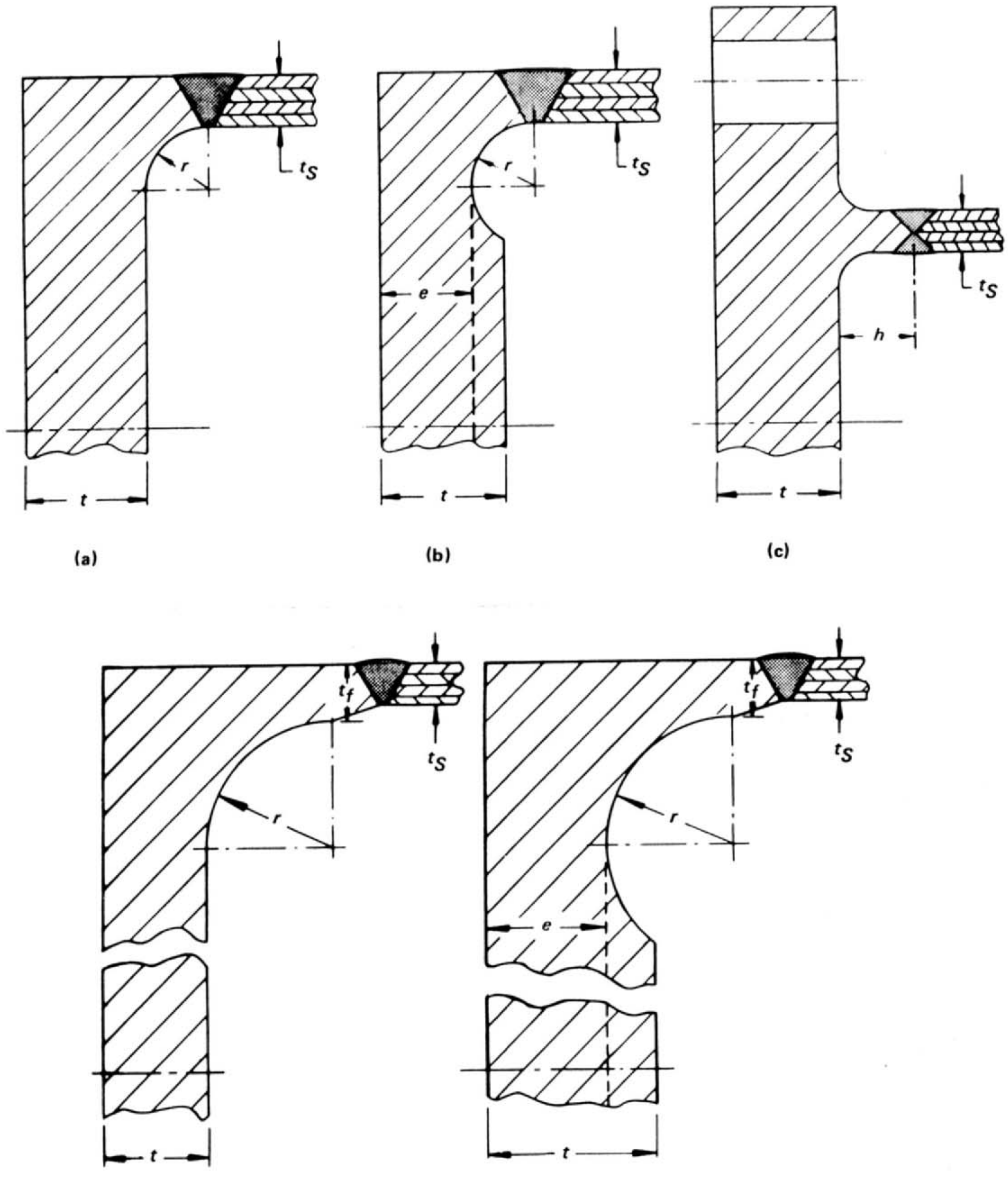
(a) Actual thickness shall be not less than theoretical head thickness.

(b) In illustration (c), Y shall be not larger than t_L. In illustration (d), Y shall be not larger than $\frac{1}{2} t_S$. In all cases ℓ shall be not less than 3 times Y. The shell centerline may be on both sides of the head centerline by a maximum of $\frac{1}{2}(t_S - t_H)$. The length of required taper may include the width of the weld.

NOTE:

(1) Taper may be inside, outside, or both.

FIG. KD-830.2 SOME ACCEPTABLE SOLID-TO-LAYERED ATTACHMENTS



GENERAL NOTES:
(a) t_S = thickness of layered shell
(b) t = thickness of flat head
(c) For all other dimensions, see Fig. KD-1112.

FIG. KD-830.3 SOME ACCEPTABLE FLAT HEADS WITH HUBS JOINING LAYERED SHELL SECTIONS

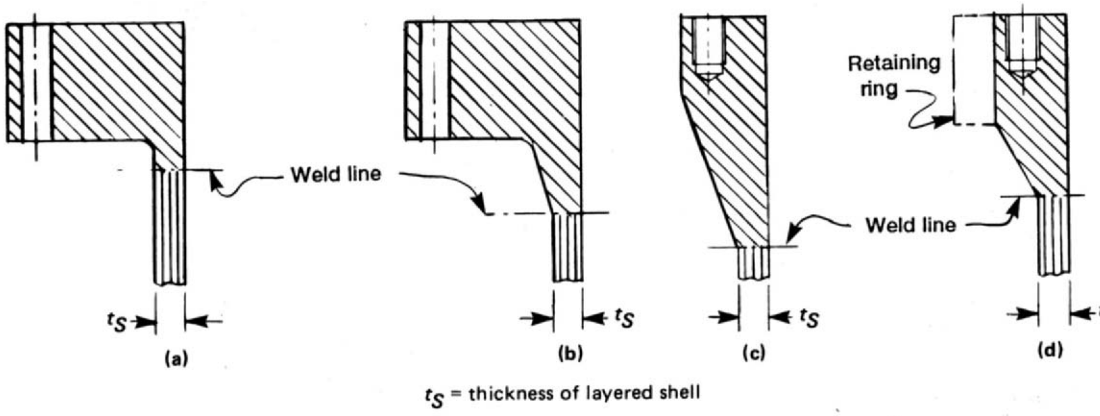
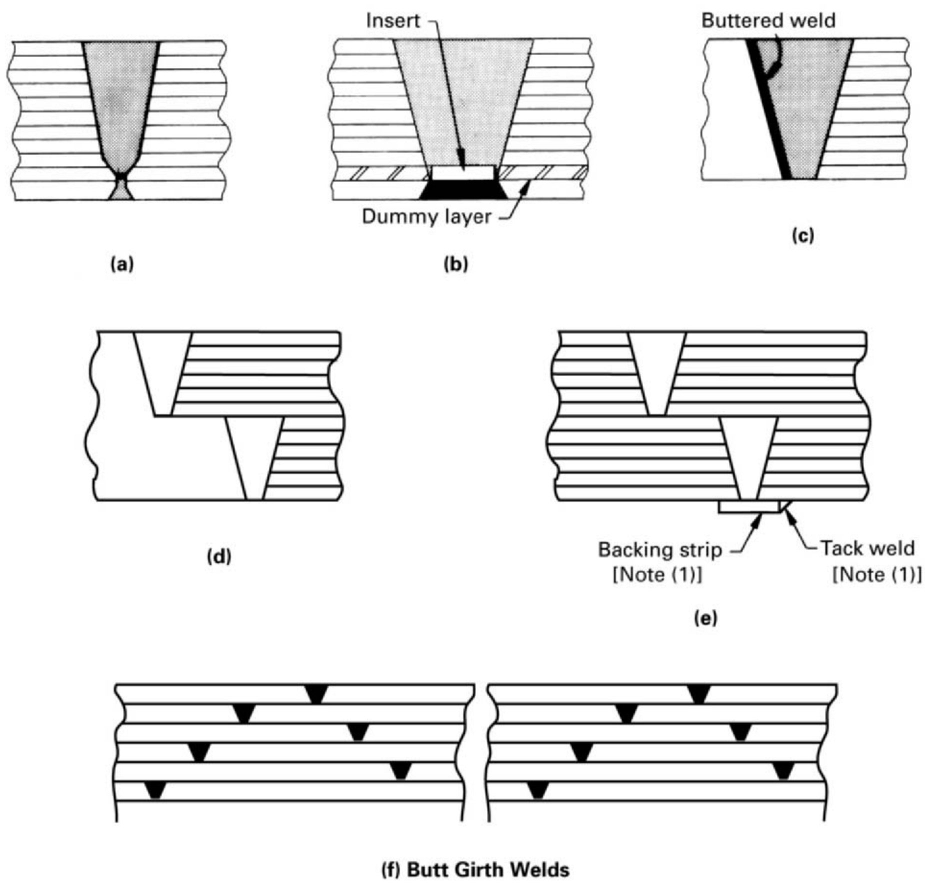
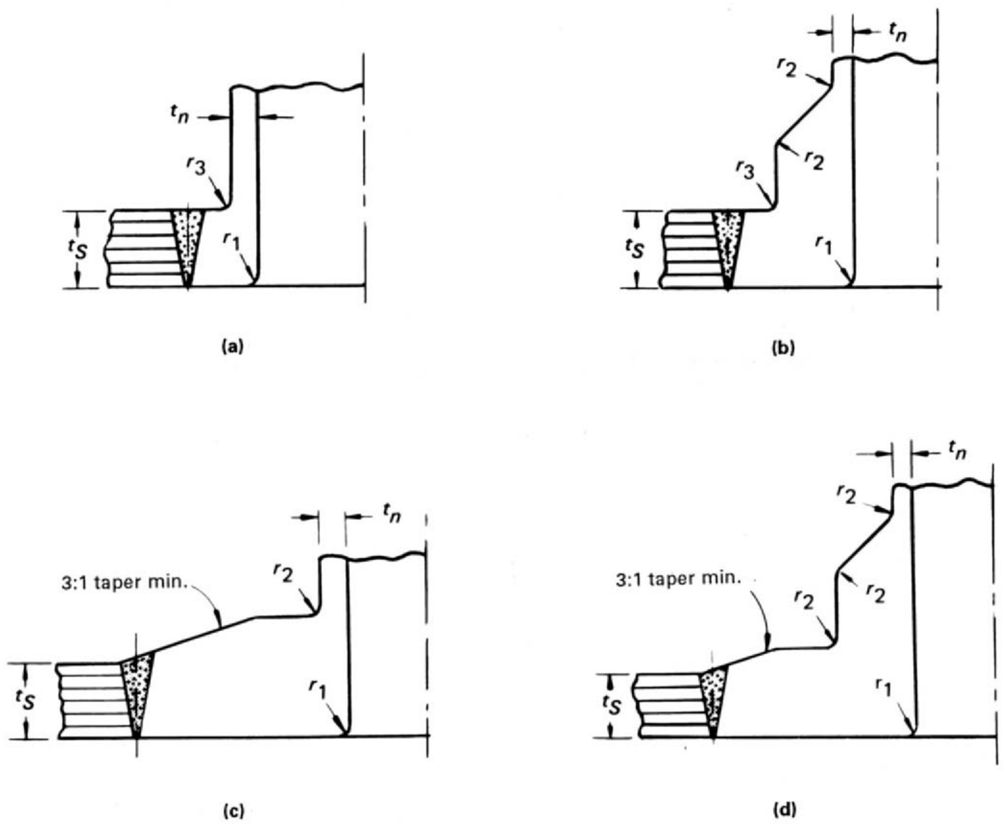


FIG. KD-830.4 SOME ACCEPTABLE FLANGES FOR LAYERED SHELLS



NOTE:
(1) Shall be removed after welding.

FIG. KD-830.5 SOME ACCEPTABLE WELDED JOINTS OF LAYERED-TO-LAYERED AND LAYERED-TO-SOLID SECTIONS



t_S = thickness of layered shell, in.
t_n = nominal thickness of nozzle wall less corrosion allowance
r_1 min. = 1/4 t_n or 3/4 in. (19 mm), whichever is less
r_2 = 1/4 in. (6 mm) minimum
r_3 min. = r_1 minimum

FIG. KD-830.6 SOME ACCEPTABLE NOZZLE ATTACHMENTS IN LAYERED SHELL SECTIONS

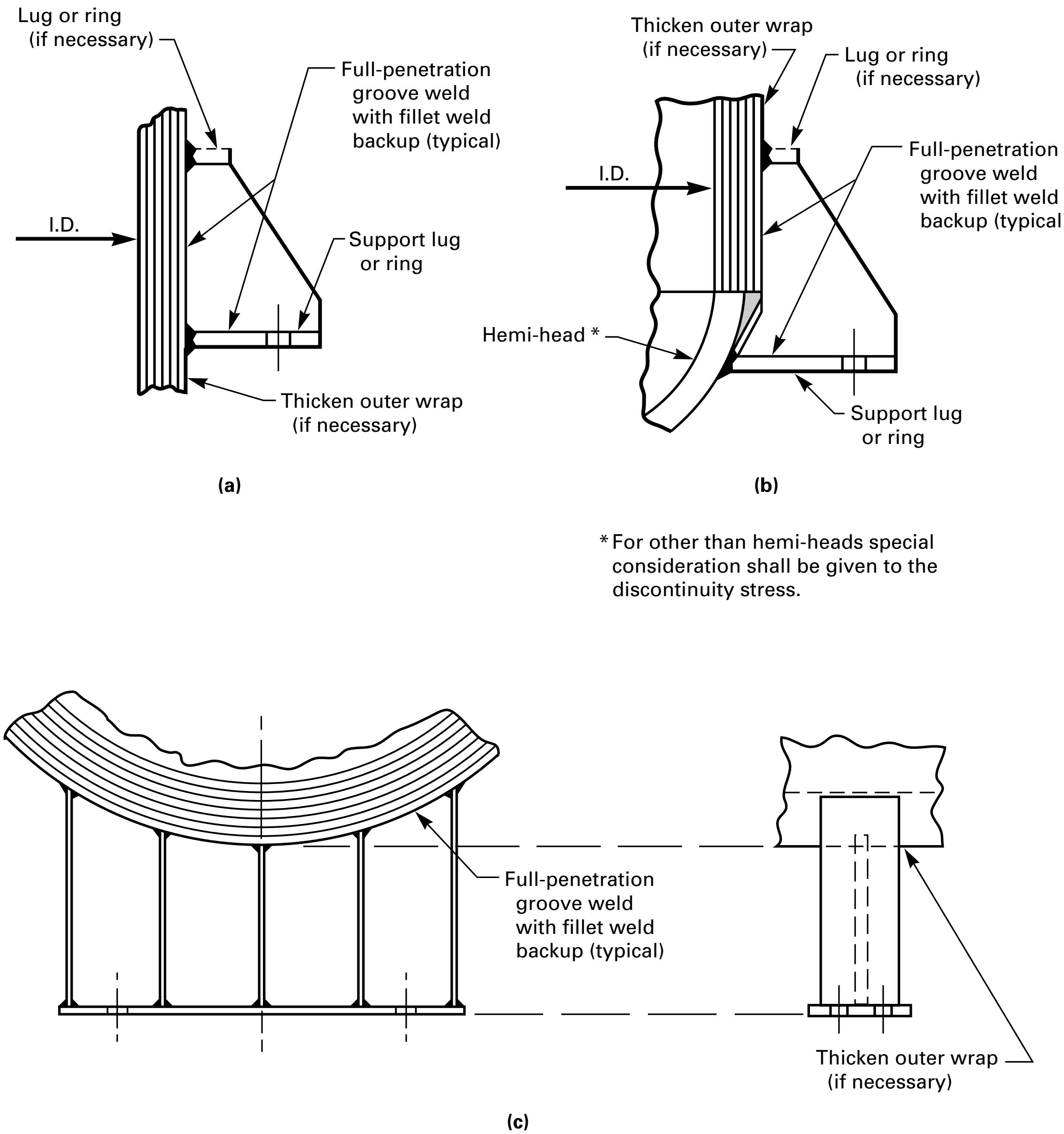


FIG. KD-850 SOME ACCEPTABLE SUPPORTS FOR LAYERED VESSELS

ARTICLE KD-9
SPECIAL DESIGN REQUIREMENTS FOR WIRE-WOUND VESSELS AND WIRE-WOUND FRAMES

KD-900 SCOPE

The requirements of this Article apply specifically to pressure vessels consisting of an inner cylinder (or a number of concentric cylinders) prestressed by a surrounding winding consisting of at least ten layers. The end load is not carried by the cylinder(s) or the winding. The winding consists of a wire helically wound edge-to-edge in pretension in a number of turns and layers around the outside of the cylinder. These requirements also apply to wire-wound frames used to carry the load from the closures. See Fig. KD-900.

The special requirements are in addition to the general requirements given in Articles KD-2, KD-3, and KD-4.

KD-910 STRESS ANALYSIS

The stresses in the vessel due to the internal pressure shall be calculated in accordance with Articles KD-1 and KD-2.

The calculation of the prestressing of the cylinder shall be based on a winding procedure that specifies the wire force that has to be used for each winding layer at the application (see KF-913). The calculation shall give the decrease of the inner diameter of the cylinder and the residual stresses at all points of the vessel wall induced by the winding operation. Equations for this calculation are given in KD-911.

A corresponding winding procedure and stress calculation for the wire-wound frame shall give the decrease of a reference length of the frame and residual principal stresses in the frame and at the different layers of the winding.

The calculated decrease of the inner diameter and the reference length of the frame shall be determined in intervals and shall be used for comparison with the results from corresponding measurements made during the winding operation.

KD-911 Residual Stresses and Deflections in Cylinders Due to Flat Wire Winding

The equations in this paragraph are valid for flat wire with rectangular cross section wound edge-to-edge. For other wire shapes, appropriate corrections shall be made. It is assumed that the winding operation is performed with the stress $S_w(x)$ in the wire and that this stress is a function of the diameter coordinate x (see Fig. KD-911). When the winding layers are applied between $x = D_{if}$ and $x = D_w$, then the following tangential stresses $\sigma_t(x_1)$, radial stresses $\sigma_r(x_1)$, and diametral deformation δ are introduced at the diameter x_1 of the inner cylinders:

$$\sigma_t(x_1) = -\left[1 + \left(\frac{D_I}{x_1}\right)^2\right] \int_{D_{if}}^{D_w} \left(\frac{x}{x^2 - D_I^2}\, S_w(x)\right) dx$$

$$\sigma_r(x_1) = -\left[1 - \left(\frac{D_I}{x_1}\right)^2\right] \int_{D_{if}}^{D_w} \left(\frac{x}{x^2 - D_I^2}\, S_w(x)\right) dx$$

$$\delta = -\frac{2D_I}{E} \int_{D_{if}}^{D_w} \left(\frac{x}{x^2 - D_I^2}\, S_w(x)\right) dx$$

where

D_I = inside diameter, in. (mm)
D_{if} = diameter of the interface between cylinder and winding, in. (mm)
D_O = outside diameter after finished winding operation, in. (mm)
D_w = instantaneous applied outside diameter of winding, in. (mm)
E = modulus of elasticity, ksi (MPa)
x_1 = any diameter of the cylinder, in. (mm)
x_2 = any diameter of the winding, in. (mm)

The corresponding stresses introduced in the winding area at the diameter $x_2(<D_w)$ of the winding are:

$$\sigma_t(x_2) = S_w(x_2) - \left[1 + \left(\frac{D_I}{x_2}\right)^2\right] \int_{x_2}^{D_w} \left(\frac{x}{x^2 - D_I^2}\, S_w(x)\right) dx$$

$$\sigma_r(x_2) = -\left[1 - \left(\frac{D_I}{x_2}\right)^2\right] \int_{x_2}^{D_w} \left(\frac{x}{x^2 - D_I^2}\, S_w(x)\right) dx$$

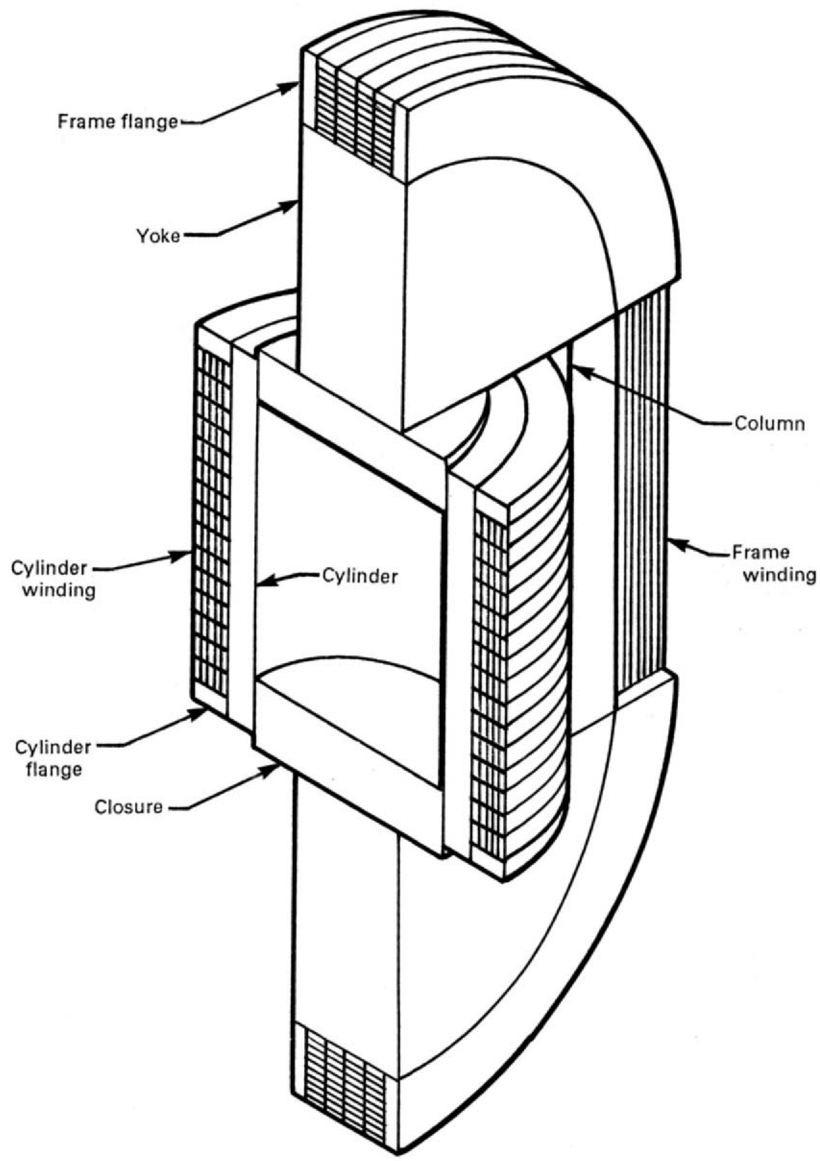


FIG. KD-900 WIRE-WOUND VESSEL AND FRAME CONSTRUCTION

The equations given above are valid as long as

(a) the helix angle of the winding is less than 1.0 deg

(b) the maximum gap between the wires in the longitudinal direction of the vessel is less than 5% of the wire width, or 0.010 in. (0.25 mm), whichever is less

(c) neither the liner nor the wire yields. See KD-920

KD-912 Stress in Wire Wound Frames

Because of the many possible geometric forms of frames, specific equations are not given here. Such frames shall satisfy the requirements of Articles KD-2, KD-3, and KD-4.

KD-920 STRESS LIMITS

KD-921 Diameter Ratio of Vessel Wall

When flat wire with rectangular cross section is used, the overall diameter ratio shall not be lower than the limit given by the equation in KD-251.2. For other wire shapes, corrections shall be made.

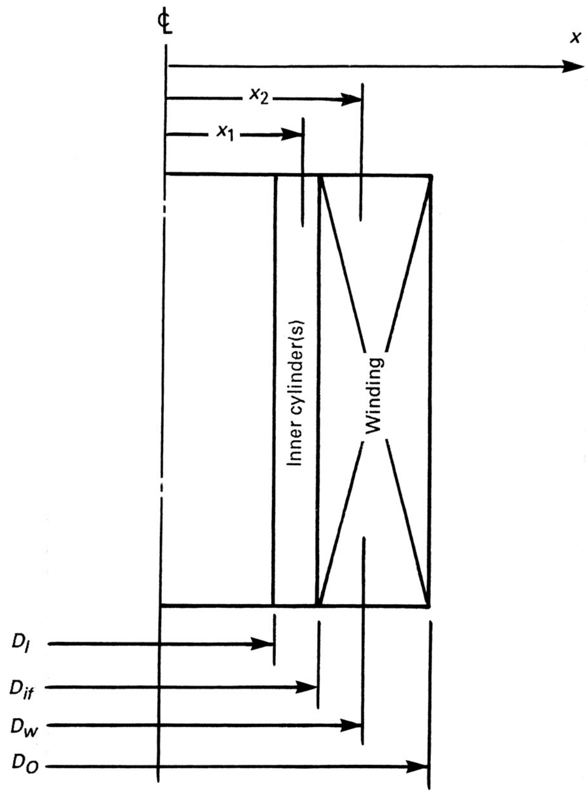


FIG. KD-911 NOMENCLATURE FOR WIRE-WOUND CYLINDERS

KD-922 Stress Intensity Limits for Inner Cylinder(s) and Wire

Under design conditions, the average stress intensity over the cross section of each individual wire at any point in the winding shall not exceed the local primary membrane stress limit, P_L, given in Fig. KD-230.

For welded wire joints (see KF-912), the corresponding average stress intensity shall not exceed two-thirds of the local primary membrane stress limit, P_L, given in Fig. KD-230, where S_y is the yield strength of the unwelded wire material.

The calculated primary-plus-secondary stress intensity for the inner cylinder(s) shall not exceed S_y at any value of pressure from atmospheric to design pressure at any specified coincident temperature, or at any value of pressure from atmospheric to test pressure at the test temperature.

KD-923 Minimum Level of Prestressing of Frames Made From Columns and Yokes

In the case when the frame is made up of nonintegral columns and yokes, the prestressing of the frame by the winding shall be high enough to ensure that the yokes and columns are in mechanical contact even at a load corresponding to 105% of the pressure to be applied at the hydrostatic test (see Article KT-3). This requirement shall be checked by calculation and documented in the Manufacturer's Data Report.

KD-930 FATIGUE EVALUATION

KD-931 General 04

(a) A calculation to determine the number of design cycles shall be performed for all components of wire-wound vessels and frames in accordance with the methods stated in KD-140, except for the wire-wound layers. The fatigue life of the wire-wound layers shall be calculated in accordance with the rules stated in KD-932.

For environmental conditions not covered by the derived design fatigue curve, the Manufacturer shall obtain supplementary fatigue test data.

(b) For wire-wound vessels, the Designer may assume a leak-before-burst failure mode for the vessel if all the following conditions are met in case of a fast fracture failure of one or more inner layers:

(1) No parts or fragments are ejected, and one or more outer layers remain intact.

(2) The end closures remain intact and in place.

(3) The calculated collapse pressure of the remaining intact vessel's pressure boundary shall be greater than 120% of the design pressure of the entire vessel.

The materials used in the construction of the inner layer that are assumed to fail in a fast fracture mode must meet the Charpy V-notch impact energy requirements stated in their applicable material specification in Section II, but do not have to meet the additional Charpy V-notch impact energy requirements given in Table KM-234.2(a). All of the pressure boundary components that are assumed to remain intact shall meet the requirements given in Table KM-234.2(a).

Some plastic deformation is permitted in this type of failure. It is also recognized that some leakage from the vessel may occur and the Designer is cautioned that this type of analysis may not be appropriate if the vessel contains harmful or lethal substances, see KG-311.10(d).

KD-932 Derivation of a Design Fatigue Curve for Wire

The design fatigue life N_D of the winding is defined as the number of operating cycles when the probability is 10% that the calculated average distance between fatigue cracks in the wire is 6,500 ft (1 980 m). The design

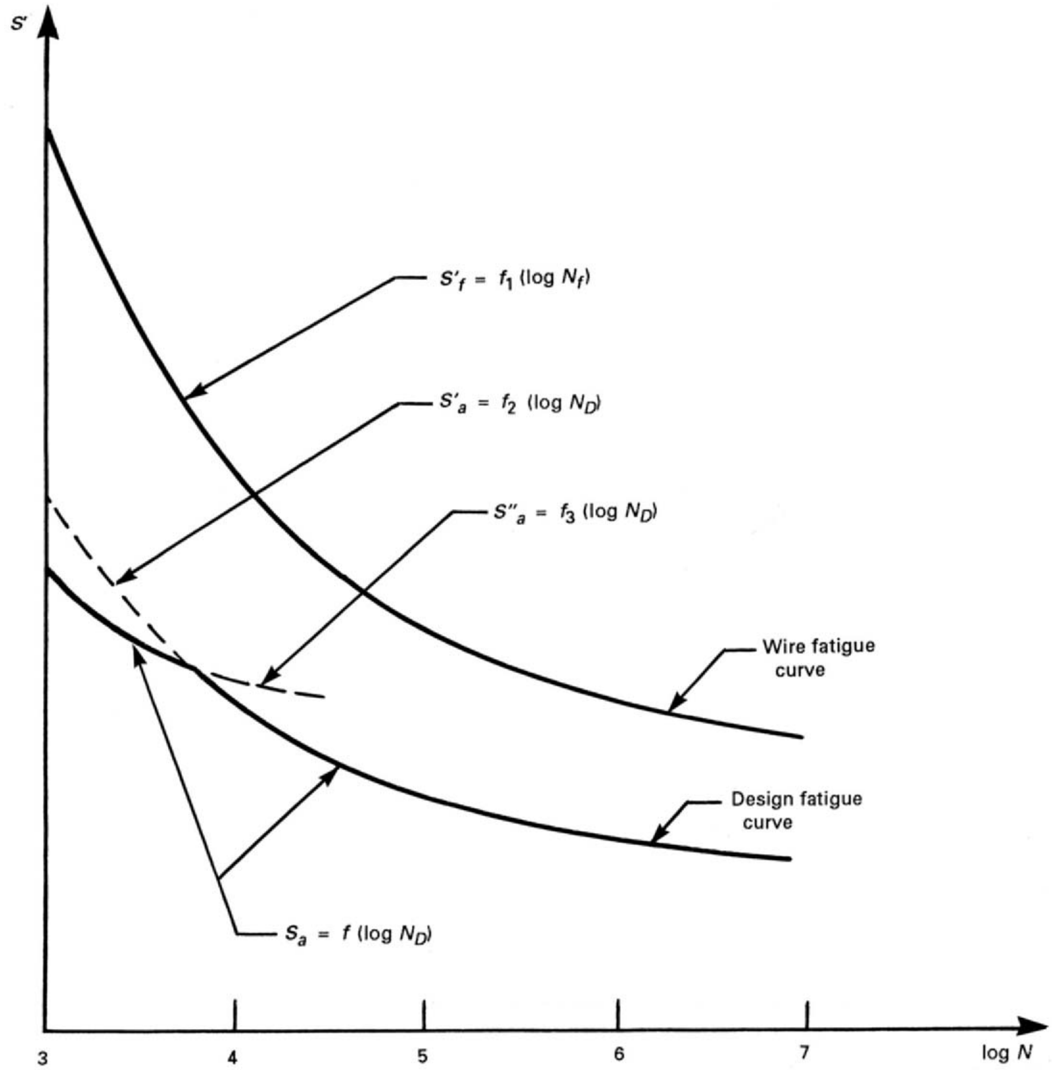


FIG. KD-932 DERIVATION OF DESIGN FATIGUE CURVE FROM WIRE FATIGUE CURVE

fatigue curve for wire shall be derived in the way stated in KD-932.1 through KD-932.3 (see Fig. KD-932).

KD-932.1 Wire Fatigue Curve. The calculation of the design fatigue life of the winding shall be based on a wire fatigue curve derived as follows:

(a) Make fatigue tests with wire pieces with a length of at least 30 times the maximum cross sectional dimension, taken from wire coils delivered from the same manufacturer and produced from the same material quality and by the same manufacturing method as the wire to be used in the vessel or frame.

(b) Select a mean stress which will avoid buckling the test specimen. Make all tests at this mean stress for all stress amplitudes used.

(c) Make the tests at no less than four levels of stress amplitude S with at least six wire pieces at each stress level. The cyclic rate of the test shall be such that appreciable heating of the wire does not occur. Note the number of cycles N_f to complete fatigue rupture.

(d) Plot the points of corresponding S and N_f on a semilog graph and draw a best-fit curve $S_f = f(\log N_f)$ based on these points.

(e) Transform this curve to a wire fatigue curve $S_f' = f(\log N_f)$ valid at mean stress $= 0$ using the equation

$$S_f' = S_f + K_s \beta \sigma_{nm}$$

where σ_{nm} is the associated mean stress used in the test (see KD-312.3). The value of β shall be 0.2 unless experimental evidence justifies another value. K_s is calculated according to Eq. (1) in KD-932.3.

KD-932.2 Design Fatigue Curve. The design fatigue curve $S_a = f(\log N_D)$ shall be derived from the wire fatigue curve as stated in KD-932.2(a) through (c).

(a) Divide the S_f' values of the wire fatigue curve by a design factor K_s, the value of which shall be determined as stated in Eq. (1) in KD-932.3, and plot the curve:

$$S_a' = S_f'/K_S = f_2 (\log N_D)$$

(b) Divide the N_f values of the wire fatigue curve by a design factor K_N, the value of which shall be determined as stated in Eq. (2) in KD-932.3, and plot the curve:

$$S_a'' = f_3 [\log (N_f/K_N)] = f_3 (\log N_D)$$

(c) The design fatigue curve, $S_a = f(\log N_D)$, is the lower of the two values S_a' or S_a'' for all values of N_D in KD-932.2(a) and (b).

KD-932.3 Design Factors K_S and K_N. The values of the design factors K_S and K_N are multiples of factors which account for the effects of stressed length and of scatter in fatigue strength of the wire. They shall be determined as stated below:

$$K_S = K_{SL}K_{SS} \tag{1}$$

where K_{SL} is the factor for the effect of stressed length and K_{SS} is the factor for the effect of statistical variation (scatter) in fatigue strength:

$$K_{SL} = (L_W/L_T)^{1/30} \tag{2}$$

where L_W is the accepted average distance between wire cracks at $N = N_D$ and a crack probability of 10% (see KD-932) and L_T is the length of the wire pieces at the fatigue tests (see KD-932.1). Assuming a case where L_W equals 6,500 ft (1 980 m) and L_T equals 8 in. (200 mm), the equation gives $K_{SL} = 1.35$.

$$K_{SS} = 1/(1 - 1.30\overline{\Delta s}) \tag{3}$$

where $\overline{\Delta s}$ is the average value of the relative standard deviation of the fatigue strength, derived from the scatter at the fatigue test of the wire pieces.

In the calculation of K_{SS}, the scatter in fatigue strength is assumed to have a standard Gaussian distribution.

The value of 1.30 in the equation corresponds to a probability of 10% for a fatigue crack to occur (see KD-932).

$$K_N = (K_S)^{4.3} \tag{4}$$

KD-933 Calculation of Design Fatigue Life of Winding

The design fatigue curve derived in KD-932 is used to calculate the design fatigue life of the winding as described in Article KD-3.

ARTICLE KD-10 04

DELETED

ARTICLE KD-11
DESIGN REQUIREMENTS FOR WELDED VESSELS

KD-1100 SCOPE

The rules contained in this Article provide for the design of welded vessels.

The special requirements of this Article are additional to the general requirements given in Articles KD-2, KD-3, and KD-4. When requirements of this Article differ from those of KD-2, KD-3, and KD-4, they are specifically delineated.

KD-1101 General Requirements for Welded Vessels

Welded vessels (see Part KF) may be constructed from forged rings or other wrought material product forms, such as rolled plate, provided

(a) the applicable welding requirements of this Division and those of ASME Section IX, Welding and Brazing Qualifications, are met

(b) all welds meet the fabrication and examination requirement of Part KF and Part KE

(c) the mechanical properties of the weld and heat-affected zone shall be verified to meet the properties of the base metal specified in Part KM after all fabrication and heat treatment has been completed

04 KD-1110 TYPES OF JOINTS PERMITTED

All joints, except for joints described in Article KD-7, KD-830(b), KD-1131, and KF-821(g), shall be Type No. 1 butt joints (see KF-221).

KD-1111 Transition Butt Joints

An angle joint, with a circumferential butt joint, connecting a transition to a cylinder shall be considered as meeting this requirement provided the angle of the cone relative to the axis of the cylinder does not exceed 30 deg and the requirements of a Type No. 1 butt joint are met. All requirements pertaining to the butt joint shall apply to the angle joint.

KD-1112 Forged Flat Heads With Hubs for Butt Joints

(a) Hubs for butt welding to the adjacent shell, head, or other pressure parts, such as hubbed and flat heads (see Fig. KD-1112), shall not be machined from flat plate.

(b) Hubs shall be forged as shown in Fig. KD-1112 to permit Type No. 1 butt welds.

(c) The mechanical properties of the forged lip that is to be welded to the shell shall be subject to the same requirements as the shell. Proof of this shall be furnished by a tension test specimen (subsize, if necessary) taken in this direction and as close to the hub as is practical.[1]

(d) The height of the hub shall be the greater of 1.5 times the thickness of the pressure part to which it is welded or $\frac{3}{4}$ in. (19 mm), but need not be greater than 2 in. (51 mm).

KD-1113 Corner Welds

Corner welds consisting of full-penetration groove welds and/or fillet welds are not permitted for the attachment of heads, flanges, etc., to shells.

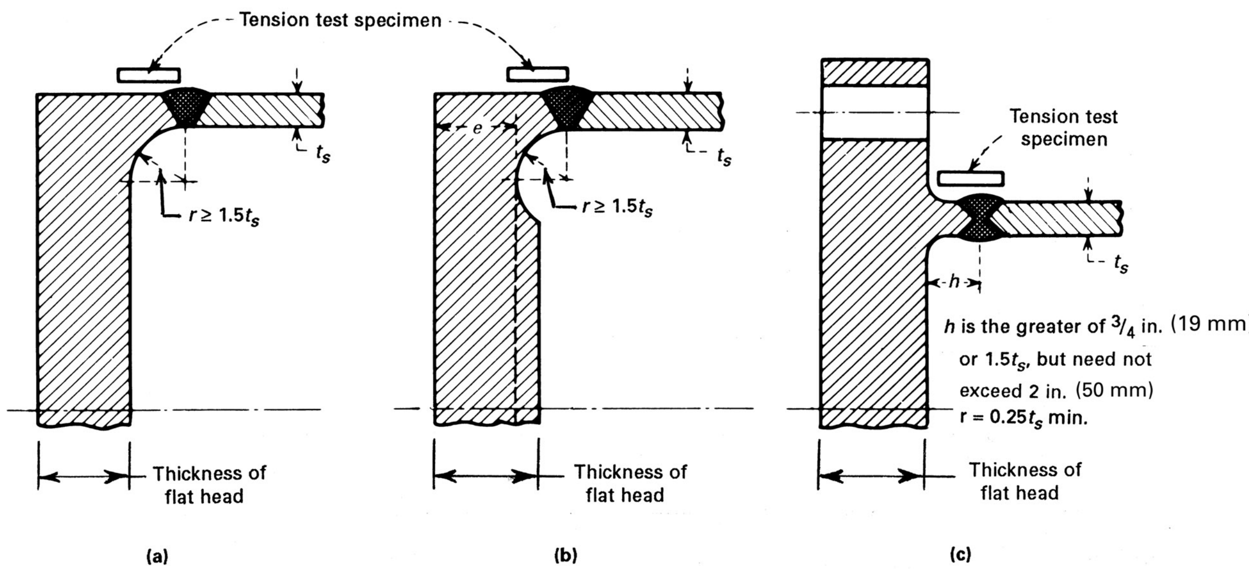
KD-1120 TRANSITION JOINTS BETWEEN SECTIONS OF UNEQUAL THICKNESS

The requirements of this paragraph do not apply to flange hubs.

KD-1121 Shell and Head Joints

(a) Unless the static and cyclic analyses (Articles KD-2, KD-3, and KD-4) or experimental analysis (Article KD-12) indicate otherwise, a tapered transition as shown in Fig. KD-1121 shall be provided between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3.2 mm), whichever is less.

[1] One test specimen may represent a group of forgings, provided they are of the same design, are from the same heat of material, and are forged in the same manner.



GENERAL NOTE: The tension test specimen may be located inside or outside of the hub.

FIG. KD-1112 TYPICAL PRESSURE PARTS WITH BUTT-WELDED HUBS
(Not Permissible if Machined From Rolled Plates)

(b) The transition may be formed by any process that will provide a uniform taper. When the transition is formed by adding additional weld metal beyond that which would otherwise be the edge of the weld, such additional weld metal buildup shall meet the weld fabrication requirements of this Division and Section IX.

(c) The butt weld may be partly or entirely in the tapered section as indicated in Fig. KD-1121. Unless the results of the static and cyclic analyses (Articles KD-2, KD-3, and KD-4) or experimental analysis (Article KD-12) indicate otherwise, the following additional requirements shall also apply:

(1) the length of taper shall be not less than three times the offset between adjacent surfaces

(2) when a taper is required on any formed head intended for butt welded attachment, the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line

(3) an ellipsoidal or hemispherical head that has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder provided the remaining thickness is at least as great as that required for a shell of the same diameter

KD-1122 Nozzle Neck to Piping Joints

In the case of nozzle necks that attach to piping of a lesser wall thickness, a tapered transition from the weld end of the nozzle may be provided to match the piping thickness although the thickness is less than otherwise required by the rules of this Division. This tapered transition shall meet the limitations shown in Fig. KD-1122.

KD-1130 NOZZLE ATTACHMENTS

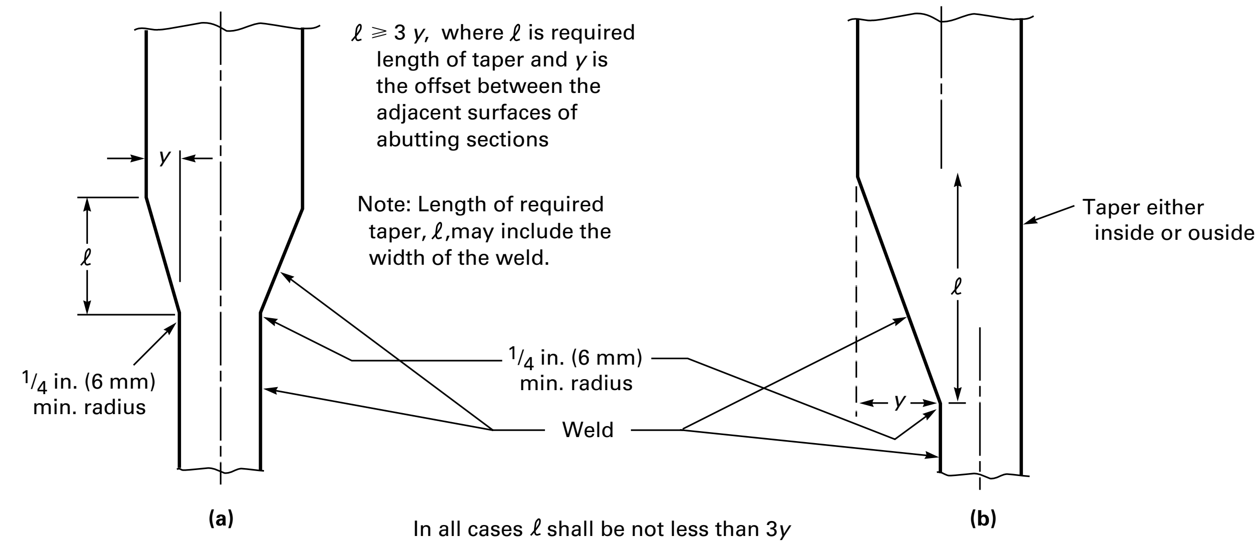
All nozzle attachment welds shall be Type No. 1 butt joints (see Fig. KD-1130) unless specifically provided for in KD-1131.

KD-1131 Nozzle Attachments to Vessel Surfaces

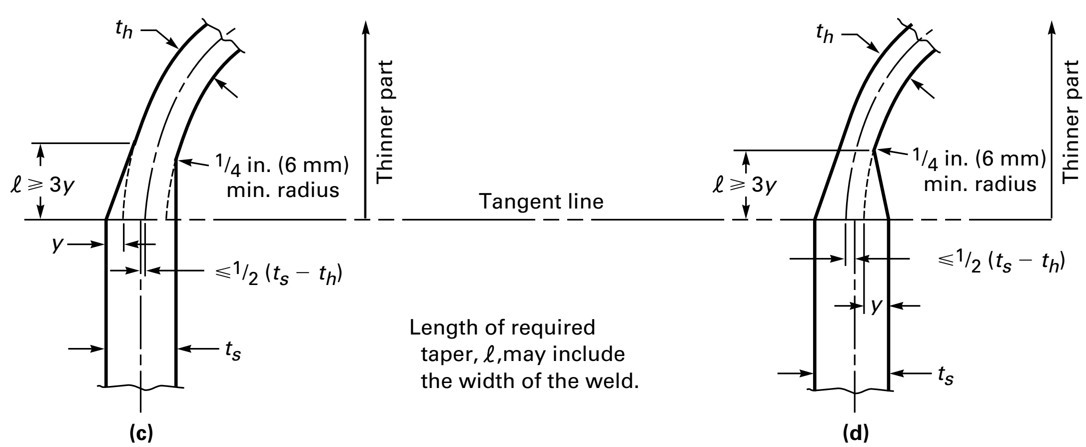
Nozzles attached to the outside surface of a vessel to form a continuous flow path with a hole cut in the vessel wall shall be attached by a full-penetration groove weld (see Fig. KD-1131).

KD-1132 Nozzle Reinforcement

Nonintegral nozzle reinforcement is not permitted. All reinforcement shall be integral with the nozzle, shell, or both. Additional guidance is provided in Nonmandatory Appendix H.

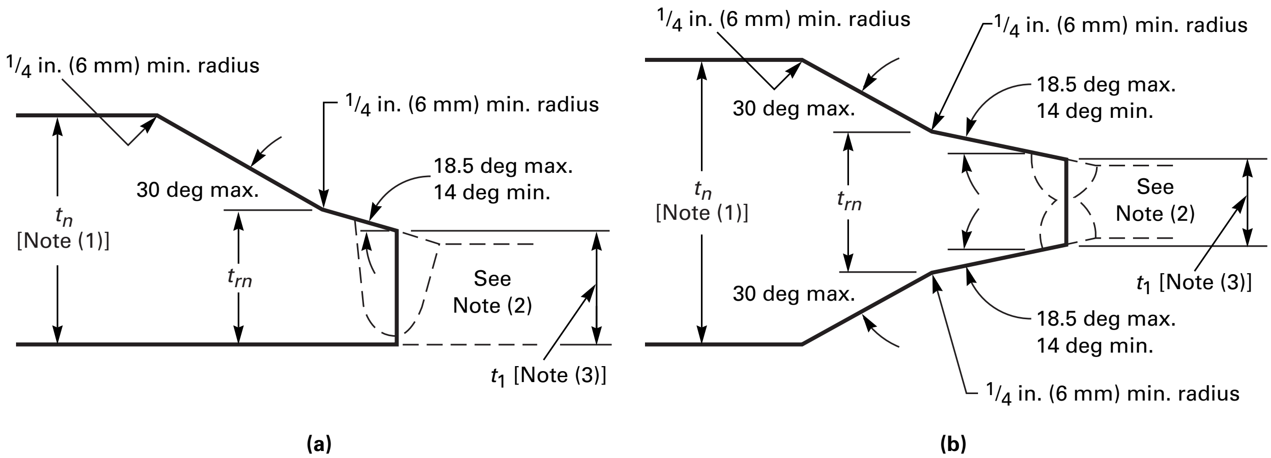


Butt Welding of Sections of Unequal Thickness



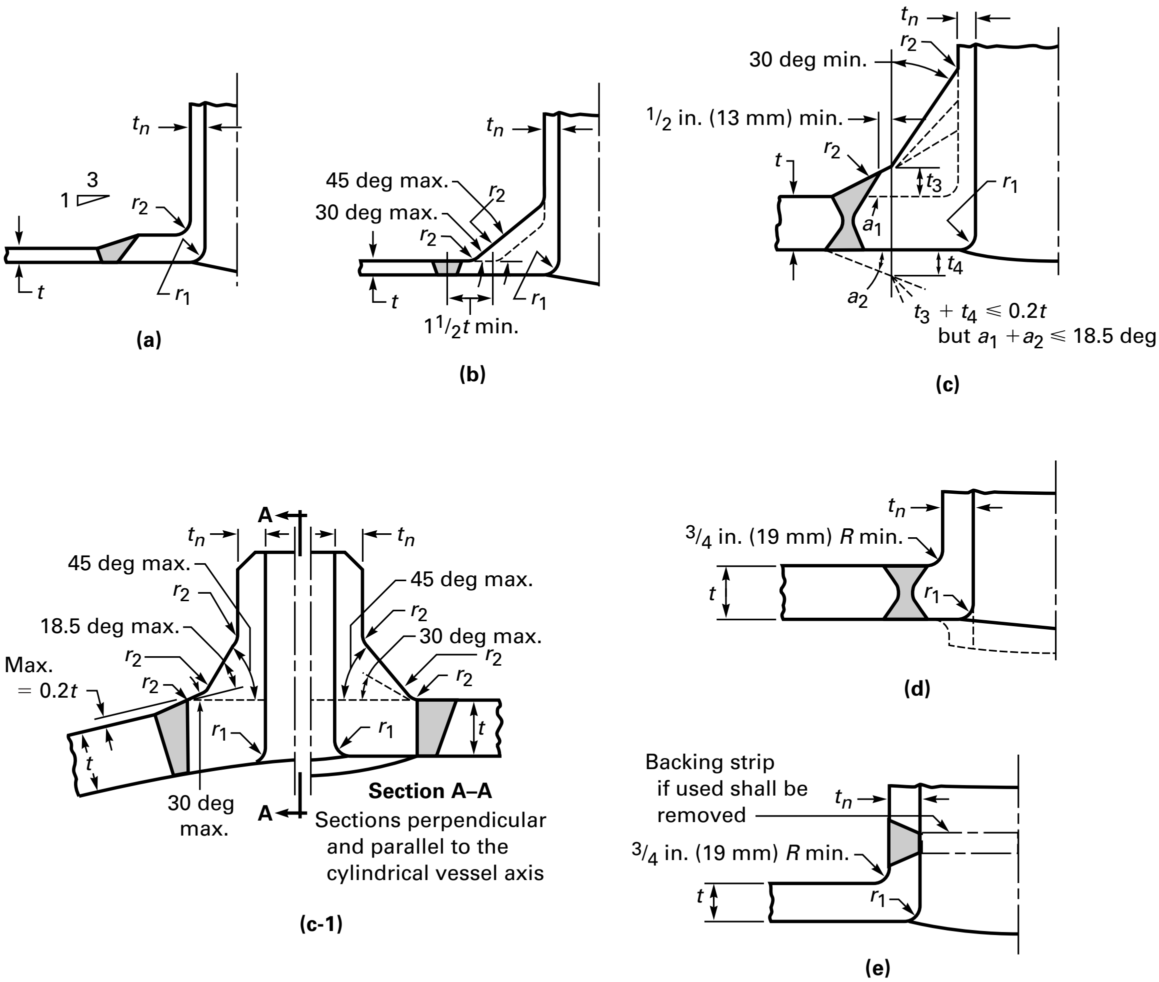
Joints Between Formed Heads and Shells

FIG. KD-1121 JOINTS BETWEEN FORMED HEADS AND SHELLS



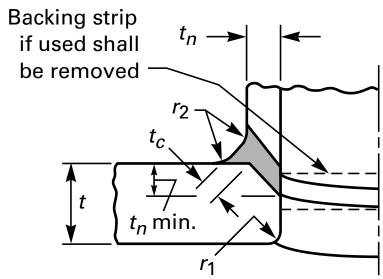
NOTES:
(1) Nominal nozzle thickness.
(2) Weld bevel is shown for illustration only.
(3) t_1 is not less than the greater of:
    (a) $0.8t_{rn}$ where
        t_{rn} = required thickness of seamless nozzle wall
    (b) Minimum wall thickness of connecting pipe

FIG. KD-1122 NOZZLE NECKS ATTACHED TO PIPING OF LESSER WALL THICKNESS



t = nominal thickness of shell or head
t_n = nominal thickness of nozzle
$r_1 \geqslant$ $^1/_4t$ or $^3/_4$ in. (19 mm), whichever is less
$r_2 \geqslant$ $^1/_4$ in. (6 mm)

FIG. KD-1130 SOME ACCEPTABLE WELDED NOZZLE ATTACHMENTS



r_1 min. = $^1/_4 t$ or $^3/_4$ in. (19 mm), whichever is less
r_2 = $^1/_4$ in. (6 mm) min.
t = thickness of part penetrated
t_c min. = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_n = thickness of penetrating part

FIG. KD-1131 AN ACCEPTABLE FULL-PENETRATION WELDED NOZZLE ATTACHMENT NOT READILY RADIOGRAPHABLE

ARTICLE KD-12
EXPERIMENTAL DESIGN VERIFICATION

KD-1200 GENERAL REQUIREMENTS

KD-1201 When Experimental Stress Analysis Is Required

The critical or governing stresses in parts for which theoretical stress analysis is inadequate or for which design values are unavailable shall be substantiated by experimental stress analysis.

KD-1202 When Reevaluation Is Not Required

Reevaluation is not required for configurations for which detailed experimental results, that are consistent with the requirements of this Article, are available.

KD-1203 Discounting of Corrosion Allowance, Etcetera

The test procedures followed and the interpretation of the results shall be such as to discount the effects of material added to the thickness of members, such as corrosion allowance or other material that cannot be considered as contributing to the strength of the part.

KD-1204 Inspection and Reports

Tests conducted in accordance with this Article need not be witnessed by the Inspector. However, a detailed report of the test procedure and the results obtained shall be included with the Manufacturer's Design Report.

KD-1210 TYPES OF TESTS

Tests may be run in order to determine governing stresses, the collapse pressure, or the adequacy of a part for cyclic loading. For determining governing stresses and the collapse pressure, a single test is normally adequate.

KD-1211 Tests for Determination of Governing Stresses

Permissible types of tests for the determination of governing stresses are strain measurement tests and photoelastic tests. Brittle coating tests may be used only for the purpose described in KD-1241. Results of displacement measurement tests and tests to destruction are not acceptable for governing stress determination.

KD-1212 Tests for Determination of Collapse Pressure *CP*

Strain measurement tests may be used for the determination of the collapse pressure *CP*. Distortion measurement tests may be used for the determination of the *CP* if it can be clearly shown that the test setup and the instrumentation used will give valid results for the configuration on which the measurements are made. Brittle coating tests and tests to destruction shall not be used to determine the *CP*.

KD-1213 Fatigue Tests

Fatigue tests may be used to evaluate the adequacy of a part for cyclic loading, as described in KD-1260.

KD-1220 STRAIN MEASUREMENT TEST PROCEDURE

KD-1221 Requirements for Strain Gages

Strain gages of any type capable of indicating strains to an accuracy of 0.00005 in./in. (mm/mm) (0.005%) or better may be used. It is recommended that the gage length be such that the maximum strain within the gage length does not exceed the average strain within the gage length by more than 10%. Instrumentation shall be such that both surface principal stresses may be determined at each gage location in the elastic range of material behavior at that gage location. A similar number and orientation of gages at each gage location are required to be used in tests beyond the elastic range of material behavior. The strain gages and cements that are used shall be shown to be reliable for use on the material surface finish and configuration considered to strain values at least 50% higher than those expected.

KD-1222 Use of Models for Strain or Distortion Measurements

Except in tests made for the measurement of the *CP,* strain gage data may be obtained from the actual component or from a model component of any scale that meets the gage length requirements of KD-1221. The model material need not be the same as the component material, but shall have an elastic modulus that is either known or has been measured at the test conditions. The requirements of dimensional similitude shall be met.

In the case of *CP* tests, only full-scale models, prototypical in all respects, are permitted unless the tester can clearly demonstrate the validity of the scaling laws used. The test vessel or component used to determine *CP* shall be made from material of the same type, grade, and class as the production vessel.

KD-1230 PHOTOELASTIC TEST PROCEDURE

Either two-dimensional or three-dimensional techniques may be used as long as the model represents the structural effects of the loading.

KD-1240 TEST PROCEDURES

KD-1241 Location of Test Gages

(a) In tests for determination of governing stresses, sufficient locations on the vessel shall be investigated to ensure that measurements are taken at the most critical areas. The location of the critical areas and the optimum orientation of test gages may be determined by a brittle coating test.

(b) In tests made for the measurement of *CP,* sufficient measurements shall be taken so that all areas which have any reasonable probability of indicating a minimum *CP* are adequately covered. It is noted, however, that the intent of the measurements is to record motion in the vessel due to primary loading effects. Care shall be taken to avoid making measurements at areas of concentrated stress due to secondary or peaking effects. If strain gages are used to determine the *CP,* particular care should be given to ensuring that strains (either membrane, bending, or a combination) are being measured which are actually indicative of the load-carrying capacity of the structure. If distortion measurement devices are used, care should be given to ensure that it is the change in significant dimensions or deflections that is measured, such as diameter or length extension, or beam or plate deflections that are indicative of the tendency of the structure to reach the *CP.*

KD-1242 Requirements for Pressure Gages and Transducers

Pressure gages and transducers shall meet the requirements of Article KT-4.

KD-1243 Application of Pressure or Load

(a) In tests for determining governing stresses, the internal pressure or mechanical load shall be applied in such increments that the variation of strain with load can be plotted so as to establish the ratio of stress to load in the elastic range. If the first loading results in strains that are not linearly proportional to the load, it is permissible to unload and reload successively until the linear proportionality has been established.

(b) When frozen stress photoelastic techniques are used, only one load value can be applied, in which case the load shall not be so high as to result in deformations that invalidate the test results.

(c) In tests made for the measurement of the *CP,* the proportional load shall be applied in sufficiently small increments so that an adequate number of data points for each gage are available for statistical analysis in the linear elastic range of behavior. All gages shall be evaluated prior to increasing the load beyond this value. A least square fit (regression) analysis shall be used to obtain the best-fit straight line and the confidence interval shall be compared to preset values for acceptance or rejection of the strain gage or other instrumentation. Unacceptable instrumentation shall be replaced and the replacement instrumentation tested in the same manner.

(d) After all instrumentation has been deemed acceptable, the test shall be continued on a strain- or displacement-controlled basis, with adequate time permitted between load changes for all metal flow to be completed.

KD-1250 INTERPRETATION OF RESULTS

KD-1251 Interpretation to Be on Elastic Basis

The experimental results obtained shall be interpreted on an elastic basis to determine the stresses corresponding to the design loads; that is, in the evaluation of stresses from strain gage data, the calculations shall be performed under the assumption that the material is elastic. The elastic constants used in the evaluation of experimental data shall be those applicable to the test material at the test temperature.

KD-1252 Required Extent of Stress Analysis

The extent of experimental stress analysis performed shall be sufficient to determine the governing stresses for which design values are unavailable, as described in KD-1201. When possible, combined analytical and experimental methods shall be used to distinguish between primary, secondary, and local stresses so that each combination of categories can be controlled by the applicable stress limit.

KD-1253 Determination of Collapse Pressure, *CP*

(a) For distortion measurement tests, the loads are plotted as the ordinate and the measured deflections are plotted as the abscissa. For strain gage tests, the loads are plotted as the ordinate and the maximum principal strains on the surface as the abscissa. The test *CP* is taken as the pressure that produces a measured strain of no more than 2%. This strain limit shall be based on the actual strain in the test vessel due to primary loading effects. Therefore, strain gages or distortion measuring devices shall be located to obtain results due to primary loading, and to avoid results due to secondary and peak effects (see KD-1241).

(b) If the vessel is destroyed or fails to maintain its pressure boundary before the *CP* can be determined, the vessel shall be redesigned and retested. The process is repeated until the vessel can sustain pressures that are large enough to obtain the *CP* in the prescribed manner.

(c) The *CP* used for design purposes shall be the test *CP* multiplied by the ratio of the specified material yield strength at design temperature to the actual measured test material yield strength at the test temperature. When the design pressure is based on the *CP* test, the maximum design pressure shall be determined in accordance with KD-1254. Careful attention shall be given to assuring that proper consideration is given to the actual as-built dimensions of the test model when correlating the *CP* of the test model to that expected for the actual structure being designed.

04 KD-1254 Determination of Maximum Design Pressure at Room Temperature

The maximum design pressure *P* when based on the *CP* testing as described in this paragraph shall be computed by one of the following equations using the actual material yield strength.

(a) If the actual measured yield strength is determined only by the testing required by the material specification,

$$P = \frac{0.8}{1.732} CP \left(\frac{S_y}{S_{yms}} \right)$$

where

S_y = specified minimum yield strength at room temperature, ksi (MPa)

S_{yms} = actual yield strength based on the testing required by the material specification, ksi (MPa), but not less than S_y

(b) If the actual yield strength is determined in accordance with the additional testing prescribed below,

$$P = \frac{1}{1.732} CP \left(\frac{S_y}{S_{yact}} \right)$$

where

S_{yact} = actual average yield strength from test specimens at room temperature, ksi (MPa), but not less than S_y

(c) The yield strength of the material in the part tested shall be determined in accordance with ASME SA-370 with the following additional requirements:

(1) Yield strength so determined (S_{yact}) shall be the average of at least three specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of the material.

(2) When excess stock from the same piece of wrought material is available and has been given the same heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimen shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen.

KD-1260 EXPERIMENTAL DETERMINATION OF ALLOWABLE NUMBER OF OPERATING CYCLES

Experimental methods may be used to determine the allowable number of operating cycles of components and vessels as an alternative to the requirements of Article KD-3. This approach shall only be used for vessels or components that have been shown to demonstrate a leak-before-burst mode of failure.

KD-1261 Test Description

When a fatigue test is used to demonstrate the adequacy of a component or a portion thereof to withstand cyclic loading, a description of the test shall be included in the Design Report. This description shall contain sufficient detail to show compliance with the requirements stated herein.

KD-1262 Test Procedure

(a) The test component or portion thereof shall be constructed of material having the same composition and

subjected to the same mechanical working and heat treating so as to produce mechanical properties equivalent to those of the material in the prototype component. Structural similitude shall be maintained, at least in those portions whose ability to withstand cyclic loading is being investigated and in those adjacent areas that affect the stresses in the portion under test.

(b) The test component or portion thereof shall withstand the number of cycles as set forth in KD-1262(c) before failure occurs. *Failure* is herein defined as a propagation of a crack through the entire thickness such as would produce a measurable leak in a pressure retaining member.

(c) The minimum number of test cycles N_T that the component shall withstand, and the magnitude of the loading P_T [see Eqs. (1), (2), and (3)] to be applied to the component during test, shall be determined by multiplying the design service cycles N_D by a specified factor K_{TN}, and the design service loads P_D by K_{TS}. Values of these factors shall be determined by means of the test parameter ratio diagram, the construction of which is as follows and is illustrated in Fig. KD-1260.1.

(1) Project a vertical line from the design service cycles N_D on the abscissa of the S_a versus N diagram, to intersect the fatigue design curve S_a of the appropriate figure in Article KD-3, to an ordinate value of K_s times S_{aD}. Label this point *A*. K_s is a factor that accounts for the effect of several test parameters [see KD-1262(g)].

(2) Extend a horizontal line through the point *D* until its length corresponds to an abscissa value of K_n times N_D. Label this point *B*. Note that K_n is a factor that accounts for the effect of several test parameters [see KD-1262(g)].

(3) Connect points *A* and *B*. The segments *AB* embrace all the allowable combinations of K_{TS} and K_{TN} [see KD-1262(e) for accelerated testing]. Any point *C* on this segment may be chosen at the convenience of the tester. Referring to Fig. KD-1260.1, the factors K_{TS} and K_{TN} are defined by:

$$K_{TS} = \frac{\text{value of ordinate at point } C}{\text{value of ordinate at point } D}$$

$$K_{TN} = \frac{\text{value of abscissa at point } C}{\text{value of abscissa at point } D}$$

Thus

$$P_T \text{ (test loading)} = K_{TS} P_D \tag{1}$$

$$N_T \text{ (test cycles)} = K_{TN} N_D \tag{2}$$

(d) It should be noted that if the test component is not full size but a geometrically similar model, the value P_T would have to be adjusted by the appropriate scale factor, to be determined from structural similitude principles, if the loading is other than pressure. The number of cycles that the component shall withstand during this test without failure must not be less than N_T, while subjected to a cyclic test loading P_T which shall be adjusted, if required, using model similitude principles if the component is not full size.

(e) Accelerated fatigue testing (test cycles N_D) *may be* conducted if the design cycles N_D are greater than 10^4 and the testing conditions are determined by the following procedures, which are illustrated in Fig. KD-1260.2. In this Figure, the points *A, B,* and *D* correspond to similar labeled points in Fig. KD-1260.1.

(1) The minimum number of test cycles $N_{T\,\min}$ shall be:

$$N_{T\,\min} = 10^2 \sqrt{N_D}$$

Project a vertical line through $N_{T\,\min}$ on the abscissa of the S_a versus N diagram such that it intersects and extends beyond the fatigue design curve.

(2) Construct a curve through the point *A* and intersect the vertical projection of $N_{T\,\min}$ [see KD-1262(e)(1)] by multiplying every point on the fatigue design curve by the factor K_s [see KD-1262(c)(1)]. Label the intersection of this curve and the vertical projection of $N_{T\min}$ as *A′*.

(3) Any point *C* on the segment *A, A′, B* determines the allowable combinations of K_{TS} and K_{TN}. The factors K_{TS} and K_{TN} are obtained in the same manner as in KD-1262(c).

(f) In certain instances, it may be desirable (or possible) in performing the test to increase only the loading or number of cycles, but not both, in which event two special cases of interest result from the above general case.

(1) Case 1 (factor applied to cycles only). In this case, $K_{TS} = 1$ and

$$K_{TN} = \frac{\text{value of abscissa at point } B}{\text{value of abscissa at point } D}$$

The number of test cycles that the component shall withstand during this test must, therefore, not be less than

$$N_T = K_{TN} N_D$$

while subjected to the cyclic design service loading, adjusted as required, if a model is used.

(2) Case 2 (factor applied to loading only). In this case, $K_{TN} = 1$ and

$$K_{TS} = \frac{\text{value of ordinate at point } A}{\text{value of ordinate at point } D}$$

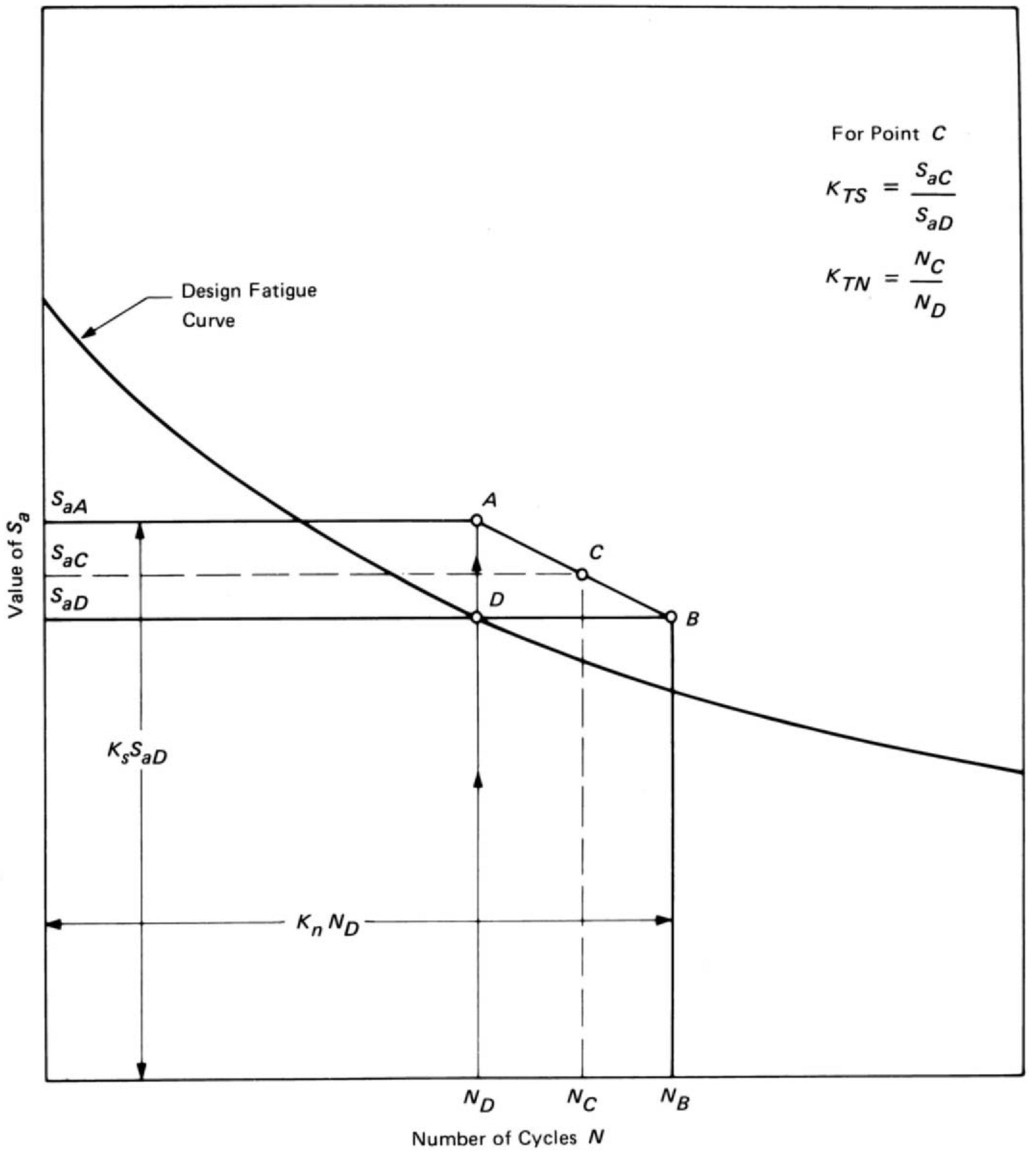


FIG. KD-1260.1 CONSTRUCTION OF TESTING PARAMETER RATIO DIAGRAM

The component must, therefore, withstand a number of cycles at least equal to the number of design service cycles, while subjected to a cyclic test loading

$$P_T = K_{TS}P_D \tag{3}$$

again adjusted as required, if a model is used.

(g) The values of K_s and K_n are the multiples of factors that account for the effects of size, surface finish, cyclic rate, temperature, and the number of replicate tests performed. They shall be determined as follows:

K_n = greater of $(K_s)^{4.3}$ or 2.6

K_s = greater of $K_{sa}K_{sf}K_{sc}K_{st}K_{ss}$ or 1.25

K_{sa} = factor for the effect of size of the highly stressed surface area on fatigue life
= greater of $(A_p/A_T)^{1/30}$ or 1.0, where A_p is the size of the highly stressed surface area of the prototype component and A_T is the size of the highly stressed surface area of the test component

K_{sc} = factor for differences in design fatigue curves at various temperatures

$$= \text{greater of } \frac{(S_aN \text{ at } T_c)\ (S_a10^n \text{ at } T_t)}{(S_aN \text{ at } T_D)\ (S_a10^n \text{ at } T_c)} \text{ or } 1.0$$

K_{sf} = factor for the effect of surface finish

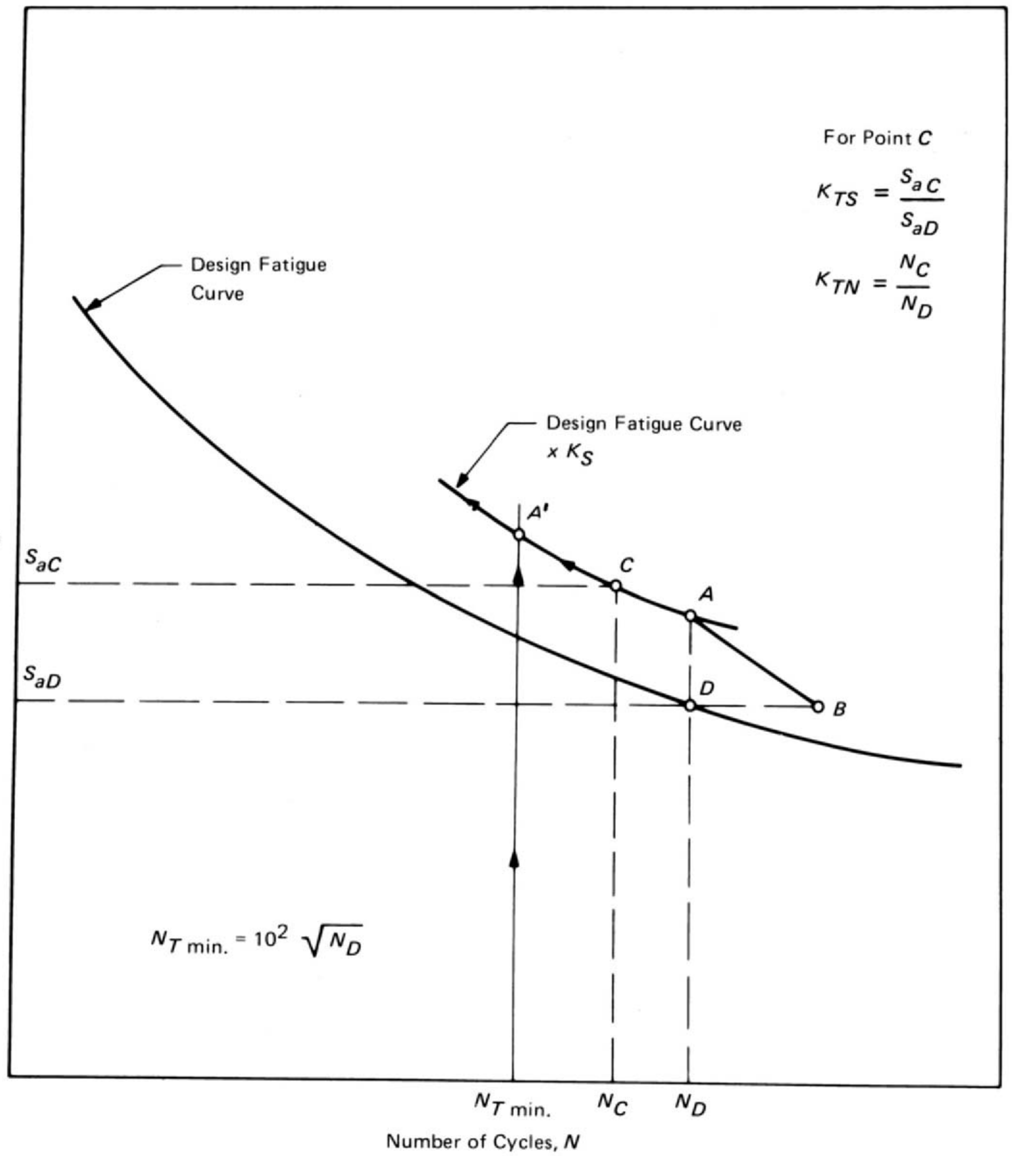


FIG. KD-1260.2 CONSTRUCTION OF TESTING PARAMETER RATIO DIAGRAM FOR ACCELERATED TESTS

= greater of $K_r(P)/K_r(T)$ or 1.0, where $K_r(P)$ is the surface roughness factor of the prototype and $K_r(T)$ is the surface roughness factor of the test component. The $K_r(P)$ and $K_r(T)$ factors are based on the surface finish and shall be taken from Fig. KD-320.3.

K_{ss} = factor for the statistical variation in test results
= greater of 1.470 − (0.044 × number of replicate tests) or 1.0

K_{st} = factor for the effect of test temperature
= greater of (E at T_t)/(E at T_D) or 1.0, where E is the elastic modulus of the component material

S_a10^n = S_a from the applicable fatigue design curve at the maximum number of cycles defined on the curve

T_c = 700°F (370°C) for carbon and low alloy steels, and 800°F (425°C) for austenitic stainless steels and nickel– chromium–iron alloys

T_D = design temperature

T_t = test temperature

KD-1270 DETERMINATION OF FATIGUE STRENGTH REDUCTION FACTORS

(a) Experimental determination of fatigue strength reduction factors shall be in accordance with the following procedures.

(1) The test part shall be fabricated from a material with the same nominal chemistry, mechanical properties, and heat treatment as the component.

(2) The stress level in the specimen shall be such that the linearized primary-plus-secondary stress intensity ($P_L + P_b + Q$) does not exceed the limit prescribed in Fig. KD-230 so that failure does not occur in less than 1,000 cycles.

(3) The configuration, surface finish, and stress state of the specimen shall closely simulate those expected in the components. In particular, the stress gradient shall not be more abrupt than that expected in the component.

(4) The cyclic rate shall be such that appreciable heating of the specimen does not occur.

(b) It is recommended that the fatigue strength reduction factor be determined by performing tests on notched and unnotched specimens and calculated as the ratio of the unnotched stress to the notched stress for failure.

PART KF
FABRICATION REQUIREMENTS

ARTICLE KF-1
GENERAL FABRICATION REQUIREMENTS

KF-100 GENERAL

(a) Types of fabrication covered by Part KF are not unique to this Division. The uniqueness of this Division lies in the credit that may be taken for favorable residual stresses that are introduced during fabrication when there is no welding and in permitting the Designer to utilize the full capability of high strength materials as primary pressure retaining boundaries.

(b) Since all vessels conforming to the rules of this Division require fatigue analysis and since most will be heavy wall construction, many of the requirements of this Part are intended to produce vessels which are consistent with the Designer's assumption that no subsurface flaw exists that would be more likely to propagate in fatigue than the assumed surface flaws restricted by the requirements of Part KE.

(c) The Manufacturer must have the ability to control the residual stress distribution and ensure that the material properties and material defects in the vessel and vessel components are consistent with the basis of the design.

04 KF-101 Scope

(a) Article KF-1 gives general fabrication requirements for all vessels in this Division.

(b) Article KF-2 gives supplemental requirements for all welded vessels in the Division. This includes those made of rolled and welded plate and those made of weldable forgings, such as ring forgings joined by circumferential welds and forgings for fully radiographable nozzles. Materials that are permitted for welded construction are listed in Part KM.

(c) Article KF-3 gives supplemental requirements for protective liners.

(d) Article KF-4 gives requirements for the postweld heat treatment of all weldments, including repair welds.

(e) Article KF-5 gives supplemental requirements for autofrettaged vessels.

(f) Article KF-6 gives supplemental requirements for vessels made from either plate or forged materials whose tensile properties have been enhanced by quenching and tempering processes.

(g) Article KF-7 gives supplemental requirements that are specific to materials which are used to fabricate vessels where welded fabrication is not permitted by Part KM.

(h) Article KF-8 gives supplemental requirements for layered vessels. Since the design allowable stresses in this Division are based on yield strength and not limited by tensile properties, the requirements of the Article are more restrictive than the layered vessel requirements in other Divisions of this Code.

(i) Article KF-9 gives requirements for wire-wound vessels and frames.

KF-110 MATERIAL

KF-111 Certification and Examination of Materials

The Manufacturer shall require certification of all materials including weld materials to ensure compliance with the requirements of Part KM. In addition, all materials shall be examined in accordance with Part KE. The certified results of these tests and examinations shall be documented in the Manufacturer's Construction Records (see KG-325).

KF-112 Material Identification

(a) Where possible, material for pressure parts shall be laid out so that when the vessel is completed, the original identification markings required in the specifications for the material will be plainly visible. In case the original identification markings are unavoidably removed or the material is divided into two or more parts, prior to cutting, the Manufacturer shall accurately transfer one set of markings to a location where the markings will be visible on the completed vessel. Alternatively, a coded marking, acceptable to the Inspector, shall be used to ensure identification of each piece of material during fabrication and subsequent identification of the markings on the completed vessel. Except as indicated in KF-112.1, material may be marked by any method acceptable to the Inspector. The Inspector need not witness the transfer of the marks, but shall be satisfied that this has been done correctly.

(b) All parts completed elsewhere shall be marked with the part manufacturer's name and the part identification. Should identifying marks be obliterated in the fabrication process and for small parts, other means of identification shall be used.

KF-112.1 Method of Transferring Markings. Where the service conditions prohibit die stamping for material identification, and when so specified by the User, the Material Manufacturer and the Manufacturer shall mark the required data on the material in a manner which will allow positive identification upon delivery. The markings shall be recorded so that each piece of material will be positively identified in its position in the finished vessel to the satisfaction of the Inspector. Transfer of markings for material that is to be divided shall be done in accordance with KF-112(a). See Article KS-1 for allowable types of markings.

KF-112.2 Transfer of Markings by Other Than the Manufacturer. When material is formed into shapes by anyone other than the Manufacturer and the original markings as required by the applicable material specification are unavoidably cut out, or the material is divided into two or more parts, the Manufacturer of the shape shall either:

(a) transfer the original identification markings to another location on the shape, or

(b) provide for identification by the use of a coded marking traceable to the original required marking, using a marking method agreed upon and described in the quality control system of the Manufacturer of the completed pressure vessel.

The mill certification of the physical and chemical requirements of this material, in conjunction with the above modified marking requirements, shall be considered sufficient to identify these shapes. Manufacturer's Partial Data Reports and parts stamping shall be as required by KM-102 and KS-120.

KF-112.3 Material Identification Records. An as-built sketch or a tabulation of materials shall be made, identifying the location of each piece of material that is traceable to the certified material test report or certificate of compliance and the Code marking.

KF-113 Repair of Defective Material

Material in which defects exceeding the limits of Article KE-2 are known or are discovered during the process of fabrication is unacceptable. Unless prohibited by the material specification in Section II, the User's Design Specification, or Part KM, defects may be removed and the material repaired by the Manufacturer or by the Material Manufacturer with the approval of the Manufacturer. All repairs shall be made in accordance with the provisions of Article KE-2 and documented in the Manufacturer's Construction Records.

KF-120 MATERIAL FORMING

All materials for shell sections and for heads shall be formed to the required shape by any process that will not unduly impair the mechanical properties of the material.

KF-121 Material Preparation

KF-121.1 Examination of Materials

(a) All materials to be used in constructing the pressure vessel shall be examined before forming or fabrication for the purpose of detecting, as far as possible, defects which exceed the acceptable limits of Article KE-2. All edges cut during fabrication (including the edges of openings cut through the thickness) shall be examined in accordance with KE-310. All defects exceeding the limits of KE-310 shall be documented and repaired.

(b) Cut edges of base materials with thicknesses over $1\frac{1}{2}$ in. (38 mm) shall be examined for discontinuities by a magnetic particle or by a liquid penetrant method in accordance with KE-233. This examination is not required for the cut edges of openings 3 in. (76 mm) in diameter and smaller. However, the material shall be ultrasonically examined over 100% of the area in which

the opening is to be cut, in accordance with KE-232. If indications are found which exceed the acceptable limits of KE-232, the indications shall be repaired in accordance with KF-113. Nonlaminar discontinuities and laminar discontinuities are treated differently for plates and forgings. See Article KE-2 for acceptance criteria for each of these. Threaded connections that seal against pressure shall not have any discontinuities.

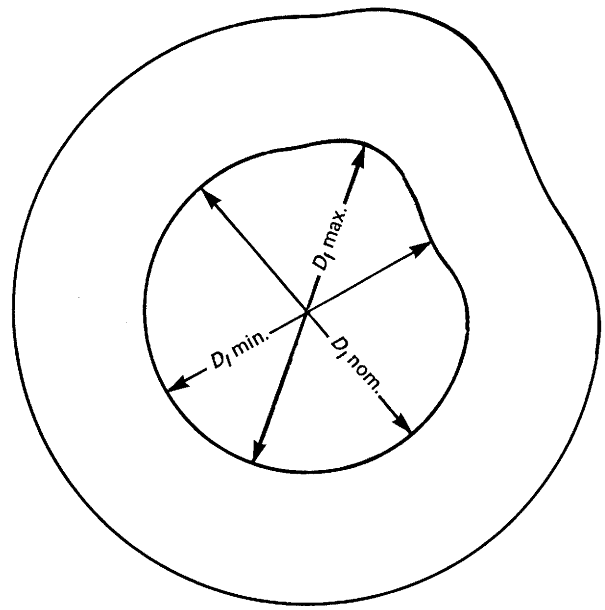
KF-121.2 Material Cutting. Plates, edges of heads, and other parts may be cut to shape and size by mechanical means such as machining, shearing, grinding, or by thermal cutting. After thermal cutting, all slag and detrimental discoloration of material which has been molten shall be removed by mechanical means suitable to the material, prior to further fabrication or use. When thermal cutting is used, the effect on mechanical properties shall be taken into consideration. The edges to be welded shall be uniform and smooth.

KF-121.3 Finish of Exposed Inside Edges of Nozzles. Exposed inside edges of nozzles other than as provided for in Figs. KD-1130 and KD-1131 shall be radiused (grinding permitted) to at least $t/4$ or $\frac{3}{4}$ in. (19 mm), whichever is less, when the inner end of the nozzle neck is flush with the inside wall of the shell. When the inner end of the nozzle neck protrudes beyond the inside wall of the shell toward the center of curvature, it shall be radiused (grinding permitted) on both inner and outer surfaces of the neck end to at least $t_n/4$ or $\frac{3}{8}$ in. (10 mm), whichever is smaller.

KF-130 TOLERANCES FOR CYLINDRICAL AND SPHERICAL SHELLS AND HEADS

KF-131 Cylindrical Shells

The difference between the maximum and minimum inside diameters at any cross section shall not exceed 1% of the nominal inside diameter at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the required minimum material thickness at the cross section under consideration (see Fig. KF-131). Fabrication deviations from the stated tolerances are prohibited, unless provision is made for the deviations in the design calculations and are agreed to by the User, Manufacturer, and Inspector (see Article KD-2).



D_l max. − D_l min. < 0.01(D_l nom.)

FIG. KF-131 EXAMPLES OF DIFFERENCES BETWEEN MAXIMUM AND MINIMUM DIAMETERS IN CYLINDRICAL SHELLS

KF-132 Spherical Shells and Formed Heads

(a) Deviations from the specified shape of the inner surface of spherical shells and formed heads shall not exceed $+1\frac{1}{4}\%$ and $-\frac{5}{8}\%$ of the nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt.

(b) Deviation measurements shall be taken on the surface of the base metal and not on welds.

(c) The straight flange or cylindrical end of a formed head or the edge of a spherical shell shall be circular within the tolerance specified in KF-131.

ARTICLE KF-2
SUPPLEMENTAL WELDING FABRICATION REQUIREMENTS

KF-200 GENERAL REQUIREMENTS FOR ALL WELDS

KF-201 Welding Processes

The welding processes that may be used in the construction of vessels under this Part are listed below:

(a) shielded metal arc
(b) submerged arc
(c) gas metal arc
(d) gas tungsten arc

Definitions are given in Section IX, which include variations of these processes.

KF-202 Restrictions Based on Carbon Content

When the carbon content of the material exceeds 0.35% by heat analysis, welded fabrication including attachment welds is not permitted. Repair welding may be permitted under the rules of Article KF-7.

KF-203 Examination of Weld Edge Preparation Surfaces

Weld edge preparation surfaces in materials 2 in. (51 mm) or more in thickness shall be examined in accordance with KE-310. Defects shall be repaired in accordance with the rules of Part KE.

KF-204 Final Weld Finish

The finished weld shall be ground or machined to blend with the surfaces of the parts being joined. Both the blend radii and the surface finish of the weld deposit shall be inspected to ensure they comply with the design requirements of the engineering design.

KF-205 Identification, Handling, and Storing of Electrodes and Other Welding Materials

The Manufacturer is responsible for control of the welding electrodes and other materials which are to be used in the fabrication of the vessel. Suitable identification, storage, and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by low-hydrogen electrodes and flux.

KF-206 Permissible Ambient Conditions During Welding

No welding of any kind shall be carried out when the temperature of the metal surface within 3 in. (76 mm) of the point of welding is lower than 60°F (16°C).

No welding shall be done when surfaces are wet or covered with ice, when rain or snow is falling on the surfaces to be welded, or during periods of high wind unless the work is properly protected.

KF-210 WELDING QUALIFICATIONS AND RECORDS

KF-211 Manufacturer's Responsibility 04

Each Manufacturer is responsible for the welding carried out by their organization. The Manufacturer shall establish and qualify welding procedures in accordance with Section IX. The Manufacturer shall also be responsible for the additional requirements of this Division and the qualification of welders and welding operators who apply these procedures and requirements. See KG-420 for requirements for subcontracted services.

KF-212 Qualification Test Limitations

Welding of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. Qualification of welding procedure by one Manufacturer shall not qualify that procedure for use by any other Manufacturer, except as provided for in QW-201 of Section IX. A performance qualification test conducted by one Manufacturer shall not qualify a welder or welding operator to do work for any other Manufacturer, except as provided for in QW-300 of Section IX.

KF-213 Production Welding Prior to Qualification

No production welding shall be carried out until after the required welding procedures have been qualified.

KF-214 Qualification of Welding Procedure

(a) Each welding procedure that is to be used shall be recorded in detail by the Manufacturer on forms provided in Section IX, or on other forms which contain the required information.

(b) The procedures used in welding pressure parts and in joining nonpressure parts (attachments) to pressure parts shall be qualified in accordance with Section IX. When tensile specimens are required by Section IX, the yield strength shall also be determined, using the method required for the base metal. The yield strength of each test specimen shall be not less than the lowest specified minimum yield strength for the base metals joined. In addition, impact tests shall be performed in accordance with Article KT-2.

(c) When making procedure qualification test plates for butt welds in accordance with Section IX, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. It is the responsibility of the Manufacturer to ensure that the procedure qualification test plates simulate the restraints on the production weldments.

KF-215 Test of Welders and Welding Operators

(a) The welders and the welding operators used in welding pressure parts and in joining nonpressure parts (attachments) to pressure parts shall be qualified in accordance with Section IX and Article KT-2. Mechanical testing is required for all performance qualification tests; qualification by NDE is not permitted. See Article KT-2 for additional requirements on weld position testing, weld impact testing, and test plate requirements.

(b) The qualification test for welding operators of machine welding equipment shall be performed on a separate test plate prior to the start of welding or on the first workpiece.

KF-216 Maintenance of Qualification and Production Records

The Manufacturer shall maintain records of the welding procedures and the welders and welding operators employed by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be certified by the Manufacturer or subcontractor to the Manufacturer and shall be accessible to the Inspector.

KF-220 WELD JOINTS PERMITTED AND THEIR EXAMINATION

Type No. 1 butt joints as described in KF-221 shall be used for all welded joints except as listed in (a) through (c) below. For further discussion, see KD-1110. Partial penetration welds, such as fillet welds, that are not used in combination with full-penetration welds as described below are not permitted on pressure retaining parts.

(a) Full-penetration welds are permitted for nozzle attachments under the rules of KD-1130. They are described in KF-222.

(b) Type No. 2 single-welded groove welds are permitted under the rules of Article KF-8 when joining layers other than the innermost shell on welded layer vessels. These welds are described in KF-223.

(c) Welds used for attaching heating and cooling jack- 04
ets and support clips are permitted under the rules of Article KD-7 and KF-224. These welds are full-penetration groove welds as shown in Fig. KD-700, and as described in KF-222. In some cases these welds may be used in combination with fillet welds.

Required weld examination shall be done after all postweld heat treatment and in accordance with Article KE-3. Discussion specific to the four types of joints permitted under the rules of this Division follows.

KF-221 Type No. 1 Butt Joints

Type No. 1 butt joints are those produced by welding from both sides of the joint or by other means that produce the same quality of deposited weld metal on both inside and outside weld surfaces. Welds using backing strips which remain in place do not qualify as Type No. 1 butt joints.

Type No. 1 butt joints shall have complete penetration and full fusion and shall be ground or machined flush with the members joined together. All Type No. 1 butt joints, whether longitudinal or circumferential, shall be completely examined for their entire length in accordance with Article KE-3.

KF-222 Full-Penetration Groove Welds Attaching Nozzles

Nozzle attachments are normally Type No. 1 butt joints, which are covered by the design rules of KD-1130 and shown in Fig. KD-1130. Full-penetration groove welds are also permitted for attaching nozzles to shells in accordance with the design rules of KD-1131. These welds are not readily radiographable. Backing strips are not permitted.

KF-222.1 Weld Procedure Qualifications. Normally this weld will be a single-welded joint. Consideration shall be given to using a welding procedure such as GTAW capable of producing a high quality of weld on the ID of the nozzle. The suitability of the electrode and procedure, including preheat and postheat, shall be established by making a groove weld specimen as shown in QW-461.1 and QW-461.3 of Section IX in material of the same analysis and of thickness in conformance with QW-451.1 and QW-451.2 of Section IX. The specimen before welding shall be in the same condition of heat treatment as the work it represents. After welding, the specimen shall be subjected to heat treatment equivalent to that specified for the final product. Tension and bend specimens, as shown in QW-462.1, QW-462.2, and QW-462.3(a) of Section IX, shall be made. These tests shall meet the requirements of QW-150 and QW-160 of Section IX. The radius of the mandrel used in the guided bend test shall be as follows:

Specimen Thickness	Radius of Mandrel B	Radius of Die D [Note (1)]
$^3/_8$ in. (10 mm)	$1^1/_4$ in. (32 mm)	$1^{11}/_{16}$ in. (43 mm)
1 in. (25 mm)	$10t/3$	$9t/2 + {}^1/_{16}$ in. (1.5 mm)

NOTE:
(1) Corresponds to dimensions B and D for P-No. 11 material in QW-466.1 of Section IX and other dimensions to be in proportion.

KF-222.2 Weld Examination. In addition to the final examination requirements of Article KE-3, consideration shall be given to intermediate weld examination, such as wet magnetic particle examination, in order to ensure weld soundness after completion of the process.

KF-223 Type No. 2 Butt Joints

Type No. 2 butt joints are only permitted in layers subsequent to the inner shell of welded layered vessels. Design and fabrication rules are listed in Article KD-8 and Article KF-8. See Article KF-8 for specific welding and weld examination requirements.

KF-224 Quality and Examination Requirements for Fillet Welds Used in Combination With Full-Penetration Groove Welds

When fillet welds are used in conjunction with full-penetration groove welds, the groove weld portion shall be qualified and performed under the rules of KF-222 before the fillet weld is made. The fillet weld shall meet the following requirements:

(a) The reduction in thickness of the adjoining surfaces at the root of the fillet weld shall not be greater than $^1/_{32}$ in. (0.8 mm) or cause the adjoining material to be below the design minimum required thickness at any point.

(b) The surface finish shall be inspected under the rules of KF-204 and the surface shall be examined under the rules of KE-334.

KF-225 Liquid Penetrant Examination

All austenitic chromium–nickel alloy steel, austenitic–ferritic duplex steel, and nickel alloy welds, both butt and fillet, shall be examined in accordance with the liquid penetrant method (see KE-334). If heat treatment is required, the examination shall be made following heat treatment. All defects shall be repaired and the repair documented in accordance with the provisions of KF-240. The repaired area shall be reexamined by the liquid penetrant method.

KF-226 Surface Weld Metal Buildup

Construction in which deposits of weld metal are applied to the surface of base metal for the purpose of restoring the thickness of the base metal or modifying the configuration of weld joints in order to meet the tapered transition requirements of KD-1120 or KF-234(b) shall meet the following requirements:

(a) Prior to production welding, a welding procedure shall be qualified for the thickness of weld metal deposited.

(b) All weld metal buildup shall be examined over the full surface of the deposit by either a magnetic particle method or by a liquid penetrant method in accordance with KE-334.

(c) All weld metal buildup that exceeds $^3/_8$ in. (10 mm) in thickness shall be examined over the entire deposit by either radiography or ultrasonic methods in accordance with KE-220.

(d) When such surface weld metal buildup is used in welded joints which require volumetric examination, the weld metal buildup shall be included in the examination.

KF-230 REQUIREMENTS DURING WELDING

Parts that are being welded shall be cleaned, aligned, fitted, and retained in position during the welding operation.

KF-231 Preparation of Reverse Side of Double-Welded Joints

Before applying weld metal to the reverse side, the reverse side of double-welded joints shall be prepared by chipping, grinding, or gouging in order to secure sound metal at the root of the weld. Removal of root pass weld is not required for any process of welding by which the base of the weld remains free from impurities. Prior to the start of the weld at the reverse side, the cleaned root area shall be examined in accordance with KE-334.

KF-232 Cleaning of Surfaces to Be Welded

The surfaces of the parts to be welded shall be clean and free of scale, rust, oil, grease, and other deleterious foreign material. For all materials, detrimental oxide shall be removed from the weld metal contact area for a distance of at least 2 in. (51 mm) from welding joint preparation. When weld metal is to be deposited over a previously welded surface, all slag shall be removed to prevent inclusion of impurities in the weld metal.

KF-233 Alignment During Welding

(a) Bars, jacks, clamps, tack welds, or other appropriate means may be used to maintain the alignment of the edges to be welded. Tack welds, if used to maintain alignment, shall either be removed completely when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified procedures and welders. Permanent tack welds shall be examined by either magnetic particle or liquid penetrant method. Acceptance criteria and repair shall be in accordance with KE-334.

(b) A single-welded joint (i.e., welds made from one side only), as permitted by KF-220, may be used provided the Inspector is satisfied that proper fusion and penetration has been obtained. When using this type of weld, particular care shall be taken in aligning and separating the components to be joined.

KF-234 Alignment Tolerances for Edges to Be Butt Welded

(a) Alignment of sections at edges to be butt welded shall be such that the maximum offset is not greater than allowed in Table KF-234.

(b) All offsets shall be faired at a three-to-one taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would have been the edge of the weld. Such additional weld metal buildup shall meet the requirements of KF-226.

(c) For transition joints between sections of unequal thicknesses, see KD-1120.

KF-235 Precautions to Be Taken When Welding Is Restarted

If the welding is stopped for any reason, extra care shall be taken in restarting to get the required penetration and fusion.

KF-236 Removal of Temporary Attachments and Arc Strikes

The areas from which temporary attachments have been removed or areas of arc strikes shall be ground smooth and examined by a magnetic particle or by a liquid penetrant method in accordance with KE-233. Defects shall be removed and the material shall be examined to ensure that the defects have been removed. If weld repairs are necessary, they shall be made using qualified welding procedures and welders, and shall be examined as outlined in KF-226.

KF-237 Peening

Controlled peening may be performed to reduce distortion. Peening shall not be used on the initial (root) layer of weld metal, nor on the final (face) layer unless the weld is postweld heat treated.

KF-238 Identification Markings or Records for Welders and Welding Operators

(a) Each welder and welding operator shall mark the identifying number, letter, or symbol, assigned by the Manufacturer, adjacent to and at intervals of not more than 3 ft (0.9 m), with marking procedures that meet the requirements of KF-112 and KF-601, along the welds which he makes in material $\frac{1}{4}$ in. (6 mm) and over in thickness. Alternatively, a record shall be kept by the Manufacturer of each joint welded by the welder or welding operator. This record shall be available to the Inspector.

(b) When a multiple number of permanent nonpressure part attachment welds are made on a vessel, the Manufacturer need not identify the welder or welding operator that welded each individual joint, provided

(1) the Manufacturer's Quality Control System includes a procedure that identifies the welders or welding operators that made such welds on each vessel so that the Inspector can verify that the welders or welding operators were all properly qualified

TABLE KF-234
MAXIMUM ALLOWABLE OFFSET IN WELDED JOINTS

Section Thickness	Direction of Joints in Cylindrical Shells: Longitudinal	Circumferential
Up to and including $^{15}/_{16}$ in. (24 mm)	Lesser of $t/5$ or $^{3}/_{32}$ in. (2.4 mm)	$t/5$
Greater than $^{15}/_{16}$ in. (24 mm), less than or equal to $1^{1}/_{2}$ in. (38 mm)	$^{3}/_{32}$ in. (2.4 mm)	$^{3}/_{16}$ in. (4.8 mm)
Greater than $1^{1}/_{2}$ in. (38 mm)	$^{3}/_{32}$ in. (2.4 mm)	$t/8$ but not greater than $^{1}/_{4}$ in. (6 mm)

(2) the welds in each category are all of the same type and configuration and are welded with the same welding procedure specification

(c) Permanent identification of welders or welding operators making tack welds that become part of the final pressure weld is not required, provided the Manufacturer's Quality Control System includes a procedure to permit the Inspector to verify that such tack welds were made by qualified welders or welding operators.

KF-240 REPAIR OF WELD DEFECTS

KF-241 Removal of Defects

Defects detected by the examinations required by Article KE-3 or the hydrostatic test shall be removed by mechanical means or by thermal gouging processes. If thermal gouging is used, the Manufacturer shall ensure the process is not detrimental to the material.

KF-242 Rewelding of Areas to Be Repaired

The areas to be repaired shall be rewelded by qualified welders using qualified welding procedures (see KF-210).

KF-243 Examination of Repaired Welds

Repaired welds shall be reexamined by the methods of the original examination of the weld. The repaired weld shall not be accepted unless the examination shows the repair to be satisfactory.

KF-244 Postweld Heat Treatment of Repaired Welds

The postweld heat treating rules in Article KF-4 shall apply to all weld repairs.

KF-245 Documentation of Repairs

All weld repairs shall be documented in the Manufacturer's Construction Records.

ARTICLE KF-3
FABRICATION REQUIREMENTS FOR MATERIALS WITH PROTECTIVE LININGS

KF-300 SCOPE

This Article applies to materials with protective linings that are applied by integral cladding or weld overlaying. Prestressed liners which are considered part of the shell for strength purposes are not covered by this Article (see Article KF-8).

KF-301 Types of Joints Permitted

The types of joints and welding procedures used shall be such as to minimize the formation of brittle weld composition by the mixture of metals of corrosion-resistant alloy and base material.[1]

KF-302 Weld Metal Composition

Welds that are exposed to the corrosive action of the contents of the vessel should have resistance to corrosion that is not substantially less than that of the corrosion-resistant integral or weld metal overlay cladding or lining. The use of filler metal that will deposit weld metal with practically the same composition as the material joined is recommended. Weld metal of different composition may be used provided it has better mechanical properties in the opinion of the Manufacturer, and the User is satisfied that its resistance to corrosion is satisfactory for the intended service. The columbium content of columbium-stabilized austenitic stainless steel weld metal shall not exceed 1.00% except when a higher content is permitted in the material being welded.

KF-303 400 Series Alloy Filler Metals

400 Series alloy filler metals are not permitted when the filler metal is welded to the base metal.

[1] Because of the different coefficients of thermal expansion of dissimilar metals, caution should be exercised in design and construction under provisions of these paragraphs in order to avoid difficulties in service under extreme temperature conditions or with unusual restraint of parts such as may occur at points of stress concentration.

KF-310 QUALIFICATION OF WELDING PROCEDURES

The specification of the welding procedure that is proposed to be followed in clad, weld overlaid or lined construction shall be recorded in detail.

KF-311 Procedure to Be Qualified Per Section IX

All weld procedures associated with protective liners shall be qualified in accordance with the provisions of Section IX, QW-217.

KF-312 Qualification of Procedure for Attaching Linings

(a) Each welding procedure to be used for attaching lining material to the base material shall be qualified on lining attachment welds made in the form and arrangement to be used in construction and with materials that are within the ranges of chemical composition of the materials to be used, respectively, for the base material, the linings, and the weld metal.

(b) Welds shall be made in each of the positions defined in Section IX, QW-120 that are to be used in construction. One specimen from each position to be qualified shall be sectioned, polished, and etched to show clearly the demarcation between the fusion zone and the base metal.

(c) For the procedure to qualify, the specimen shall show, under visual examination without magnification, complete fusion and complete freedom from cracks in the fusion zone and in the heat-affected metal.

KF-313 Requirements for Composite Welds

KF-313.1 Procedure Qualification for Groove Welds in Base Material With Corrosion-Resistant Integral Cladding or Weld Metal Overlay. The requirements in Section IX, QW-217 for procedure qualification shall be followed. The procedure for groove welds may be qualified as in KF-311, or the weld in the base joint or cladding joint may be qualified individually in accordance with the rules in Section IX.

KF-313.2 Performance Qualification for Composite Welds. The requirements in Section IX, QW-310 and KF-313.1 or KF-313.3 shall be followed for performance qualification.

KF-313.3 Test Plates for Composite Welds. Performance qualification tests shall be made in accordance with Section IX by preparing test material from integral clad or weld overlay material having the same P-Numbers in QW/QB-422 as that of the base material. Integral or weld metal overlay cladding materials to be used in the test shall have the same F-Number in QW-432 as the filler metal that will be used in construction. When the integral clad or weld metal overlay material is not listed in QW/QB-422, qualification shall be made on the same grade as used in the vessel. Heat treatment is not required but is permitted if the welder's work on construction is to be heat treated. The following conditions shall also be met. A section cut from the test material perpendicular to the welding direction and properly prepared and etched shall show no lack of fusion longer than $\frac{1}{8}$ in. (3.2 mm). The total length of unfused cladding shall not exceed 10% of the length of the test material perpendicular to the direction of welding.

KF-320 INTEGRALLY CLAD MATERIALS

A shear test shall demonstrate a minimum shear strength of 20 ksi (138 MPa) for integral clad materials.

KF-330 POSTWELD HEAT TREATMENT OF LININGS

KF-331 When Base Metal Must Be Postweld Heat Treated[2]

Vessels or parts of vessels constructed of an integrally clad material or weld metal overlay shall be postweld heat treated when the base material is required to be postweld heat treated. In applying these rules, the determining thickness shall be the total thickness of base material. When the thickness of the base material requires postweld heat treatment, it shall be performed after the application of weld metal overlay or clad restoration.

[2] Postweld heat treatment temperatures may be in the carbide precipitation range for unstabilized austenitic chromium–nickel steel, as well as within the range where a sigma phase may form. Improper treatment could result in material of inferior physical properties and inferior corrosion resistance and could result in the ultimate failure of the vessel.

KF-332 Requirements When Base Metal or Lining Is Chromium-Alloy Steel

Vessels or parts of vessels constructed of chromium-alloy stainless steel cladded base material and those lined with chromium-alloy stainless steel applied linings shall be postweld heat treated in all thicknesses, except that vessels clad or lined with Type 405 or Type 410S and welded with an austenitic electrode or non-air-hardening nickel–chromium–iron electrode need not be postweld heat treated unless required by KF-331.

KF-333 Heat Treatment That May Affect Vessel Stress Redistribution

The Manufacturer shall ensure and document, in accordance with KG-323(d), that any heat treatment given to a vessel or vessel part does not adversely affect the stress distribution required by Articles KD-5, KD-8, KD-9, and KD-10. In addition, for layered or autofrettaged vessels, the Manufacturer shall meet the requirements for heat treatment given in KF-830 or KF-540(b), as applicable.

KF-340 EXAMINATION REQUIREMENTS

KF-341 Examination of Base Materials Protected by Welded Overlay

The examination required by the rules in Article KE-3 shall be made after the joint, including the corrosion-resistant layer, is complete. The examination may be made on the weld in the base material before the alloy cover weld is deposited, provided the following requirements are met:

(a) the thickness of the base material at the welded joint is not less than that required by the design calculation

(b) the corrosion-resistant alloy weld deposit is non-air-hardening

(c) the completed alloy weld deposit is examined by any method that will detect cracks in accordance with KE-233

KF-342 Examination of Chromium-Alloy Cladding Overlay

The joints between chromium-alloy cladding overlay or loose liner sheets shall be examined for cracks as specified in KF-342.1 and KF-342.2.

KF-342.1 Straight Chromium-Alloy Filler Metal

(a) Joints welded with straight chromium-alloy filler metal shall be examined throughout their full length. Chromium-alloy welds in continuous contact with the welds in the base metal shall be examined in accordance with Article KE-3.

(b) Liner welds that are attached to the base metal, but merely cross the seams in the base metal, shall be examined in accordance with KE-334.

KF-342.2 Austenitic Chromium–Nickel Steel Filler Metal. Joints welded with austenitic chromium–nickel steel filler metal or non-air-hardening nickel–chromium–iron filler metal shall be dye penetrant examined over their entire length per KE-334 and spot UT examined over 10% of their length in accordance with Article KE-3.

KF-350 INSPECTION AND TESTS

KF-351 General Requirements

The rules in the following paragraphs shall be used in conjunction with the general requirements for inspection in Part KE, and for testing in Part KE that pertain to the method of fabrication used.

KF-352 Leak Test of Protective Lining

A test for pressure tightness of the protective lining that will be appropriate for the intended service is recommended, but the details of the test shall be a matter for agreement between the User and the Manufacturer. The test should not damage the load-carrying baseplate. When rapid corrosion of the base material is to be expected from contact with the contents of the vessel, particular care should be taken in devising and executing the leak test.

KF-360 STAMPING AND REPORTS

The provisions for stamping and reports in Part KS shall apply to vessels that are constructed of integral clad, weld metal overlay, or protective liners and shall include the specification and type of lining material. This information shall be included in the Manufacturer's Data Reports.

ARTICLE KF-4
HEAT TREATMENT OF WELDMENTS

KF-400 HEAT TREATMENT OF WELDMENTS

This section gives requirements for heat treatment of weldments. For additional heat treatment requirements for quenched and tempered steels, see KF-630.

KF-401 Requirements for Preheating

The welding procedure specification for the material being welded shall specify the minimum preheating requirements in accordance with the weld procedure qualification requirements of Section IX. The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature physical properties, and material thicknesses.

KF-402 Requirements for Postweld Heat Treatment[1]

Before applying the detailed requirements and exemptions in these paragraphs, satisfactory qualification of the welding procedures to be used shall be performed in accordance with Section IX and the restrictions listed below. Except for nonferrous materials and except as otherwise provided in Table KF-402.1 for ferrous materials, all welded pressure vessels or pressure vessel parts shall be given a postweld heat treatment at a temperature not less than that specified in Table KF-402.1 when the nominal thickness, including corrosion allowance, of any welded joint in the vessel or vessel parts exceeds the limits in Table KF-402.1. Materials in Table KF-402.1 are listed by P-Number, which may be found in QW/QB-422 of Section IX and the tables of stress values in Section II Part D.

KF-402.1 When Holding Temperatures and Times May Be Exceeded. Except where prohibited in Table KF-402.1, holding temperatures and/or holding times exceeding the minimum values given in Table KF-402.1 may be used (see KT-112 for additional requirements for time at temperature). A time–temperature recording of all postweld heat treatments shall be provided for review by the Inspector. The total holding time at temperature specified in Table KF-402.1 may be an accumulation of time of multiple postweld heat treat cycles.

KF-402.2 Heat Treatment of Pressure Parts When Attached to Different P-Number Groups and Nonpressure Parts. When pressure parts of two different P-Number groups are joined by welding, the postweld heat treatment shall be that specified in Table KF-402.1 with applicable notes for the material requiring the higher postweld heat treatment temperature. When nonpressure parts are welded to pressure parts, the postweld heat treatment temperature of the pressure part shall control.

KF-402.3 Definition of Nominal Thickness Governing Postweld Heat Treatment. The nominal thickness in Table KF-402.1 and Table KF-630 is the thickness of the welded joint as defined herein. For pressure vessels or parts of pressure vessels being postweld heat treated in a furnace charge, it is the greatest weld thickness in any vessel or vessel part which has not previously been postweld heat treated.

(a) When the welded joint connects parts of equal thickness, using a full-penetration butt weld, the nominal thickness is the total depth of the weld exclusive of any permitted weld reinforcement.

(b) For groove welds, the nominal thickness is the depth of the groove.

(c) For fillet welds, the nominal thickness is the throat dimension. If a fillet weld is used in conjunction with a groove weld, the nominal thickness is the depth of the groove or the throat dimension, whichever is greater.

(d) For stud welds, the nominal thickness shall be the diameter of the stud.

(e) When a welded joint connects parts of unequal thicknesses, the nominal thickness shall be the following:

(1) the thinner of two adjacent butt welded parts including head-to-shell connections

(2) the thickness of the shell in connections to tubesheets, flat heads, covers, flanges, or similar constructions

[1] Additional postweld heat treatment requirements may result from the requirements of Article KT-2.

TABLE KF-402.1
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS
(U.S. Customary Units)

Material	Nominal Holding Temperature, °F, min.	Minimum Holding Time at Normal Temperature for Nominal Thickness (See KF-402.1)		
		Up to 2 in.	Over 2 to 5 in.	Over 5 in.
P-No. 1 [Note (1)]	1,100	1 hr/in. (1 hr min.)	2 hr plus 15 min for each additional inch over 2 in.	2 hr plus 15 min for each additional inch over 2 in.
P-No. 3 [Notes (2), (3)]	1,100	1 hr/in. (1 hr min.)	2 hr plus 15 min for each additional inch over 2 in.	2 hr plus 15 min fore-ach additional inch over 2 in.
P-No. 5A [Notes (2), (3)]	1,250	1 hr/in. (1 hr min.)	1 hr/in.	5 hr plus 15 min for each additional inch over 5 in.
P-No. 8 [Note (4)]	...	...	...	...
P-No. 10A [Notes (3), (5)]	1,100	1 hr min. plus 15 min for each addi-tional inch over 1 in.	1 hr min. plus 15 min for each addition-alinch over 1 in.	1 hr min. plus 15 min for each additional inch over 1 in.
P-No. 42 [Note (4)]	...	...	...	...
P-No. 43 [Note (4)]	...	...	...	...
P-No. 44 [Note (4)]	...	...	...	...
P-No. 45 [Note (4)]	...	...	...	...

NOTES:
(1) Postweld heat treatment is mandatory under the following conditions:
(a) for materials over $1\frac{1}{4}$ in. nominal thickness
(b) on material over $\frac{5}{8}$ in. nominal thickness for pressure parts subject to direct firing
(2) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of KT-112, additional test coupons shall be made and tested.
(3) Postweld heat treatment is mandatory under the following conditions:
(a) for all materials over $\frac{3}{8}$ in. nominal thickness
(b) on materials of all thicknesses intended for pressure parts subject to direct firing
(4) Postweld heat treatment is neither required nor prohibited for joints between materials of P-Nos. 8, 42, 43, 44, or 45, or any combination thereof.
(5) Consideration should be given for possible embrittlement of materials containing up to 0.15% vanadium when postweld heat treating at minimum temperatures.

(3) in Figs. KD-700, KD-1112, KD-1121, KD-1122, KD-1130, and KD-1131, the thickness of the weld across the nozzle neck, shell, head, or attachment fillet weld, whichever is greater

(4) the thickness of the nozzle neck at the joint in nozzle neck-to-flange connections

(5) the thickness of the weld at the point of attachment when a nonpressure part is welded to a pressure part

(6) the thickness of the weld in tube-to-tubesheet connections

(f) For repairs, the nominal thickness is the depth of the repair weld.

KF-410 HEATING PROCEDURES FOR POSTWELD HEAT TREATMENT

KF-411 Methods of Heating

The postweld heat treatment shall be performed in accordance with one of the procedures of this paragraph.

TABLE KF-402.1M
REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF PRESSURE PARTS AND ATTACHMENTS
(SI Units)

Material	Nominal Holding Temperature, °C, min.	Minimum Holding Time at Normal Temperature for Nominal Thickness (See KF-402.1)		
		Up to 50 mm	Over 50 mm to 125 mm	Over 125 mm
P-No. 1 [Note (1)]	595	1 hr/25 mm (1 hr min.)	2 hr plus 15 min for each additional 25 mm over 50 mm	2 hr plus 15 min for each additional 25 mm over 50 mm
P-No. 3 [Notes (2), (3)]	595	1 hr/25 mm (1 hr min.)	2 hr plus 15 min for each additional 25 mm over 50 mm	2 hr plus 15 min for each additional 25 mm over 50 mm
P-No. 5A [Notes (2), (3)]	680	1 hr/25 mm (1 hr min.)	1 hr/25 mm	5 hr plus 15 min for each additional 25 mm over 125
P-No. 8 [Note (4)]	...	...	...	...
P-No. 10A [Notes (3), (5)]	595	1 hr min. plus 15 min for each additional 25 mm over 25 mm	1 hr min. plus 15 min for each additional 25 mm over 25 mm	1 hr min. plus 15 min for each additional 25 mm over 25 mm
P-No. 42 [Note (4)]	...	...	...	...
P-No. 43 [Note (4)]	...	...	...	...
P-No. 44 [Note (4)]	...	...	...	...
P-No. 45 [Note (4)]	...	...	...	...

NOTES:
(1) Postweld heat treatment is mandatory under the following conditions:
(a) for materials over 30 mm nominal thickness
(b) on material over 15 mm nominal thickness for pressure parts subject to direct firing
(2) If during the holding period of postweld heat treatment, the maximum time or temperature of any vessel component exceeds the provisions of KT-112, additional test coupons shall be made and tested.
(3) Postweld heat treatment is mandatory under the following conditions:
(a) for all materials over 10 mm nominal thickness
(b) on materials of all thicknesses intended for pressure parts subject to direct firing
(4) Postweld heat treatment is neither required nor prohibited for joints between materials of P-Nos. 8, 42, 43, 44, or 45, or any combination thereof.
(5) Consideration should be given for possible embrittlement of materials containing up to 0.15% vanadium when postweld heat treating at minimum temperatures.

In the procedures that follow, the soak band is defined as the volume of metal required to meet or exceed the minimum PWHT temperatures listed in Table KF-402.1. As a minimum, the soak band shall contain the weld, heat-affected zone, and a portion of base metal adjacent to the weld being heat treated. The minimum width of this volume is the widest width of weld plus 1*t* or 2 in. (51 mm), whichever is less, on each side or end of the weld. The term *t* is the nominal thickness as defined in KF-402.3.

KF-411.1 Heating Entire Vessel. Heating the vessel as a whole in a closed furnace is preferred and should be used whenever practical.

KF-411.2 Heating Vessel Portions. Heating the vessel in more than one heat in a furnace is permitted, provided the overlap of the heated sections of the vessel is at least 5 ft (1.5 m). When this procedure is used, the portion outside of the furnace shall be shielded so that the temperature gradient is not harmful (see KF-412). The cross section where the vessel projects from the furnace shall not intersect a nozzle or other structural discontinuity.

KF-411.3 Heating Components and Circumferential Welds

(a) It is permissible to heat shell sections, heads, and other components of vessels, for postweld heat treatment of longitudinal joints or complicated welded details, before joining any sections to make the completed vessel. Circumferential joints not previously postweld heat treated may be locally postweld heat treated by heating a circumferential band that includes such joints.

(b) This procedure may also be used for local heat treatment of circumferential joints in pipe, tubing, or nozzle necks. In the latter case, proximity to the shell increases thermal restraint, and the designer should provide adequate length to permit heat treatment without harmful gradients at the nozzle attachments. If this is not practical, see KF-411.5.

(c) The width of the heated band on each side of the greatest width of the finished weld shall be not less than two times the shell thickness. The portion outside the heating device shall be protected so that the temperature gradient is not harmful. For such local heating, the soak band shall extend around the full circumference. The portion outside the soak band shall be protected so that the temperature gradient is not harmful. This procedure may also be used to postweld heat treat portions of new vessels after repairs.

KF-411.4 Heating Vessel Internally. The vessel may be heated internally by any appropriate means when adequate temperature indicating and recording devices are utilized to aid in the control and maintenance of a uniform distribution of temperature in the vessel wall. The vessel shall be fully insulated where required prior to heating so the temperature requirements of KF-413 are met.

KF-411.5 Local Heating of Nozzles and External Attachments on Vessels

(a) Heating a circumferential band containing nozzles or other welded attachments that require postweld heat treatment in such a manner that the entire band shall be brought up uniformly to the required temperature (see KF-413) and held for the specified time. Except as modified in KF-411.5(b), the soak band shall extend around the entire vessel, and shall include the nozzle or welded attachment. The portion of the vessel outside of the circumferential soak band shall be protected so that the temperature gradient is not harmful.

(b) This procedure may also be used for local heat treatment of circumferential joints in pipe, tubing, or nozzle necks. In the latter case, proximity to the shell increases thermal restraint, and the designer should provide adequate length to permit heat treatment without harmful gradients — at the nozzle attachment, or heat a full circumferential band around the shell, including the nozzle.

The circumferential soak band width may be varied away from the nozzle or attachment weld requiring PWHT, provided the required soak band around the nozzle or attachment weld is heated to the required temperature and held for the required time. As an alternate to varying the soak band width, the temperature within the circumferential band away from the nozzle or attachment may be varied and need not reach the required temperature, provided the required soak band around the nozzle or attachment weld is heated to the required temperature, held for the required time, and the temperature gradient is not harmful throughout the heating and cooling cycle. The portion of the vessel outside of the circumferential soak band shall be protected so that the temperature gradient is not harmful.

(c) The procedure in KF-411.5(a) may also be used to postweld heat treat portions of vessels after repairs.

KF-411.6 Local Area Heating of Double Curvature Heads or Shells. Heating a local area around nozzles or welded attachments in the larger radius sections of a double curvature head or a spherical shell or head in such a manner that the area is brought up uniformly to the required temperature (see KF-413) and held for the specified time. The soak band shall include the nozzle or welded attachment. The soak band shall include a circle that extends beyond the edges of the attachment weld in all directions by a minimum of t or 2 in. (51 mm), whichever is less. The portion of the vessel outside of the soak band shall be protected so that the temperature gradient is not harmful.

KF-411.7 Heating of Other Configurations. Local area heating of other configurations not addressed in KF-411.1 through KF-411.6 is permitted, provided that other measures (based upon sufficiently similar documented experience or evaluation) are taken that consider the effect of thermal gradients, all significant structural discontinuities (such as nozzles, attachments, head to shell junctures) and any mechanical loads that may be present during PWHT. The portion of the vessel outside of the soak band shall be protected so that the temperature gradient is not harmful.

KF-412 Heat Treatment That May Affect Vessel Stress Redistribution

The Manufacturer shall ensure, in accordance with KG-323(d), that any heat treatment given to a vessel or vessel part does not adversely affect the stress redistribution required by Articles KD-5, KD-8, and KD-9. In addition, the Manufacturer shall meet the requirements for heat treatment given in KF-830 or KF-540(b), as applicable.

KF-413 Heating and Cooling Rates

Postweld heat treatment shall be carried out by one of the methods given in KF-411 in accordance with the following requirements:

(a) The temperature of the furnace shall not exceed 800°F (425°C) at the time the vessel or part is placed in it.

(b) Above 800°F (425°C), the rate of heating shall be not more than 400°F/hr (220°C/hr) per inch (25 mm) of the maximum metal thickness of the shell or head plate, but in no case more than 400°F/hr (220°C/ hr) and in no case need it be less than 100°F/hr (55°C/ hr). During the heating period, there shall not be a greater variation in temperature throughout the portion of the vessel being heated than 250°F (140°C) within any 15 ft (4.6 m) interval of length.

(c) The vessel or vessel part shall be held at or above the temperature specified in Table KF-402.1 for the period of time specified. During the holding period, there shall not be a difference greater than 100°F (55°C) between the highest and lowest temperatures throughout the portion of the vessel being heated, except where the range is further limited in Table KF-402.1.

(d) During the heating and holding periods, the furnace atmosphere shall be so controlled as to avoid excessive oxidation of the surface of the vessel. The furnace shall be of such design as to prevent direct impingement of the flame on the vessel.

(e) Unless modified by Article KF-6, above 800°F (425°C) cooling shall be done in a closed furnace or cooling chamber at a rate not greater than 500°F/hr (280°C/hr) per inch (25 mm) of the maximum metal thickness of the shell or head plate, but in no case need it be less than 100°F/hr (55°C/hr). From 800°F (425°C), the vessel may be cooled in still air.

KF-420 POSTWELD HEAT TREATMENT AFTER REPAIRS

Vessels or parts of vessels that have been postweld heat treated in accordance with the requirements of this Article shall again be postweld heat treated after repairs have been made if the welds made in such repairs required postweld treatment under the requirements of this Article. The Manufacturer shall ensure that any additional heat treatments required shall not adversely affect the vessel material properties.

ARTICLE KF-5
ADDITIONAL FABRICATION REQUIREMENTS FOR AUTOFRETTAGED VESSELS

KF-500 GENERAL

The rules in this Article apply specifically to the fabrication of autofrettaged vessels and shall be used in conjunction with Article KF-1.

KF-510 EXAMINATION AND REPAIR

(a) All base materials to be used in fabrication shall be examined ultrasonically in accordance with KE-232.

(b) The concurrence of the Professional Engineer who certifies the Manufacturer's Design Report shall be obtained prior to making any repairs by welding.

(c) All repairs shall be made by the Material Manufacturer or the Manufacturer in accordance with Article KE-2 and documented in accordance with KE-214.

KF-520 AUTOFRETTAGE PROCEDURES

The Manufacturer shall have a written detailed procedure. The procedure shall contain, as a minimum, the following.

(a) Method of accomplishing autofrettage.

(b) Method of controlling the extent of autofrettage.

(c) Method of recording time, temperature, and pressure during autofrettage.

(d) Method for measuring the extent of autofrettage achieved and for determining that it is within acceptable limits. Article KD-5 contains an equation which relates measured strain to the extent of autofrettage.

(e) Any machining after autofrettage shall be documented. The influence of machining after autofrettage is discussed in KD-520(b).

KF-521 Documentation of Number of Pressurizations

The effect on crack initiation and ultimate fatigue life of multiple autofrettage attempts which exceed 1.25 times the design pressure shall be documented by the Designer. The Vessel Manufacturer shall document all such attempts and submit them to the Professional Engineer who certified the Manufacturer's Design Report for approval.

KF-530 EXAMINATION AFTER AUTOFRETTAGE

Surfaces which are expected to undergo plastic deformation during autofrettage and which will not be accessible during the final surface examination required in KE-400 shall be examined by one of the methods in KE-230 as appropriate.

KF-540 REPAIR OF DEFECTS AFTER AUTOFRETTAGE

(a) Defects may be removed and the vessel repaired by the Manufacturer in accordance with KF-510.

(b) If repair by welding is performed, no credit for the favorable effects of autofrettage in the area of the weld repair shall be taken in the fatigue analysis required in Part KD. Repair welding shall be done in accordance with the requirements of Article KE-2. If postweld heat treatment is required, the effects of this heat treatment on the residual stress distribution shall be documented by the Manufacturer in the Manufacturer's Construction Report.

KF-550 STAMPING AND REPORTS

The provisions for stamping and reports in Part KS shall apply to pressure vessels fabricated per this Article. In addition to the required marking, the letters PS shall be applied below the symbol (see KF-601).

ARTICLE KF-6
ADDITIONAL FABRICATION REQUIREMENTS FOR QUENCHED AND TEMPERED STEELS

KF-600 GENERAL

The following supplementary rules are applicable to steels suitable for welded vessel parts, the material properties of which have been enhanced by quenching and tempering heat treatment. The provisions of KM-240 shall also apply to materials whose properties are enhanced by quenching and tempering heat treatment.

KF-601 Marking on Plates and Other Materials

Any steel stamping shall be done with low stress stamps. Steel stamping of all types may be omitted on material with a thickness of $\frac{1}{2}$ in. (13 mm) or less. For the use of other markings in lieu of stamping, see KF-112.

KF-602 Requirements for Heat Treating After Forming

(a) Parts formed after quenching and tempering, and which are formed at a temperature lower than the final tempering temperature, shall be heat treated in accordance with Table KF-630 when the extreme fiber elongation from forming exceeds 5% as determined by Eqs. (1) or (2).

(1) For double curvature (for example, heads):

$$\%\text{ extreme fiber elongation} = \frac{75t}{R_f}\left(1 - \frac{R_f}{R_o}\right) \tag{1}$$

(2) For single curvature (for example, cylinders):

$$\%\text{ extreme fiber elongation} = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right) \tag{2}$$

where

R_f = final centerline radius, in. (mm)
R_o = original centerline radius (equals infinity for flat plate), in. (mm)
t = plate thickness, in. (mm)

(b) Parts formed at temperature equal to or higher than the original tempering temperature shall be requenched and tempered in accordance with the applicable material specifications either before of after welding into the vessel.

KF-603 Minimum Thickness After Forming

The minimum thickness after forming of any section subject to pressure shall be $\frac{1}{4}$ in. (6 mm).

KF-610 WELDING REQUIREMENTS

KF-611 Qualification of Welding Procedures and Welders

The qualification of the welding procedure and the welders shall conform to the requirements of Section IX and any additional requirements of this Section.

KF-612 Filler Metal

Filler metal containing more than 0.08% vanadium shall not be used for weldments subject to postweld heat treatment.

KF-613 Preparation of Base Metal

Preparation of plate edges, welding bevels, and chamfers, and similar operations involving the removal of metal, shall be by machining, chipping, grinding, or by gas cutting or air arc gouging, as provided in KF-613.1.

KF-613.1 Precautions Necessary When Using Gas Cutting or Gouging. When metal removal is accomplished by methods involving melting, such as gas cutting or arc air gouging, etc., it shall be done with due precautions to avoid cracking. Where the cut surfaces are not to be subsequently eliminated by fusion with weld deposits, they shall be removed by machining or grinding to a depth of at least $\frac{1}{16}$ in. (1.6 mm) followed by inspection by a magnetic particle or liquid penetrant method in accordance with KE-233.

TABLE KF-630
POSTWELD HEAT TREATMENT REQUIREMENTS FOR QUENCHED AND TEMPERED MATERIALS IN TABLE KCS-1 (U.S. Customary Units)

Spec. No.	Grade or Type	P-No. and Group No.	Thickness Requiring PWHT, in.	Postweld Heat Treatment Temp., °F	Holding Time	
					hr/in.	min. hr
Plate Steels						
SA-517	Grade A	11B Gr. 1	Over 0.58	1,000–1,100	1	$^1/_4$
SA-517	Grade B	11B Gr. 4	Over 0.58	1,000–1,100	1	$^1/_4$
SA-517	Grade E	11B Gr. 2	Over 0.58	1,000–1,100	1	$^1/_4$
SA-517	Grade F	11B Gr. 3	Over 0.58	1,000–1,100	1	$^1/_4$
SA-517	Grade J	11B Gr. 6	Over 0.58	1,000–1,100	1	$^1/_4$
SA-517	Grade P	11B Gr. 8	Over 0.58	1,000–1,100	1	$^1/_4$
SA-533	Grades B & D, Cl. 3	11A Gr. 4	Over 0.58	1,000–1,050	$^1/_2$	$^1/_2$
SA-724	Grades A & B	1 Gr. 4	None	NA [Note (1)]	NA [Note (1)]	NA [Note (1)]
SA-724	Grade C	1 Gr. 4	Over 1.5	1,050–1,100	1	2
Forgings						
SA-372	Grade E, Cl. 70	. . .	— See SA-372 in Section II, Part A for heat treating requirements			
SA-372	Grade F, Cl. 70	. . .				
SA-372	Grade J, Cl. 110	. . .				
SA-508	Grade 4N, Cl. 1	11A Gr. 5	Note (2)	1,000–1,050	$^1/_2$	$^1/_2$
SA-508	Grade 4N, Cl. 3	3 Gr. 3	Note (2)	1,000–1,050	$^1/_2$	$^1/_2$

NOTES:
(1) NA indicates not applicable.
(2) PWHT is neither required nor prohibited. Consideration should be given to the possibility of temper embrittlement. The cooling rate from PWHT, when used, shall not be slower than that obtained by cooling in still air.

KF-614 Weld Finish

All weld deposits shall merge smoothly into the base metal without abrupt transitions.

KF-615 Toughness Requirements for Welds

For welded vessels in which the welds are not subject to quenching and tempering, the deposited weld metal and the heat-affected zone shall meet the impact test values of KM-234 when tested in accordance with Article KT-2. When welds are quenched and tempered, they shall be impact tested as required by Article KM-2.

KF-620 TEMPORARY WELDS WHERE NOT PROHIBITED

(a) Temporary welds for pads, lifting lugs, and other nonpressure parts, as well as temporary lugs for alignment, shall be made by qualified welders and procedures in accordance with KF-210.

(b) Temporary welds shall be removed and the metal surface shall be restored to a smooth contour. The area shall be examined by a magnetic particle or liquid penetrant method in accordance with KE-233. If repair welding is required, it shall be documented in accordance with KE-210. Temporary welds and repair welds shall be considered the same as all other welds insofar as requirements for qualified operators and procedures and for heat treatment are concerned.

KF-630 POSTWELD HEAT TREATMENT

(a) Vessels or parts of vessels constructed of quenched and tempered steels shall be postweld heat treated when required in Table KF-630. When determining the thickness requiring postweld heat treatment in Table KF-630 for clad or weld deposit overlayed vessels or parts of vessels, the total thickness of the base material shall be used.

(b) Postweld heat treatment shall be performed in accordance with Article KF-4, as modified by the requirements of Table KF-630. In no case shall the PWHT temperature exceed the tempering temperature. PWHT and tempering may be accomplished concurrently. Where accelerated cooling from the tempering temperature is

TABLE KF-630M
POSTWELD HEAT TREATMENT REQUIREMENTS FOR QUENCHED AND TEMPERED MATERIALS IN TABLE KCS-1 (SI Units)

Spec. No.	Grade or Type	P-No. and Group No.	Thickness Requiring PWHT, mm	Postweld Heat Treatment Temp., °C	Holding Time hr/25 mm	Holding Time min. hr
Plate Steels						
SA-517	Grade A	11B Gr. 1	Over 14.7	540–595	1	1/4
SA-517	Grade B	11B Gr. 4	Over 14.7	540–595	1	1/4
SA-517	Grade E	11B Gr. 2	Over 14.7	540–595	1	1/4
SA-517	Grade F	11B Gr. 3	Over 14.7	540–595	1	1/4
SA-517	Grade J	11B Gr. 6	Over 14.7	540–595	1	1/4
SA-517	Grade P	11B Gr. 8	Over 14.7	540–595	1	1/4
SA-533	Grades B & D, Cl. 3	11A Gr. 4	Over 14.7	540–565	1/2	1/2
SA-724	Grades A & B	1 Gr. 4	None	NA [Note (1)]	NA [Note (1)]	NA [Note (1)]
SA-724	Grade C	1 Gr. 4	Over 38	565–595	1	2
Forgings						
SA-372	Grade E, Cl. 70	. . .	See SA-372 in Section II, Part A for heat treating requirements			
SA-372	Grade F, Cl. 70	. . .				
SA-372	Grade J, Cl. 110	. . .				
SA-508	Grade 4N, Cl. 1	11A Gr. 5	Note (2)	540–565	1/2	1/2
SA-508	Grade 4N, Cl. 3	3 Gr. 3	Note (2)	540–565	1/2	1/2

NOTES:
(1) NA indicates not applicable.
(2) PWHT is neither required nor prohibited. Consideration should be given to the possibility of temper embrittlement. The cooling rate from PWHT, when used, shall not be slower than that obtained by cooling in still air.

required by the material specification, the same minimum cooling rate shall apply to PWHT.

(c) All welding of connections and attachments shall be postweld heat treated whenever required by Table KF-630, based on the greatest thickness of material at the point of attachment to the head or shell (see KF-402.1 and KF-402.2).

(d) Furnaces shall be provided with suitable equipment for the automatic recording of temperatures. The metal temperature of the vessel or vessel part during the holding period shall be recorded and shall be controlled within ±25°F (±14°C).

(e) Parts or entire vessels may be rapidly cooled after PWHT by spraying or immersion when temper embrittlement is of concern. See KM-240 for heat treatment certification requirements.

KF-640 EXAMINATION AND TESTING

KF-641 Examination After Heat Treatment

After final heat treatment, such vessels shall be examined for the presence of cracks on the outside surface of the shell and heads and on the inside surface where practicable. This examination shall be made in accordance with KE-233.

KF-642 Check of Heat Treatment by Hardness Testing

After final heat treatment, quenched and tempered materials shall be subjected to Brinell hardness tests. The readings shall be taken at a minimum of three locations representing the approximate center and each end of the components. The axial interval between each location shall not exceed 5 ft (1.5 m). Four readings shall be taken equally spaced around the circumference at each of these locations. The average Brinell hardness at any location where hardness is measured shall not vary by more than 40 HB.[1]

KF-650 STAMPING AND REPORTS

The provisions for stamping and reports in Part KS shall apply to pressure vessels constructed in whole or

[1] Other hardness testing methods may be used and converted to Brinell numbers by means of the table in ASTM E 140.

in part of quenched and tempered steels, except that the use of nameplates is mandatory for shell thicknesses below $\frac{1}{2}$ in. (13 mm). Nameplates are preferred on vessels of quenched and tempered steels in thicknesses above $\frac{1}{2}$ in. (13 mm) instead of stamping. In addition to the required marking, the letters UQT shall be applied below the symbol (see KF-601).

ARTICLE KF-7
SUPPLEMENTARY REQUIREMENTS FOR MATERIALS WITH WELDING RESTRICTIONS

KF-700 SCOPE

This Article gives additional requirements for forged vessels and vessel components fabricated of materials in which welding is restricted.

KF-710 REPAIR OF DEFECTS

KF-711 Localized Thin Areas

Surface defects may be removed by blend grinding subject to the restrictions of KE-211.

KF-712 Repair of Defects by Welding

Materials not permitted by Part KM for welded construction may be repaired by welding if *all* of the following conditions are met:

(a) The carbon content is less than or equal to 0.40% by heat analysis.

(b) Repair welding is not prohibited by either Part KM or the material specification listed in Section II, Part A.

(c) Both the user and Material Manufacturer or the Manufacturer agree to repair welding.

(d) The repair welding is per a qualified welding procedure specification and performed by welders or welding operators qualified in accordance with Section IX.

(e) The suitability of the electrode and procedure, including preheat and postheat, shall be established by making a groove weld specimen as shown in QW-461.2 and QW-461.3 of Section IX in material of the same analysis and of thickness in conformance with QW-451.1 and QW-451.2 of Section IX. Before welding, the specimen shall be in the same condition of heat treatment as the work it represents, and after welding, the specimen shall be subjected to heat treatment equivalent to that contemplated for the work. Tension and bend specimens, as shown in QW-462.1, QW-462.2, and QW-462.3(a) of Section IX, shall be made. These tests shall meet the requirements of QW-150 and QW-160 of Section IX. The radius of the mandrel used in the guided bend test shall be in accordance with KF-222.1.

(f) For allowable depth of repairs, see Article KE-2.

(g) The finished welds shall be postweld heat treated or given a further heat treatment as required by the applicable material specification. This welding shall be performed prior to final heat treatment except for seal welding of threaded openings, which may be performed either before or after final treatment.

(h) The finished welds shall be examined after postweld heat treatment in accordance with the requirements of Article KE-3.

KF-720 METHODS OF FORMING FORGED HEADS

Except for integral heads as described in KD-640, heads shall be made as separate forgings or by closing the extremities of a hollow forged body to such shape and dimensions as may be required to produce the final form desired.

ARTICLE KF-8
SPECIFIC FABRICATION REQUIREMENTS FOR LAYERED VESSELS

KF-800 SCOPE

(a) The rules of this Division apply to all layered vessels except as specifically modified by this Article. The rules in this Article apply specifically to layered vessels, layered shells, and layered heads.

(b) This Division provides rules for two basic types of layered vessels: those constructed by shrink fitting fabricated layers, and those constructed by fitting and welding concentrically wrapped layers together. For a further discussion of these types of layered vessels, refer to Article KD-8.

(c) Fabrication rules for these two vessel types differ. Paragraphs KF-810 through KF-814 give rules for vessels of shrink-fit construction, while KF-820 through KF-827 give rules for concentrically wrapped, welded layered vessels.

(d) Paragraph KF-830 gives rules for postweld heat treatment that apply to both types of vessel construction.

KF-810 RULES FOR SHRINK-FIT VESSELS

KF-811 Fabrication of Individual Layers

Prior to the shrink-fit assembly process, each layer shall be individually fabricated, heat treated as applicable, and examined in accordance with the rules given for vessels in this Division. If a layer is autofrettaged prior to the shrink-fit process, the rules of Article KF-5 shall apply to the autofrettaged layer. If a layer is rolled and welded, the requirements of Articles KF-2 and KF-4 shall apply to the layer prior to the assembly process. The examination rules of Part KE shall apply to each layer where applicable.

KF-812 Shrink-Fit Process Temperatures

The temperatures needed to produce the design interference fit shall not exceed the tempering temperature of the material. The Manufacturer shall ensure that there will be no loss in the material properties due to the heating process.

KF-813 Assembly Procedure and Report

The Manufacturer shall provide a written procedure that describes in detail the fabrication process steps that will be used to produce the design residual stress distribution. This procedure shall address but is not limited to the following:

(a) The method for accomplishing the stress redistribution shall be identified, together with the necessary process controls.

(b) Variables that are to be controlled to accomplish the design residual stress distribution shall be identified, together with changes in their values necessary to ensure adequate control of the process.

(c) The methods used to measure the amount of residual stress distribution that is achieved, with precision consistent with the criteria of KF-813(b), shall be identified. Reliability of measuring devices shall be ensured through redundancy or other means. If thermally compensated resistance strain gages are used, a minimum of four gages shall be provided.

(d) All measured data from KF-813(a), (b), and (c) shall be documented and reported to the Designer who signs the Manufacturer's Design Report. A copy of the shrink fitting assembly procedure shall also be given to the Designer with this data.

KF-814 Examination of Vessels With Three or More Layers

In addition to the examinations required by KF-811 and KE-400, for vessels containing three or more layers the following examinations are also required. After each shrink fitting operation is completed, the entire surface of the subassembly that will be covered by the next layer in the assembly process shall be given a surface examination in accordance with KE-233.

KF-820 RULES FOR CONCENTRICALLY WRAPPED WELDED LAYERED VESSELS

KF-821 Welding Fabrication Requirements

(a) The inner layer shall be seamless or contain Type No. 1 butt joints (see KF-221). Welds attaching the inner shell layer to the inner head layer shall be Type No. 1 butt joints. The use of permanent backing strips is prohibited.

(b) Type No. 2 butt joints are single-welded butt joints which use the previous layer for backing. These types of joints shall be staggered. They shall not be used as full thickness welds to attach layered section to layered section. Where Type No. 2 butt joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joints for their full length.

(c) Weld joints shall be ground to ensure contact between the weld area and the succeeding layer, before application of the layer.

(d) Category A weld joints in layered shell sections shall be in an offset pattern such that the centers of the welded longitudinal joints of adjacent layers are separated circumferentially by a distance of at least five times the layer thickness in the joint to be welded. Weld categories are described in KE-321.

(e) Category A weld joints in layered heads may be in an offset pattern; if offset, the joints of adjacent layers shall be separated by a distance of at least five times the layer thickness in the joint to be welded.

(f) Category A or B weld joints that attach a layered section to a solid section shall be Type No. 1 butt joints. See Fig. KD-830.6 for some acceptable configurations.

(g) Category B weld joints that attach a layered section to a layered section shall either be Type No. 1 butt joints or shall be in an offset pattern such that the centers of the adjacent weld joints are separated by a minimum of five times the layer thickness to be joined.

KF-822 Welding Procedure Qualification

Requirements for welding qualification and records shall be in accordance with KF-210, except that the layered test plate welding procedure qualification shall be modified as follows:

(a) The minimum and maximum thicknesses qualified by procedure qualification test plates shall be as shown in table QW-451 of Section IX, except that

(1) for category A welds in the layer section of the shell, the qualification shall be based upon the thickness of the thickest individual layer exclusive of the inner shell or inner head

(2) for category B weld procedure qualification, the thickness of the layered test plate need not exceed 3 in. (76 mm), shall consist of at least two layers, but shall not be less than 2 in. (51 mm) in thickness

(3) for category B weld joints made individually for single layers and spaced at least one layer thickness apart, the procedure qualification for category A welds applies

(b) The longitudinal weld joint of the inner shell or inner head and the longitudinal weld joint of layered shell or layered head shall be qualified separately unless it is of the same P-Number material. The weld gap of the longitudinal layer weld joint shall be the minimum width used in the procedure qualification for layers $\frac{7}{8}$ in. (22 mm) and less in thickness.

(c) Circumferential layer-to-layer weld joints, or the layer-to-solid weld joints in a solid head, flange, or end closure, shall be qualified with a simulated layer test plate as shown in Fig. KF-822(a) for layer thicknesses $\frac{7}{8}$ in. (22 mm) and under. A special type of joint tensile specimen shall be made from the layer test coupon as shown in Fig. KF-822(b). Face and root bend specimens shall be made of both the inner and outer weld to the thickness of the layer by cutting the weld to the layer thickness.

KF-823 Welder Performance Qualification

Welding shall be performed only by welders and welding operators who have been qualified in accordance with Section IX. The minimum and maximum thicknesses qualified by any welder test plate shall be as shown in table QW-452 of Section IX.

KF-824 Venting Between Layers

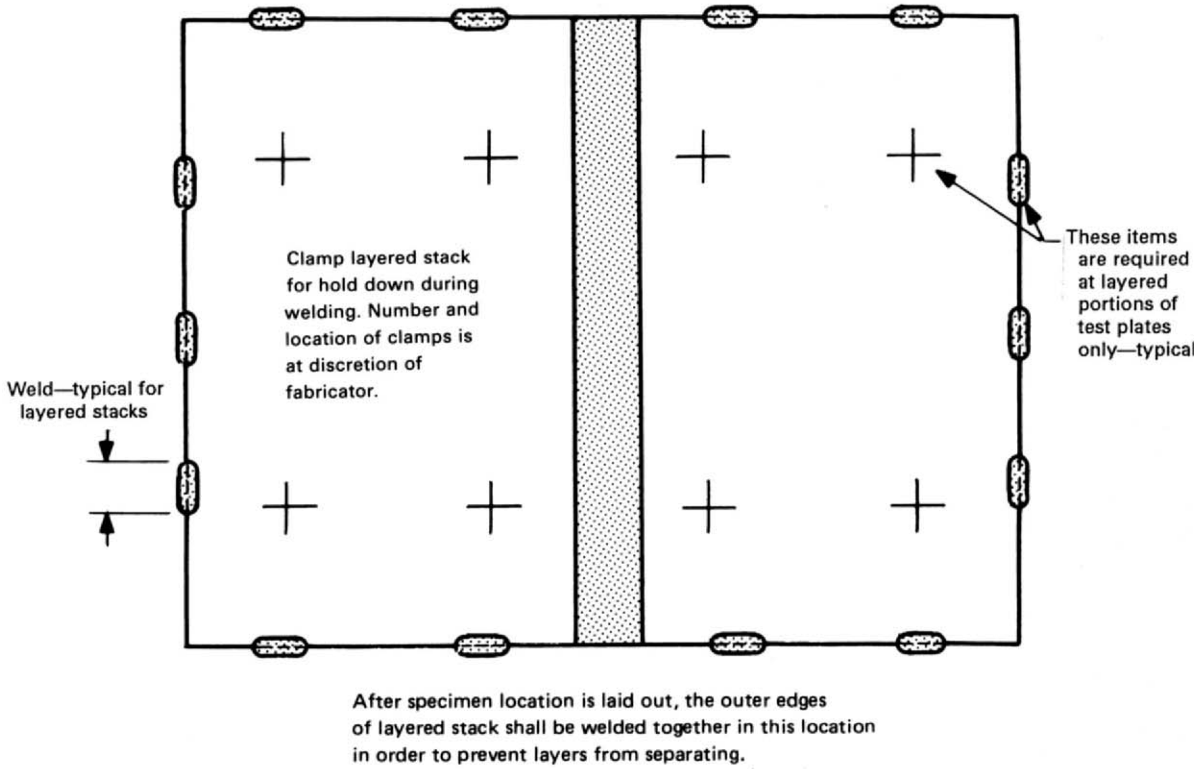
Vent holes shall be provided to detect leakage of the inner shell and to prevent buildup of pressure within the layers as follows:

(a) In each shell course or head segment, a layer may be made up of one or more plates. Each layer plate shall have at least two vent holes $\frac{1}{4}$ in. (6 mm) diameter or larger. Holes may be drilled radially through the multiple layers or may be staggered in individual layer plates.

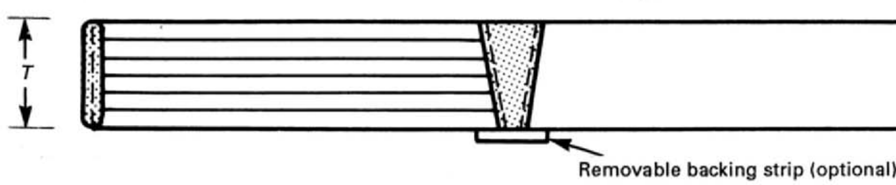
(b) Vent holes shall not be obstructed. If a monitoring system is used, it shall be designed to prevent buildup of pressure within the layers.

KF-825 Nondestructive Examination of Welded Joints

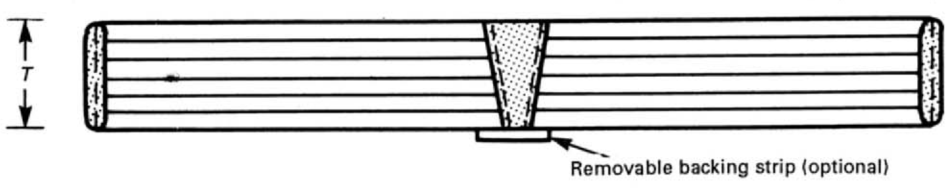
The rules of the following paragraphs supplement and modify the requirements of Part KE. They apply specifically to the nondestructive examination of pressure vessels and vessel parts that are fabricated using layered construction.



(a) Plan-View of Solid-to-Layered and Layered-to-Layered Test Plates



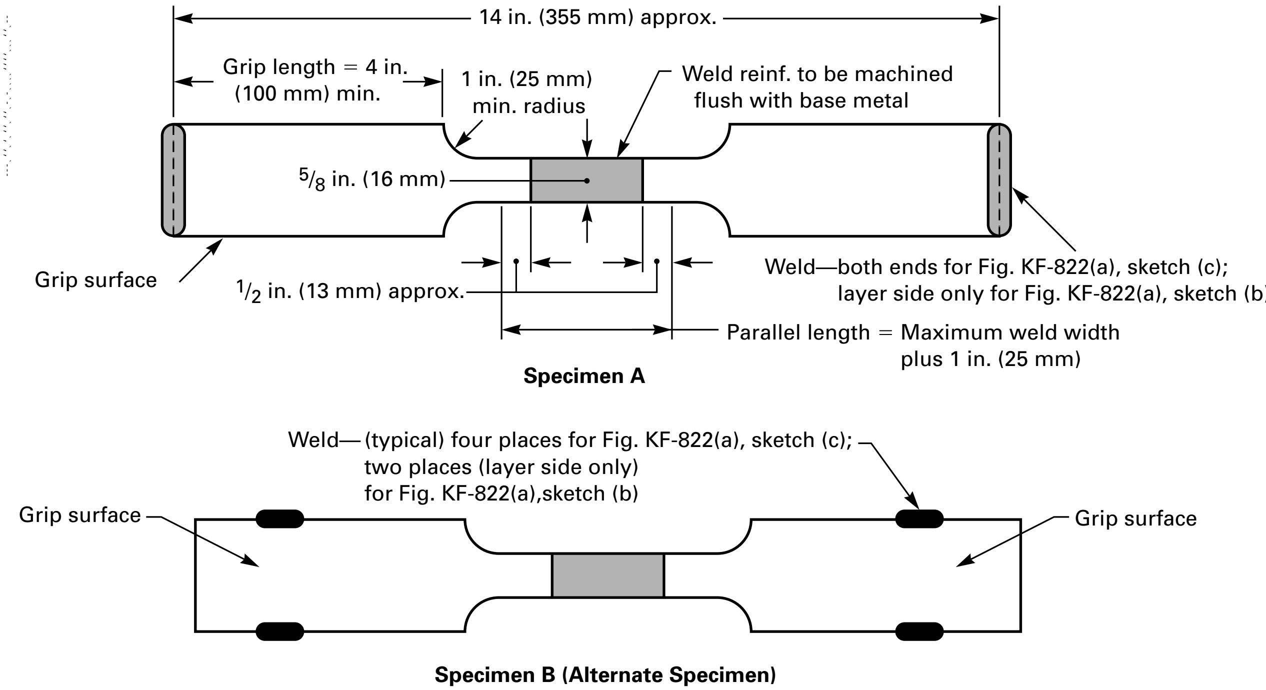
(b) Layered-to-Solid Test Plate



(c) Layered-to-Layered Test Plate

GENERAL NOTE: For $T > 1$ in. (25 mm), multiple specimens per Section IX, QW-151 may be used.

FIG. KF-822(a) SOLID-TO-LAYERED AND LAYERED-TO-LAYERED TEST PLATES



GENERAL NOTE: Specimens A and B are plan views of Fig. KF-822(a), illustrations (b) and (c), and are identical except for locations of grip surfaces and welds. All grip surfaces are to be machined flat.

FIG. KF-822(b) TEST SPECIMENS FOR WELD PROCEDURE QUALIFICATION

KF-825.1 Inner Shells and Inner Heads. Category A and B joints in the inner shells of layered shell sections and in the inner heads of layered heads shall be examined throughout their entire length in accordance with Article KE-3 before application of subsequent layers.

KF-825.2 Category A Weld Joints in Layers

(a) Category A joints in layers $\frac{1}{4}$ in. (6 mm) through $\frac{5}{16}$ in. (8 mm) in thickness welded to the previous surface shall be examined for 100% of their length in accordance with Article KE-3 by the magnetic particle or liquid penetrant method only.

(b) Category A joints in layers over $\frac{5}{16}$ in. (8 mm) in thickness welded to the previous layer shall be examined for 100% of their length by both a surface and a volumetric examination in accordance with Article KE-3. For the ultrasonic method, the distance amplitude correction curve or reference level shall be raised by 6 dB for the bottom 10% of the weld thickness.

KF-825.3 Step Welded Girth Joints in Layers

(a) Category B joints in layers $\frac{1}{4}$ in. (6 mm) through $\frac{5}{16}$ in. (8 mm) in thickness shall be spot examined over a minimum of 10% of their length in accordance with Article KE-3 by the magnetic particle or liquid penetrant method. The random spot examination shall be performed as specified in KF-825.8.

(b) Category B joints in layers over $\frac{5}{16}$ in. (8 mm) through $\frac{7}{8}$ in. (22 mm) in thickness shall be examined for 100% of their length in accordance with Article KE-3 by the magnetic particle or liquid penetrant method. In addition, these joints shall be spot examined over a minimum of 10% of their length by the ultrasonic method in accordance with Article KE-3, except that the distance amplitude correction curve or reference level shall be raised by 6 dB for the bottom 10% of the weld thickness. The random spot examination shall be performed as specified in KF-825.8.

(c) Category B joints in layers over $\frac{7}{8}$ in. (22 mm) in thickness shall be examined for 100% of their length by both a surface and volumetric means in accordance with Article KE-3. For ultrasonic examination, the distance amplitude correction curve or reference level shall be raised by 6 dB for the bottom 10% of the weld thickness.

KF-825.4 Through-Thickness Butt Joints

(a) Category B and D joints attaching a solid section to a layered section or a layered section to a layered section shall be examined over their entire length in accordance with Article KE-3.

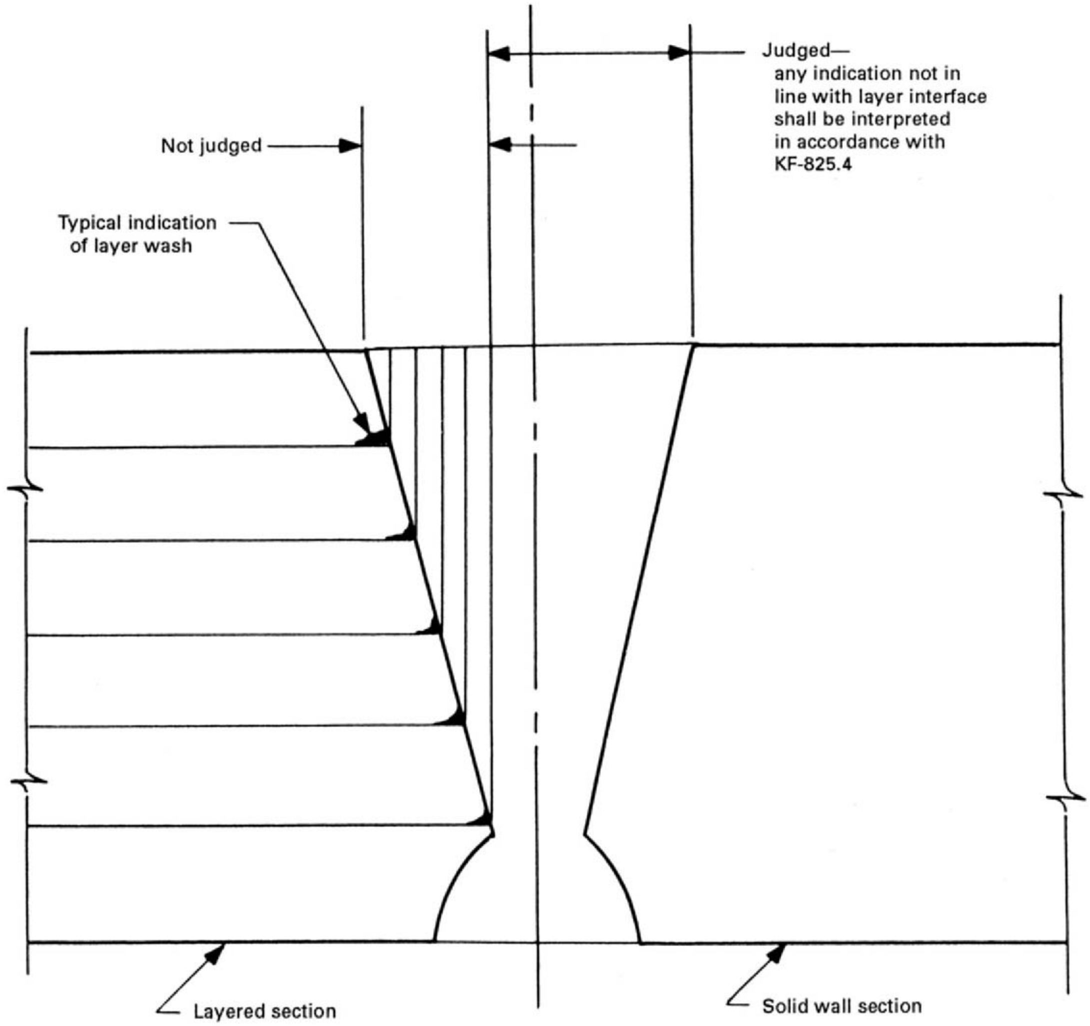


FIG. KF-825.4(a) INDICATIONS OF LAYER WASH

(b) It is recognized that layer wash[1] or acceptable gaps (see KF-826) may show as indications difficult to distinguish from slag on radiographic film. Acceptance shall be based on reference to the weld geometry as shown in Fig. KF-825.4(a). As an alternative, an angle radiographic technique, as shown in Fig. KF-825.4(b), may be used to locate individual gaps in order to determine the acceptability of the indication.

KF-825.5 Flat Head and Tubesheet Weld Joints. Category C joints attaching layered shell or layered heads to flat heads and tubesheets shall be examined to the same requirements as specified for Category B joints in KF-825.3.

KF-825.6 Welds Attaching Nonpressure Parts and Stiffeners. All welds attaching supports, lugs, brackets, stiffeners, and other nonpressure attachments to pressure parts (see Article KD-7) shall be examined on all exposed surfaces by the magnetic particle or liquid penetrant method in accordance with the requirements of Article KE-3. However, the examination required in KF-224 shall be made after any postweld heat treatment.

KF-825.7 Transition Welds

(a) All weld metal buildup in solid wall sections in layered transitions shall be examined over the full surface of the deposit by either a magnetic particle method or by a liquid penetrant method in accordance with Article KE-3.

(b) When such surface weld metal buildup is used in welded joints which require radiographic or ultrasonic

[1] Layer wash is defined as the indications resulting from slight weld penetration at the layer interfaces.

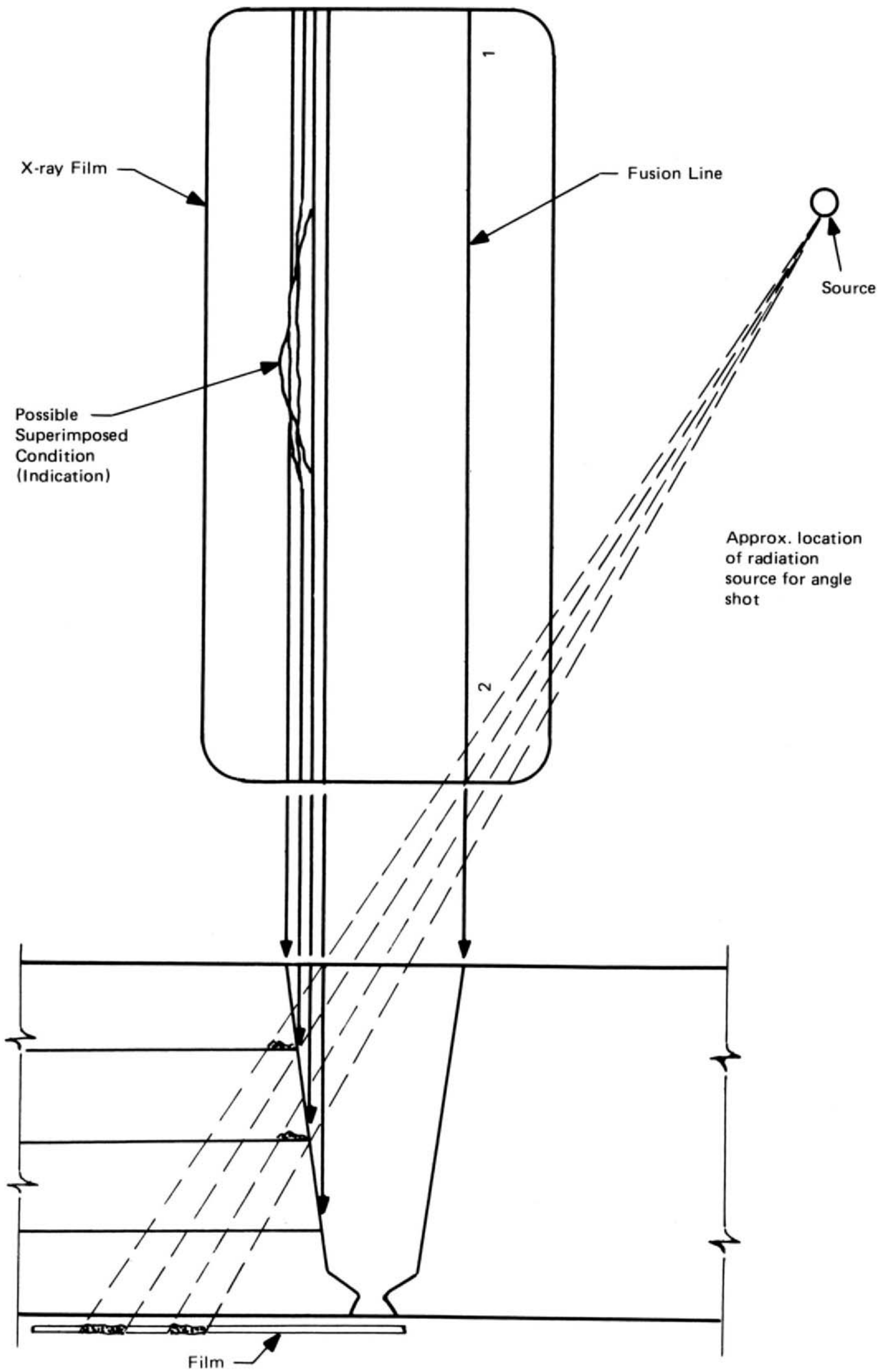


FIG. KF-825.4(b) ANGLED RADIOGRAPHIC TECHNIQUE FOR DETECTING LAYER WASH examination, the weld metal buildup shall be included in the examination.

KF-825.8 Random Spot Examination and Repair of Weld. The random magnetic particle examinations or liquid penetrant examinations required by KF-825.3(a), and the ultrasonic examinations required by KF-825.3(b), shall be performed as follows:

(a) The location of the random spot shall be chosen by the Inspector, except that when the Inspector has been duly notified in advance and cannot be present or otherwise make the selection, the Manufacturer may exercise his own judgment in selecting the random spot or spots. The minimum length of a spot shall be 6 in. (150 mm).

(b) When any random spot examination discloses welding which does not comply with the minimum quality requirements of the applicable paragraphs of Article KE-3, two additional spots of equal length shall be examined in the same weld unit at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or Manufacturer as provided for in the original spot examination.

(c) If either of the two additional spots examined shows welding which does not comply with the minimum quality requirements of the applicable paragraphs of Article KE-3, the entire unit of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded or, at the Manufacturer's option, the entire unit of weld represented shall be completely examined and defective welding only need be corrected.

(d) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint or the weld repaired areas shall be random spot examined at one location in accordance with the requirements of KF-825.3(a) and KF-825.3(c).

KF-826 Gaps Between Layers

(a) After weld preparation and before welding circumferential seams, the height of the radial gaps between any two adjacent layers shall be measured at the ends of the layered shell section or layered head section at right angles to the vessel axis, and also the length of the relevant radial gap in inches shall be measured, neglecting radial gaps of less than 0.010 in. (0.25 mm) as nonrelevant. An approximation of the area of the gap shall be calculated as indicated in Fig. KF-826.

(b) In the case of layered spheres or layered heads, if the gaps cannot be measured as required in KF-826(a), measurement of gap heights shall be taken through vent holes (see KF-824) in each layer course to ensure that the height of gaps between any two layers does not exceed the gap permitted in KF-826(c). The spacing of the vent holes shall be such that gap lengths can be determined. In the event an excessive gap height is measured through a vent hole, additional vent holes shall be drilled as required to determine the gap length. There shall be at least two vent holes per layer segment.

(c) The maximum number and size of gaps permitted in any cross section of a layered vessel shall be limited by the most stringent conditions given in KF-826(c)(1) through (c)(5).

(1) Maximum gap between any two layers shall not exceed the value of h given by Eq. (1) or $^3/_{16}$ in. (5 mm), whichever is less:

$$h = 0.55\left(2.5 - \frac{P}{0.67S_y}\right)\left(\frac{0.67S_yR_g}{E}\right) \tag{1}$$

where

E = modulus of elasticity, ksi (MPa)
h = gap between any two layers, in. (mm)
P = design pressure, ksi (MPa)
R_g = outside radius of layer above which the gap is located, in. (mm)
S_y = yield stress at design temperature, ksi (MPa)

(2) Maximum permissible number of gaps and their corresponding arc lengths at any cross section of a layered vessel shall be calculated as follows. Measure each gap and its corresponding length throughout the cross section, h and b; then calculate the value of F for each of the gaps using Eq. (2):

$$F = 0.109\frac{bh}{R_g^2} \tag{2}$$

where

b = length of gap, in. (mm)
F = gap value (dimensionless)
h = gap between any two layers, in. (mm)
R_g = outside radius of layer above which the gap is located, in. (mm)

(3) The total sum of the values of F calculated above shall not exceed the value F_T calculated by Eq. (3):

$$F_T = \frac{1-\nu^2}{E}\left(1.67S_y - \frac{2PR_O^2}{R_O^2 - R_I^2}\right) \tag{3}$$

where

E = modulus of elasticity, ksi (MPa)
P = design pressure, ksi (MPa)
R_I = inside radius of vessel, in. (mm)
R_O = outside radius of vessel, in. (mm)
S_y = yield stress at design temperature, ksi (MPa)
ν = Poisson's ratio

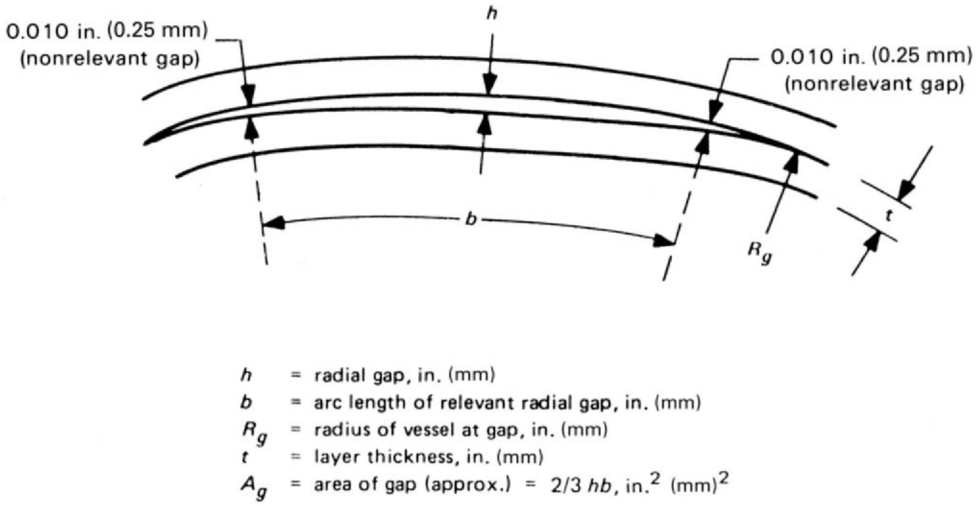


FIG. KF-826 GAP AREA BETWEEN LAYERS

(4) The gap area, A_g, between any two adjacent layers shall not exceed the thickness of the thinner of the two adjacent layers expressed in area units.

(5) The maximum length of any single gap shall not exceed the inside diameter of the vessel. Where more than one gap exists between any two adjacent layers, the sum of the gap lengths between these layers shall not exceed the inside diameter of the vessel.

(d) All measured data from KF-826(a), (b), and (c) shall be documented and reported to the Designer who signs the Manufacturer's Design Report.

KF-827 Circumferential Expansion During Hydrotest

The following measurements shall be taken at the time of the hydrostatic test to check on the contact between successive layers, and the effect of gaps which may or may not be present between layers:

(a) The circumference shall be measured at the midpoint between adjacent circumferential joints, or between a circumferential joint and any nozzle in a shell course. Two sets of measurements are to be taken. The first is to be taken at zero pressure prior to hydrotest. The second set is to be taken during the hydrotest (see KT-330). After the hydrotest pressure has been successfully maintained for a minimum of 5 min, the measurements shall be made while the hydrotest pressure is maintained. The difference in measurements shall be averaged for each course in the vessel and the results recorded as average middle circumferential expansion e_m in inches.

(b) The theoretical circumferential expansion e_{th} of a solid vessel shall be calculated in accordance with KD-822.

(c) Acceptance criteria for circumferential expansion at the hydrotest pressure shall be per KD-822.

(d) All measured data from KF-827(a), (b), and (c) shall be documented and reported to the Designer who signs the Manufacturer's Design Report.

KF-830 HEAT TREATMENT OF WELDMENTS

(a) Postweld heat treatments of layers after the shrink-fit assembly process will cause the residual stress distribution obtained by the shrink fitting operation to be reduced. The residual stress will not be known within the tolerance required in KD-810(a). Therefore, if a postweld heat treatment is given to shrink-fitted layers, no credit shall be taken for the beneficial effects of the prestress obtained by shrink fitting. For alternative rules pertaining to postweld heat treatment of layered vessels, refer to KF-830(b).

(b) When required, pressure parts shall be postweld heat treated in accordance with Articles KF-4 and KF-6; however, completed layered vessels or layered sections need not be postweld heat treated provided all welded joints connect a layered section to a layered section, or a layered section to a solid wall, and all of the following conditions are met.

(1) The thickness referred to in Table KF-402.1 and Table KF-630 is the thickness of one layer. Should more than one thickness of layer be used, the thickness of the thickest layer shall govern.

(2) The finished joint preparation of a solid section or solid nozzle which is required to be postweld heat treated under the provisions of Table KF-402.1 or Table KF-630 shall be provided with a buttered layer of at

least $\frac{1}{4}$ in. (6 mm) thick welding material not requiring postweld heat treatment. Solid sections of P-No. 1 materials need not have this buttered layer. Postweld heat treatment of the buttered solid section shall then be performed prior to attaching to the layered sections. Postweld heat treatment following attachment to the layered section is not required unless the layered section is required to be postweld heat treated.

(3) A multipass welding technique shall be used and the weld layer thickness shall be limited to $\frac{1}{4}$ in. (6 mm) maximum. When materials listed in Table KF-630 is used, the last pass shall be given a temper bead[2] technique treatment.

(4) The postweld heat treating rules in Article KF-4 shall apply to all weld repairs.

[2] A *temper bead welding technique* is when additional weld beads are deposited after completion of the main weld for tempering purposes. These additional beads are deposited only on previous beads without making contact with the base metal, resulting in an over-flush condition. The additional beads are then removed by grinding or other mechanical means.

ARTICLE KF-9
SPECIAL FABRICATION REQUIREMENTS FOR WIRE-WOUND VESSELS AND FRAMES

KF-900 SCOPE

The requirements of this Article apply specifically to pressure vessels consisting of an inner cylindrical shell (or a number of concentric shells) prestressed by a surrounding winding. The end load is not carried by the cylinder(s) or the winding. The winding consists of a wire helically wound in pretension in a number of turns and layers around the outside of the cylinder. These requirements also apply to additional frames used to carry the load from the closures.

The rules of this Article shall be used as a supplement to or in lieu of applicable requirements given in Articles KF-1 through KF-7. When requirements of this Article differ from those of Articles KF-1 through KF-7, they are specifically delineated.

KF-910 FABRICATION REQUIREMENTS

The general and special requirements stated in Articles KF-1, KF-6, KF-7, and KF-8 shall be valid when applicable. The welding fabrication requirements stated in Articles KF-2 through KF-8 shall be replaced by the requirements in KF-911.

KF-911 Welding Fabrication Requirements

Welds and repair welds are not permitted in parts that are prestressed by wire winding and carry pressure loads. However, an exception is made for the welded joints that are necessary to lengthen the wire in order to get an uninterrupted winding. The requirements for these welded wire joints are stated in KF-912.

KF-912 Welded Wire Joints

When it is necessary to get a winding consisting of an uninterrupted length of wire, butt welded joints may be used to join wire lengths. The minimum distance between these joints shall not be less than 6,500 ft (1 980 m), and the average distance not less than 12,000 ft (3 660 m). Welded joints are not permitted in the outermost winding layer. The welded joint shall be carefully ground in order to get a smooth surface and thereby reestablish the original cross-section shape.

The Manufacturer shall measure the reduction in strength of welded wire joints obtained by his welding procedure. The wire force shall be reduced to a corresponding lower level for a minimum of two turns before and after the welded joint.

After welding and before proceeding with fabrication, each joint shall be subjected to a tensile stress level of not less than two-thirds of the specified minimum tensile strength of the nonwelded wire. If the joint breaks, the welding shall be repeated until the strength requirement specified above is fulfilled.

KF-913 Winding Procedure Requirements

Each wire-wound vessel shall be wound in accordance with a detailed wire winding procedure. This procedure shall provide all details relevant to winding, including a description of the winding machine and how tensile force in the wire is applied, controlled, and measured. All winding shall be carried out in accordance with this procedure.

The application of the winding onto the cylinder or the frame shall be carried out in a special winding machine equipped with devices that make it possible to control and measure the tensile force used for applying the wire. This force shall also be recorded on a diagram that shall be filed by the Manufacturer. The measuring devices shall be calibrated at least every 6 months, or at any time there is reason to believe that the measuring devices are erroneous.

The winding procedure shall include a calculated wire force (see KD-912) that shall be used for each winding layer. Measurements shall be made of the compression at intervals specified in the program and the results compared with the calculations. The measurements shall be made using methods that guarantee a result with adequate accuracy. If differences are noted between specified and measured compression at these checkpoints and there is reason to presume that the specified final compression will not be reached if the original program is followed, a change may be made in the remaining program by increasing the specified wire force by not more than 10%. The final difference between originally specified and measured compression shall not exceed 5%.

The wire end shall be properly locked to prevent unwrapping.

ARTICLE KF-10 04

DELETED

PART KR
PRESSURE RELIEF DEVICES

ARTICLE KR-1
GENERAL REQUIREMENTS

KR-100 PROTECTION AGAINST OVERPRESSURE

All pressure vessels within the scope of this Division shall be provided with protection against overpressure according to the requirements of this Part. Combination units (such as heat exchangers with shells designed for lower pressures than the tubes) shall be protected against overpressure from internal failures. The User or his Designated Agent shall be responsible for establishing a procedure for sizing and/or flow capacity calculations for the device and associated flow paths, as well as changes in fluid conditions and properties as appropriate. These calculations shall be based on the most severe credible combinations of final compositions and resulting temperature. Alternatively, sizing shall be determined on an empirical basis by actual capacity tests with the process in question at expected relieving conditions. The User shall be responsible for providing or approving the assumptions used in all flow capacity calculations.

KR-110 DEFINITIONS

Unless otherwise defined in this Division, definitions relating to pressure relief devices in Section 2 of ASME PTC 25, Pressure Relief Devices, shall apply.

Assembler: a person or organization who purchases or receives from a Manufacturer the necessary component parts or valves and who assembles, adjusts, tests, seals, and ships pressure relief valves certified under this Division, at a geographical location other than and using facilities other than those used by the Manufacturer. An Assembler may be organizationally independent of a Manufacturer, or may be wholly or partly owned by a Manufacturer.

coincident disk temperature (supplied to the rupture disk manufacturer): the expected temperature of the disk when a specified overpressure condition exists, and the disk is expected to rupture.

combination device: one rupture disk in series with one pressure relief valve.

compressibility factor: the ratio of the specific volume of a given fluid at a particular temperature and pressure to the specific volume of that fluid as calculated by ideal gas laws at that temperature and pressure.

gas: for the purpose of Part KR, a gas shall be defined as a fluid that undergoes a significant change in density as it flows through the pressure relief device.

liquid: for the purpose of Part KR, a liquid shall be defined as a fluid that does not undergo a significant change in density through the pressure relief device.

Manufacturer: within the requirements of Part KR, a Manufacturer is defined as a person or organization who is completely responsible for design, material selection, capacity certification when required, and manufacture of all component parts, assembly, testing, sealing, and shipping of pressure relief valves certified under this Division of the Code.

manufacturing design range: a range of pressure within which a rupture disk will be stamped as agreed upon between the rupture disk Manufacturer, and the User or his Agent. The range shall have a minimum and a maximum burst pressure specified. If the rupture disk is used as the primary safety relief device, caution should be taken in determining the disk manufacturing range so that the stamped bursting pressure of the disk will not exceed the design pressure of the vessel.

nonreclosing pressure relief device: a pressure relief device designed to remain open after operation.

overpressure: a pressure increase over the set pressure of a pressure relief valve, usually expressed as a percentage of set pressure.

pressure relief valve: a passive pressure relief device that is actuated by static inlet pressure. The opening is characterized by a rapid opening (pop action), or by opening in proportion to the difference between the static pressure and the set pressure of the valve, depending on the valve design and the application. A pressure relief valve is also designed to reclose to prevent further discharge of fluid after the inlet pressure decreases below the set pressure of the valve. Also referred to as a safety relief valve, safety valve, relief valve, and pop off valve.

pressure relief valve set pressure: that pressure which causes the valve stem to lift at least 5% of its full travel.

rupture disk: the rupture disk is the pressure retaining and pressure sensitive element of a rupture disk device. The failure of the rupture disk is the cause of the opening of the rupture disk device. Rupture disks need not be flat round disks, as long as their design configuration meets the design burst pressure and flow capacity requirements.

rupture disk device: a nonreclosing differential pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure retaining disk. The rupture disk device includes the rupture disk, the rupture disk holder, and all other components that are required for the device to function in the prescribed manner. The holder is the structure which encloses, clamps, and seals the rupture disk in position.

KR-120 TYPES OF OVERPRESSURE PROTECTION

Pressure relief valves, rupture disks, flow paths, or vents directly or indirectly open to the atmosphere, or inherent overpressure protection in accordance with KR-125, may be used for overpressure protection. The overpressure limits specified in KR-150 shall apply to these devices.

KR-121 Rupture Disk Devices

Because of the high pressures associated with this Division, it may be impractical to accomplish full-scale flow capacity performance testing and certification of pressure relieving devices. For this reason, rupture disk devices may be the more commonly used means of overpressure protection for vessels within the scope of this Division. All rupture disks shall meet the requirements of Article KR-2.

The use of rupture disk devices may be advisable when very rapid rates of pressure rise may be encountered, or where the relief device must have intimate contact with the process stream. Intimate contact may be required to overcome inlet line fouling problems or to ensure that the temperature of the disk is the same as the interior temperature of the vessel.

KR-122 Pressure Relief Valves

All pressure relief valves shall meet the requirements of Article KR-3, and shall be flow capacity performance tested and certified in accordance with Article KR-5, except in the case where their opening is not required to satisfy the overpressure limits given in KR-150. See KR-123(c) for further discussion about the use of relief valves in parallel with rupture disks.

KR-123 Combinations

A rupture disk device used in combination with a pressure relief valve may be advisable on vessels containing substances that may render a pressure relief valve inoperative by fouling, or where a loss of valuable material by leakage should be avoided, or where contamination of the atmosphere by leakage of noxious, flammable, or hazardous fluids must be avoided.

(a) Multiple rupture disk devices in parallel shall not be used on the inlet side of a pressure relief valve.

(b) When a combination device is used, both the rupture disk device and the pressure relief valve shall meet the applicable requirements of Part KR. The rupture disk device shall be installed to prevent fragments from the rupture disk from interfering with the proper operation of the pressure relief valve. For additional requirements, see KR-220 and KR-340.

(c) A rupture disk device may be used in parallel with a pressure relief valve whose set pressure is lower than the rupture disk when it is important to limit the quantity of a release or it is impractical to certify the flow capacity of the pressure relief valve under the rules of this Division. The calculated flow capacity of the rupture disk device acting alone shall be adequate to meet the requirements of KR-150, and the rupture disk device shall meet all the

applicable requirements of this Part. With the exception of the flow capacity certification, the pressure relief valve shall meet all the requirements of this Part.

KR-124 Requirements for Pressure Retaining Components

All components subject to the design pressure shall meet the requirements of this Division; requirements for the pressure relief valve seat, spring, and valve stem are given in Article KR-3, and requirements for the rupture disk component are given in Article KR-2. Components that are subject to pressures lower than the design pressure when the pressure relief device opens shall meet the requirements of this Division or other Divisions of Section VIII.

KR-125 Inherent Overpressure Protection

Overpressure protection need not be provided when the source of pressure is external to the vessel and when the source of pressure is under such positive control that the pressure in the vessel cannot exceed the design conditions except as permitted in KR-150.

KR-126 Intensifier Systems

In the case where a vessel is pressurized by an intensifier system whose output pressure to the vessel is a fixed multiple of the supply pressure, the pressure relief device may be located on the low pressure supply side of the intensifier if all the following requirements are met:

(a) There shall be no intervening stop valves or check valves between the driving chamber(s) and the relief device(s).

(b) Heating of the discharge fluid shall be controlled to prevent further pressure increase which would exceed vessel design conditions.

(c) The discharge fluid shall be stable and nonreactive (water, hydraulic fluid, etc.).

(d) The material being processed in downstream equipment is stable and nonreactive, or is provided with a suitable secondary vent system which will effectively prevent transfer of secondary energy sufficient to overpressure the vessel.

The Designer is cautioned to consider the effects of leaking check valves in such systems.

KR-130 SIZE OF OPENINGS AND NOZZLES

The flow characteristics of the entire pressure relieving system shall be part of the relieving capacity calculations. The size of nozzles and openings shall not adversely affect the proper operation of the pressure relieving device.

KR-140 INTERVENING STOP VALVES

There shall be no intervening stop valves between the vessel and any overpressure protection device associated with the vessel, except as permitted in KR-141.

A full-area stop valve may be placed on the discharge side of a pressure relieving device when its discharge is connected to a common header with other discharge lines from other pressure relief devices on vessels that are in operation, so that this stop valve when closed will prevent a discharge from any connected operating vessels from backing up beyond the valve so closed. Such a stop valve shall be so arranged that it can be locked or sealed in either the open or closed position by an authorized person. Under no condition shall this valve be closed while the vessel is in operation.

KR-141 Dual Overpressure Protection

Where it is desirable to perform maintenance on relief devices without shutting down the process, a full-area three-way transfer valve may be installed on the inlet of the relief device(s). The design of the transfer valve and relief devices must be such that the requirements of KR-150 are met at any position of the transfer valve. Alternatively, the User may elect to install stop valves in each branch, but so controlled that one branch is open at all times and the requirements of KR-150 are always met while the process is in operation.

KR-150 PERMISSIBLE OVERPRESSURES

The aggregate capacity of the safety relief devices, open flow paths, or vents shall be sufficient to prevent overpressures in excess of 10% above the design pressure of the vessel when the safety relief devices are discharging.

The Designer shall consider the effects of the pressure drop in the overpressure protection system piping during venting when specifying the set pressures and flow capacities of pressure relief valves and rupture disk devices. When multiple pressure relief devices can discharge through a common stack or vent path, the maximum back pressure that can exist during simultaneous releases at the exit of each pressure relief device shall not impair its operation.

KR-160 SET PRESSURES

KR-161 Single Pressure Relief Device

A single safety relief device shall open at a nominal pressure not exceeding the design pressure of the vessel at the operating temperature, except as permitted in KR-162.

KR-162 Multiple Pressure Relief Devices

If the required discharging capacity is supplied by more than one device, only one need be set to operate at a pressure not exceeding the design pressure of the vessel. The additional device or devices may be set at a higher pressure but not to exceed 105% of the design pressure of the vessel. The requirements of KR-150 shall also apply.

KR-163 Pressure Effects to Be Included in the Setting

The pressure at which any device is set shall include the effects of superimposed back pressure through the pressure relief device and the vent system (see KR-150).

ARTICLE KR-2
REQUIREMENTS FOR RUPTURE DISK DEVICES

KR-200 MATERIALS FOR RUPTURE DISK DEVICES

Rupture disks may be fabricated from either ductile or brittle materials. The materials used in the rupture disk holder shall meet all the requirements of this Division for pressure boundary components.

KR-201 Marking and Stamping Requirements

Every rupture disk shall have a stamped bursting pressure within a manufacturing design range at a specified disk temperature. It shall be marked with a lot number, and shall be certified by its Manufacturer to burst within a tolerance of ±5% of its stamped bursting pressure at the coincident disk temperature. A lot of rupture disks shall consist of all disks manufactured from the same lot of material, made in the same production run, and having the same size and stamped bursting pressure. (See also Article KR-4.)

KR-202 Burst Testing Requirements

For a given lot of rupture disks, the stamped bursting pressure within the manufacturing design range at the coincident disk temperature shall be derived as follows. All the tests of disks for a given lot shall be made in a holder of the same form and dimensions as that with which the disk is to be used. At least four but not less than 10% of the rupture disks from each lot shall be burst tested, to verify that the stamped bursting pressure falls within the manufacturing design range at the coincident disk temperature of these four tests, including a minimum of one burst test at room temperature and a minimum of two burst tests within 25°F (14°C) of the coincident disk temperature. The stamped rating of the rupture disk shall be the average of the bursts at specified disk temperature.

KR-210 FLOW CAPACITY RATING

The flow capacity of the rupture disk device shall be demonstrated by either calculations or by certification testing to meet the requirements of KR-150.

(a) The calculated capacity rating of a rupture disk device shall not exceed a value based on the applicable theoretical formula for the various media multiplied by a coefficient of discharge:

$$K_D = 0.62$$

The area used in the theoretical formula shall be the minimum net area after the rupture disk burst.

The Designer is cautioned that normal capacity calculations may not be applicable for supercritical fluids. Flow through the entire relieving system shall be analyzed with due consideration for the wide variation of physical properties which will occur due to the wide range of flowing pressures.

(b) In lieu of the method for capacity rating given in KR-210(a), the Manufacturer may have the capacity of a given rupture disk device design certified for the K_D coefficient in general accordance with the applicable procedures of Article KR-5. Rupture disks may be certified as to burst pressure, provided the test stand has enough volume to provide a complete burst. The coefficient of discharge K_D may be established at a lower pressure using a suitable fluid. The Designer is cautioned, however, to consider the critical point and nonlinear thermodynamic properties of the fluid used in service at or near the design pressure.

KR-220 RUPTURE DISK DEVICES USED IN COMBINATION WITH FLOW CAPACITY CERTIFIED PRESSURE RELIEF VALVES

KR-221 Rupture Disk Devices Installed Upstream of Flow Capacity Certified Pressure Relief Valves

A rupture disk device may be installed between a pressure relief valve and the vessel, provided the requirements of KR-221(a) through (g) are met.

(a) The combination of the spring loaded pressure relief valve and the rupture disk device meets the requirements of KR-150.

(b) The stamped capacity of a pressure relief valve is multiplied by a factor of 0.90 of the rated relieving capacity of the valve alone, or the capacity of the combination of the rupture disk device and the pressure relief valve may be established according to KR-560.

(c) The volume between the rupture disk device and the pressure relief valve is provided with a means to prevent pressure buildup between the rupture disk and the pressure relief valve, or the series combination is provided with a second rupture disk device in parallel whose burst pressure is 116% of design pressure.

(d) The opening provided through the rupture disk after burst is sufficient to permit a flow equal to the capacity of the valve [see KR-221(b)], and there is no chance of interference with proper functioning of the pressure relief valve. In addition, the flow area of the burst rupture disk shall not be less than 90% of the area of the inlet of the valve unless the capacity and functioning of the specific combination of rupture disk and valve have been established by test according to KR-560.

(e) The use of a rupture disk device in combination with a pressure relief valve should be carefully evaluated to ensure that the media being handled and the valve operational characteristics will result in opening action of the valve coincident with the bursting of the rupture disk, so that the requirements of KR-150 are met.

(f) The installation shall ensure that solid material will not collect in the inlet or outlet of a rupture disk which could impair the relieving capacity of the vent system.

(g) Fragmenting and shearing plug type disks shall be provided with an adequate catcher to retain disk parts and prevent interference with proper functioning of the pressure relief valve.

KR-222 Rupture Disk Devices Installed Downstream of Flow Capacity Certified Pressure Relief Valves

A rupture disk device may be installed on the outlet side of a pressure relief valve, provided KR-222(a) through (g) are met.

(a) The pressure relief valve is designed so that the pressure between the valve outlet and the rupture disk does not affect the valve's set pressure. This volume should be vented or drained to prevent accumulation of fluid due to a small amount of leakage from the valve.

(b) The valve and disk combination shall meet the requirements of KR-150.

(c) The stamped bursting pressure of the rupture disk at the coincident temperature, plus the additional pressure in the outlet piping that will occur during venting, shall not exceed the design pressure of the outlet portion of the pressure relief device and any pipe or fitting between the pressure relief valve and the rupture disk device. In addition, the stamped bursting pressure of the rupture disk at the coincident disk temperature plus the pressure developed in the outlet piping during venting shall not exceed the set pressure of the pressure relief valve.

(d) The opening provided through the rupture disk after breakage is sufficient to permit a flow capacity greater than or equal to the rated capacity of the pressure relief valve.

(e) Any piping beyond the rupture disk shall be designed so that it will not be obstructed by the rupture disk or its fragments.

(f) The contents of the vessel are clean fluids, free from gumming or clogging matter, so accumulation in the relief system will not interfere with pressure relief valve function.

(g) The design pressure of the pressure relief valve's bonnet, bellows if any, and exit connection to the rupture disk is greater than or equal to the burst pressure of the disk.

ARTICLE KR-3
REQUIREMENTS FOR PRESSURE RELIEF VALVES

KR-300 GENERAL REQUIREMENTS

(a) The requirements of this Article apply to pressure relief valves within the scope of this Division, including those which do not have to be flow capacity tested and certified; see KR-123(c).

(b) Pressure relief valves shall be the direct acting, spring loaded type.

(c) The set pressure tolerance of pressure relief valves shall not exceed ±3%.

(d) Pressure relief valves meeting the requirements of ASME Boiler and Pressure Vessel Code Section VIII, Division 1 or 2, may be used provided all requirements of this Article are met. If the valve is the primary relief device [see KR-123(c)], the requirements of Article KR-5 and Appendix 4 shall be met.

KR-310 DESIGN REQUIREMENTS

KR-311 Guiding

The design shall incorporate guiding arrangements necessary to ensure consistent opening at the set pressure, and reseat when the inlet pressure decreases to some pressure below the set pressure. Consideration shall be given to the effects of galling and friction on the valve operation.

KR-312 Spring

The spring shall be designed so that the spring compression at full lift of the valve shall not be greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the original free length and the free length measured 10 min after the spring has been compressed to its solid height three times after the valve has been preset at room temperature) shall not exceed 0.5% of the original free length.

KR-313 Seat

If the seat is not integral with the relief valve, it shall be secured to the valve body so that there is no possibility of the seat lifting or separating.

KR-314 Body and Pressure Retaining Components

In the design of the valve body, consideration shall be given to minimizing the effects of deposits. See also KR-124 for requirements for all pressure retaining components.

KR-315 Bonnet

The bonnet of the pressure relief valve shall be vented to prevent accumulation of pressure. Sealing/isolation of the bonnet area from the relieving fluid may be required for protection of the spring assembly from corrosion or solids accumulation.

KR-316 Inlet Fittings

Valves having threaded inlet or outlet connections in accordance with Article KD-6 shall be provided with wrenching surfaces as required to allow for normal installation without damaging operating parts.

KR-317 Sealing of Valve Settings

Means shall be provided in the design of all pressure relief valves for use under this Division for sealing all adjustments which can be made without disassembling the valve before or after installation. Seals shall be installed by the Manufacturer at the time of initial shipment and after field adjustment of the valves by either the Manufacturer or his authorized representative. Seals shall be installed in a manner to prevent changing the adjustment without breaking the seal. For valves larger than NPS $\frac{1}{2}$ (DN 15), the seal shall identify the Manufacturer or Assembler making the adjustment.

KR-318 Drain Requirements

If the design of a pressure relief valve is such that liquid can collect on the discharge side of the disk, the valve shall be equipped with a drain at the lowest point where liquid can collect.

KR-320 MATERIAL SELECTION

KR-321 Seats and Disks

Cast iron seats and disks are not permitted. The seats and disks of pressure relief valves shall be of suitable material to resist corrosion by the fluid to be contained (see KG-311.7), and meet the requirements of KR-324(a), (b), or (c).

KR-322 Guides and Springs

The materials used for guides and springs shall meet the requirements of KR-324(a), (b), or (c). Adjacent sliding surfaces such as guides and disks or disk holders shall both be of corrosion resistant and galling resistant material or shall have a corrosion-resistant coating applied. Galling resistance shall be demonstrated on a prototype valve by popping a valve to full stem lift ten times with subsequent disassembly and inspection showing no indication of galling.

KR-323 Pressure Retaining Parts

Materials used in pressure retaining parts shall be listed in Part KM.

KR-324 Nonpressure-Retaining Parts

Materials used in nozzles, disks, and other parts contained within the external structure of the pressure relief valves shall be one of the following categories:

(a) listed in Section II

(b) listed in ASTM specifications

(c) controlled by the Manufacturer of the pressure relief valve to a specification ensuring control of chemical and physical properties and quality at least equivalent to ASTM standards

KR-330 INSPECTION OF MANUFACTURING AND/OR ASSEMBLY OF PRESSURE RELIEF VALVES

KR-331 Quality

A Manufacturer shall demonstrate to the satisfaction of an ASME designee that manufacturing as applicable; assembling, production, and testing facilities; and quality control procedures ensure that the valves produced by the Manufacturer or Assembler meet the requirements of this Division. For pressure relief valves requiring flow capacity certification (see Article KR-5), it shall also be demonstrated to the satisfaction of an ASME designated organization that there will be close agreement between the performance of random production samples and the performance of those valves submitted for capacity certification.

KR-332 Verification

(a) Manufacturing, assembly, inspection, and test operations, including capacity testing as appropriate, are subject to inspection at any time by an ASME designee.

(b) At the time of the production testing in accordance with KR-340, or the submission of valves for flow capacity certification testing in accordance with Article KR-5, as applicable, the ASME designee and/or its consultants has the authority to reject or require modification of designs which do not conform with the requirements of this Part.

KR-340 PRODUCTION TESTING BY MANUFACTURERS AND ASSEMBLERS

All pressure relief valves manufactured in accordance with this Division shall be tested as described below. Pressure relief valves may be flow capacity tested in accordance with this Article and Article KR-5 [see KR-123(c)].

KR-341 Hydrostatic Testing

The primary pressure retaining parts of each pressure relief valve to which the UV3 Code symbol is to be applied shall be hydrostatically tested to not less than 1.25 times the design pressure of the parts. These tests shall be conducted after all machining operations on the parts have been completed. There shall be no visible signs of leakage. The secondary pressure zone of each closed bonnet valve shall be tested at 1.25 times the stated design pressure of the secondary pressure zone but not less than 0.125 times the design pressure of the primary parts.

KR-342 Test Media

Each pressure relief valve to which the Code symbol is to be applied shall be tested by the Manufacturer or Assembler to demonstrate set pressure of the pressure relief valve and the leak tightness. Valves intended for compressible fluid service shall be tested with air or other suitable gas, and valves intended for incompressible fluid service shall be tested with water or other suitable incompressible fluid (see KG-311.11).

KR-343 Leak Tightness

A leak tightness test shall be conducted at a maximum expected operating pressure, but at a pressure not exceeding the reseating pressure of the valve. When testing with water, a valve exhibiting no visible signs of leakage shall be considered leak tight. The leak rate of the valve tested with a gas shall meet the criteria specified in the User's Design Specification (see KG-311.11).

KR-344 Instrumentation

A Manufacturer or Assembler shall have a documented program for the application, calibration, and maintenance of test gages and instruments.

KR-345 Set Pressure Tolerance

Test fixtures and test drums for pressure relief valves, where applicable, shall be of adequate size and capacity to ensure representative action and response at blowdown ring adjustments intended for installation. Under these conditions, the valve action shall be consistent with the stamped set pressure within a tolerance of ±3%.

KR-346 Flow Capacity Testing

The following sampling schedule of tests applies to production pressure relief valves that are to be flow capacity certified in accordance with Article KR-5; produced, assembled, tested, sealed, and shipped by the Manufacturer or Assembler; and having a normal scope of size and capacity within the capability of ASME accepted laboratories. Production valves for flow capacity and operational testing shall be selected by an ASME designee and the testing shall be carried out in the presence of a representative of the same organization at an ASME accepted laboratory in accordance with the following:

(a) Initial flow capacity certification shall be valid for 1 year, during which time two production valves shall be tested for operation, and stamped flow capacity verified. Should any valve fail to meet performance requirements, the test shall be repeated at the rate of two valves for each valve that failed. Initial flow capacity verification may be extended for 1 year intervals until the valve is in production. Valves having an adjustable blowdown construction shall be adjusted to the position recommended by the Manufacturer for use in service prior to flow testing. This adjustment may be made on the flow test facility.

(b) Thereafter, two valves shall be tested within each 5 year period of time. The valve Manufacturer shall be notified of the time of the test and may have a witness present during the test. Should any valve fail to relieve at or above its stamped flow capacity, or should it fail to meet performance requirements of this Division after adjustments, the test shall be repeated at the rate of two valves for each valve that failed. Valves having an adjustable blowdown construction shall be set in accordance with KR-346(a). These valves shall be furnished by the Manufacturer. Failure of any valve to meet the stamped flow capacity or the performance requirements of this Division shall be cause for revocation within 60 days of the authorization to use the Code symbol on that particular type of valve. During this period, the Manufacturer shall demonstrate the cause of such deficiency and the action taken to guard against future occurrence, and the requirements of KR-346(a) shall apply.

ARTICLE KR-4
MARKING AND STAMPING REQUIREMENTS

KR-400 MARKING

KR-401 Marking of Pressure Relief Valves

Each pressure relief valve shall be plainly marked by the Manufacturer or Assembler with the required data in such a way that the markings will not be obliterated in service. The markings shall be located on a plate securely fastened to the valve. Small valves [less than NPS $\frac{1}{2}$ (DN 15) inlet] may have the nameplate attached with a chain or wire. See KS-130 for methods of application. The marking shall include

(a) the name or identifying trademark of the Manufacturer and/or Assembler, as appropriate

(b) Manufacturer's or Assembler's design or type number

(c) valve inlet size, in. (mm)

(d) set pressure, ksi (MPa)

(e) flow capacity, SCFM (m^3/hr) of air (60°F and 14.7 psia) (16°C and 101 kPa), or gal/min (L/min) of water at 70°F (21°C), if the pressure relief valve is to be tested to have a certified flow capacity; see KR-122 and KR-123(b). If the pressure relief valve is not flow capacity tested and certified, the flow capacity shall be stamped "NONE."

NOTE: In addition, the Manufacturer/Assembler may indicate the flow capacity in other fluids (see KR-530).

(f) year built or, alternatively, a coding may be marked on the valve such that the valve Manufacturer/ Assembler can identify the year built

(g) ASME Code symbol as shown in Fig. KR-401

(h) Use of the Code symbol stamp by an Assembler shall indicate the use of original, unmodified parts in strict accordance with instructions of the Manufacturer of the valve. The nameplate marking shall include the name of the Manufacturer and the Assembler, and the Code symbol stamp shall be that of the Assembler.

FIG. KR-401 OFFICIAL SYMBOL FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD

KR-402 Marking of Rupture Disk Devices

Every rupture disk shall be plainly marked by the Manufacturer in such a way that the marking will not be obliterated in service and will not interfere with the function of the disk. The marking may be placed on the flange of the disk or on a metal tab permanently attached thereto. Alternatively, the marking may be placed on a metal tag packaged with each individual rupture disk, to be attached to the holding fixture at assembly; see KR-201 for additional requirements. The marking shall include the following:

(a) the name or identifying trademark of the Manufacturer

(b) Manufacturer's design, type number, or drawing number

(c) lot number

(d) material

(e) size, in. (mm)

(f) stamped burst pressure, ksi (MPa)

(g) coincident disk temperature, °F (°C)

Items (a), (b), (d), and (e) shall also be marked on the rupture disk holder. See also KR-201.

In lieu of marking all of the listed items on the flange or tab of each rupture disk, the marking may consist of the stamped bursting pressure and a Manufacturer's coding number sufficient to identify each disk with a Certificate which includes the required information, if such a Certificate is supplied for each lot of rupture disks.

KR-403 Marking of Pressure Relief Valves in Combination With Rupture Disk Devices

Pressure relief valves in combination with rupture disk devices shall be marked with the flow capacity established in accordance to KR-220, in addition to the marking of KR-401 and KR-402. The marking may be placed on the valve or on a plate or plates securely fastened to the valve. The marking shall include the marking required by KR-401(a) through (g) and the specific details of the rupture disk device so that the rupture disk device is uniquely identified and specified.

KR-410 USE OF CODE SYMBOL STAMP

Each pressure relief device to which the Code symbol is to be applied shall be fabricated or assembled by a Manufacturer or Assembler who is in possession of a Code symbol stamp (see Fig. KR-401) and a valid Certificate of Authorization, obtainable when the conditions of Article KS-2 have been met.

A Certified Individual (CI) shall provide oversight to ensure that each use of the Code symbol is in accordance with the requirements of this Division. In addition, each use of the Code symbol is to be documented on a Certificate of Conformance Form K-4 as appropriate.

(a) Requirements for the Certified Individual (CI). The CI shall

(1) be an employee of the Manufacturer or Assembler.

(2) be qualified and certified by the Manufacturer or Assembler. Qualifications shall include as a minimum

(a) knowledge of the requirements of this Division for the application of the appropriate Code symbol

(b) knowledge of the Manufacturer's or Assembler's quality program

(c) training commensurate with the scope, complexity, or special nature of the activities to which oversight is to be provided

(3) have a record, maintained and certified by the Manufacturer or Assembler, containing objective evidence of the qualifications of the CI and the training program provided

(b) Duties of the Certified Individual (CI). The CI shall

(1) verify that each item to which the Code symbol is applied meets all applicable requirements of this Division and has a current capacity certification for the UV3 symbol

(2) for UV3 symbol, review documentation for each lot of items to be stamped to verify, for the lot, that requirements of this Division have been completed

(3) sign the appropriate Certificate of Conformance Form K-4, as appropriate, prior to release of control of the item

(c) Certificate of Conformance Form K-4

(1) The appropriate Certificate of Conformance shall be filled out by the Manufacturer or Assembler and signed by the CI. Multiple duplicate pressure relief devices may be recorded on a single entry, provided the devices are identical and produced in the same lot.

(2) The Manufacturer's or Assembler's written quality control program shall include requirements for completion of Certificates of Conformance forms and retention by the Manufacturer or Assembler for a minimum of 5 years.

ARTICLE KR-5
CERTIFICATION OF FLOW CAPACITY OF PRESSURE RELIEF VALVES

KR-500 FLOW CAPACITY CERTIFICATION TESTS

KR-501 Fluid Media

Flow capacity certification tests shall be conducted with liquids, or vapors as appropriate. For fluids which are to be handled near their critical point, or in any region where their thermodynamic properties are significantly nonlinear, or where a change of phase may occur in the valve (flashing), the flow capacity shall be determined from the vapor and liquid capacity data using appropriate correlations and procedures. Saturated water service is addressed in KR-532(a). Alternatively, the flow capacity and design of the overpressure protection system may be specified by the User or his Agent, based on basic data, testing, and demonstration on such actual fluids at expected operating conditions. This information is stated in the User's Design Specification; see KG-311.11.

KR-502 Test Pressures

Flow capacity certification tests shall be conducted at a pressure not to exceed 110% of the set pressure of the pressure relief valve. The reseating pressure shall be noted and recorded. Valves having an adjustable blowdown construction shall be adjusted prior to testing so that the blowdown does not exceed 5% of the set pressure. Flow tests to certify flow capacity tested at a given pressure shall not be extrapolated to a higher pressure.

KR-510 RECERTIFICATION TESTING

When changes are made in the design of a pressure relief valve that affect the flow path, lift, or may affect other performance characteristics of the pressure relief valve, new tests shall be performed in accordance with this Division.

KR-520 PROCEDURES FOR FLOW CAPACITY CERTIFICATION TESTS

KR-521 Three-Valve Method

A flow capacity certification test is required on a set of three valves for each combination of size, design and pressure setting. The stamped flow capacity rating for each combination of design, size, and test pressure shall not exceed 90% of the average flow capacity of the three valves tested. Test valves must be installed with an adequate vent system that will not affect the flow capacity of the valves or cause chatter. The flow capacity of any one of a set of three valves shall fall within a range of ±5% of the average flow capacity. Failure to meet this requirement shall be cause to refuse certification of a particular safety valve design.

KR-522 Slope Method

If a Manufacturer wishes to apply the Code symbol to a design of pressure relief valves, four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures that cover the approximate range of pressures for which the valve will be used or covering the range available at the certified test facility, which shall conduct the tests. The capacities based on these four tests shall be as follows:

(a) For compressible fluids, the slope W/P of the actual measured capacity versus the flow pressure for each test point shall be calculated and averaged:

$$\text{Slope} = \frac{W}{P} = \frac{\text{measured capacity}}{\text{absolute flow pressure}}$$

All values derived from the testing must fall within ±5% of the average value:

$$\text{Minimum slope} = 0.95 \times \text{average slope}$$

$$\text{Maximum slope} = 1.05 \times \text{average slope}$$

If the values derived from the testing do not fall between the minimum and maximum slope values, the authorized observer shall require that additional valves be tested at the rate of two or each valve beyond the maximum and minimum values, with a limit of four additional valves.

The relieving capacity to be stamped on the valve shall not exceed 90% of the average slope times the absolute accumulation pressure:

$$\text{Rated slope} = 0.90 \times \text{average slope}$$

Stamped capacity ≤ rated slope (set pressure × 1.10 + 14.7) psi, (set pressure × 1.10 + 101) kPa

(b) For incompressible fluids, the capacities shall be plotted on log–log paper against the differential (inlet minus discharge pressure) test pressure and a straight line drawn through these four points. If the four points do not establish a straight line, two additional valves shall be tested for each unsatisfactory point, with a limit of two unsatisfactory points. Any point that departs from the straight line by more than 5% should be considered an unsatisfactory point. The relieving capacity shall be determined from this line. The certified capacity shall not exceed 90% of the capacity taken from the line.

KR-523 Coefficient of Discharge Method

KR-523.1 Procedure. Instead of individual flow capacity certification, as provided in KR-521 and KR-522, a coefficient of discharge K_D may be established for a specific pressure relief valve design according to the procedure in KR-523.2 and KR-523.3. This procedure will not be applicable to fluids handled near their critical point, or in any region where their thermodynamic properties are nonlinear. Refer to KR-501.

KR-523.2 Number of Valves. For each design, the pressure relief valve Manufacturer shall submit for test at least three valves for each of three different sizes (a total of nine valves) together with detailed drawings showing the valve construction. Each valve of a given size shall be set at a different pressure.

04 **KR-523.3 Calculation Method.** Tests shall be made on each pressure relief valve to determine its flow capacity, lift, popping, and blowdown pressures and actual flow capacity in terms of the fluid used in the test. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{actual flow}}{\text{theoretical flow}} = \frac{W}{W_T}$$

where theoretical flow is determined quantitatively by testing, and theoretical flow is calculated by the appropriate formula which follows:

For tests with air

(U.S. Customary Units)

$$W_T = 0.356AP\,(M/ZT)^{0.5}\ \text{lbm/hr}$$

(SI Units)

$$W_T = 0.0000271AP\,(M/ZT)^{0.5}\ \text{kg/hr}$$

For tests with other gases:

$$W_T = CAP\,(M/ZT)^{0.5}$$

For tests with water or other incompressible fluids:

(U.S. Customary Units)

$$W_T = 76.1A\sqrt{\rho(P - P_B)}\ \text{lbm/hr}$$

(SI Units)

$$W_T = 0.161A\sqrt{\rho(P - P_B)}\ \text{kg/hr}$$

where

A = actual discharge area through the device during venting, in.^{2} (mm ^{2})

C = constant for gas or vapor based on k, the ratio of specific heats C_P/C_V (refer to Fig. KR-523.3)

(U.S. Customary Units)

$$= 0.520\sqrt{\mathrm{K}\left(\frac{2}{\mathrm{k}+1}\right)^{\left(\frac{\mathrm{k}+1}{\mathrm{k}-1}\right)}}\ \frac{\text{lbm}\sqrt{{}^\circ\text{R}}}{\text{hr ksi.in.}^2}$$

(SI Units)

$$= 0.0000396\sqrt{\mathrm{K}\left(\frac{2}{\mathrm{k}+1}\right)^{\left(\frac{\mathrm{k}+1}{\mathrm{k}-1}\right)}}\ \frac{\text{kg}\sqrt{{}^\circ\text{K}}}{\text{hr MPa mm}^2}$$

M = molecular weight for specific fluid or mixture

P = absolute pressure at inlet at full flow conditions, ksi (MPa)

P_B = absolute back pressure at discharge from valve/rupture disk, ksi (MPa)

T = absolute temperature at inlet, °R = °F + 460 (°K = °C + 273)

W = actual flow, lbm/hr (kg/hr)

W_T = theoretical flow, lbm/hr (kg/hr)

Z = compressibility factor for the specific fluid at the specified conditions

ρ = mass density of fluid, lbm/ft^3 (kg/L)

KR-523.4 Determining Coefficients. The average of the coefficients K_D of all nine tests required shall be multiplied by 0.90, and this product shall be taken as the coefficient K_D of that design. All experimentally determined coefficients K_D shall fall within a range of ±5% of the average K_D found. Failure to meet this requirement

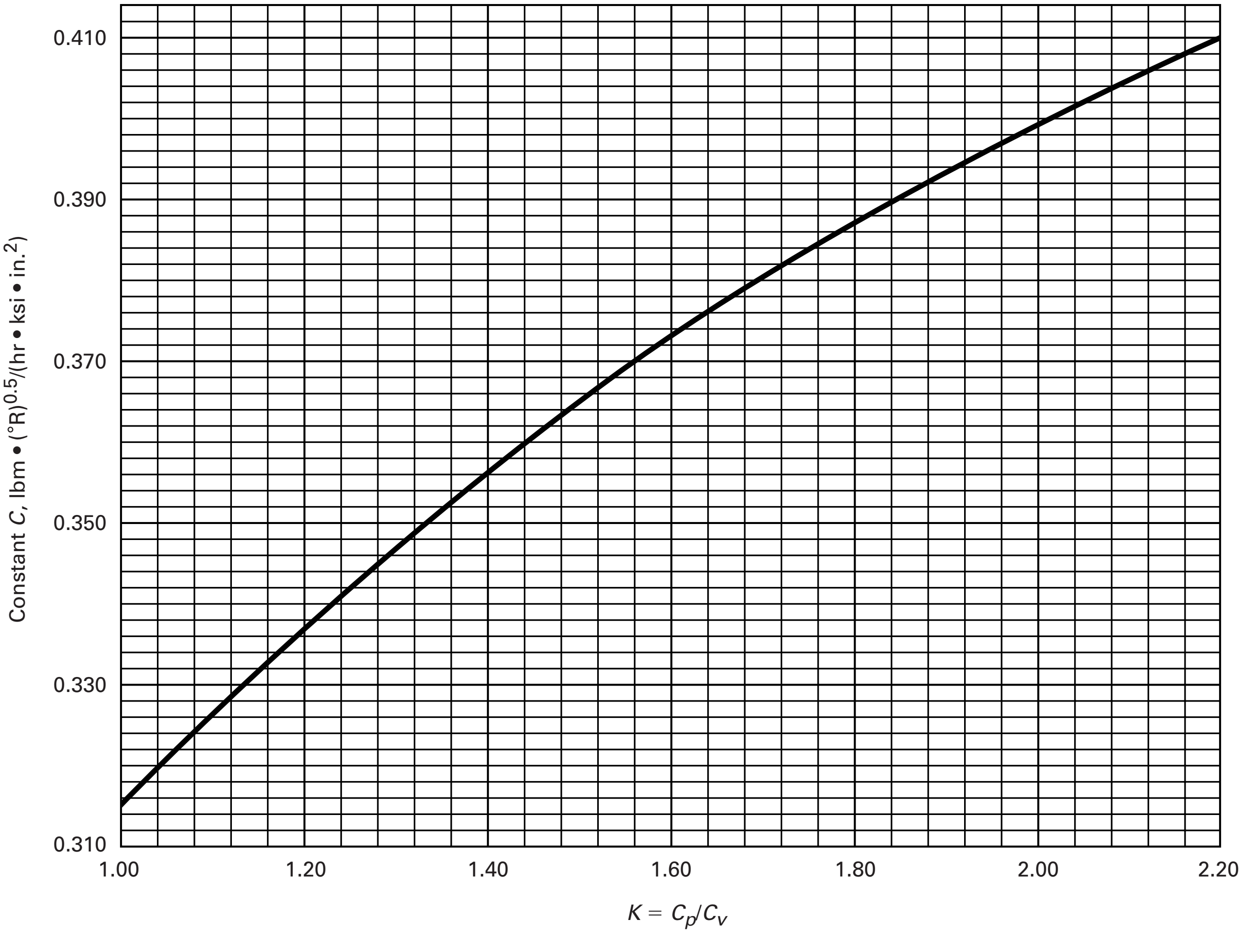


FIG. KR-523.3 CONSTANT C FOR GAS VERSUS SPECIFIC HEAT RATIO
(U.S. Customary Units)

shall be cause to refuse certification of that particular valve design.

KR-523.5 Flow Capacity. The certified relieving flow capacity of all sizes and pressures of a given design, for which K_D has been established under the provisions of KR-523.3, that are manufactured subsequently shall not exceed the value calculated by the appropriate formula in KR-523.3 multiplied by the coefficient K_D (see KR-530). In no case shall the set pressure of the pressure relief valve so certified ever exceed the highest of the test pressures used to determine K_D.

KR-530 FLOW CAPACITY CONVERSIONS

KR-531 Gas and Air Service

For low pressure gases (gases at pressures less than two-thirds of their critical pressure), the capacity of the relief valve in terms of a gas other than that for which its rating was certified shall be determined as follows:

(a) For air:

$$W_a = CK_DAP(M/TZ)^{0.5}$$

where

$$C = 0.356 \frac{\text{lbm}\sqrt{°\text{R}}}{\text{hr ksi in.}^2} \text{ or } \left(0.0000271 \frac{\text{kg}\sqrt{°\text{K}}}{\text{hr MPa mm}^2}\right)$$

M = 28.97
T = 520°R (289°K) when W_a is the rated capacity

(b) For any gas or vapor with linear thermodynamic properties through the valve: 04

$$W = CK_DAP(M/TZ)^{0.5}$$

where

A = actual discharge area of the relief valve, in.^{2} (mm^2)

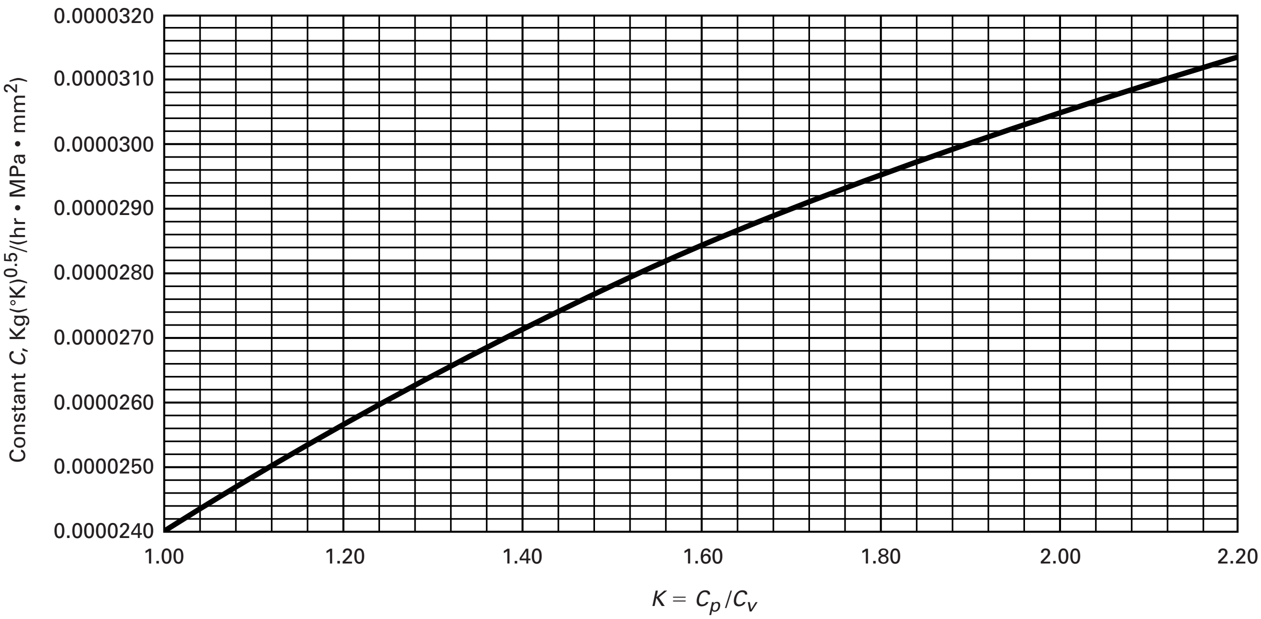


FIG. KR-523.3M CONSTANT *C* FOR GAS VERSUS SPECIFIC HEAT RATIO
(SI Units)

C = constant for gas which is a function of the ratio of specific heats; see Fig. KR-523.3
K_D = coefficient of discharge; see KR-523
M = molecular weight
P = 110% of set pressure plus atmospheric pressure
T = absolute gas temperature at the inlet, °R = °F + 460 (°K = °C + 273)
W = capacity of any gas in lbm/hr (kg/hr)
W_a = rated capacity, converted to lbm/hr (kg/hr) of air at 60°F (16°C), inlet temperature
Z = compressibility factor

(c) Knowing the certified capacity rating of a relief valve including the gas and conditions of the gas for which it certified, it is possible to determine the overall value of the product of K_DA for that given valve by solving the above equations for K_DA. This value of K_DA can then be used to solve for W or W_a at a new set of conditions. For hydrocarbons and other gases where the value of k (C_P/C_V) is not known, assume a value of k = 1.001 and a corresponding value of

$$C = 0.315 \frac{\text{lbm}\sqrt{°\text{R}}}{\text{hr ksi in.}^2} \quad \text{or} \quad 0.000024 \frac{\text{kg}\sqrt{°\text{K}}}{\text{hr MPa mm}^2}$$

(see Fig. KR-523.3).

KR-532 Liquid and High Pressure Gas Service

For gas pressure service above the pressure limits given in KR-531, and for liquid service, additional consideration shall be given to the fact that the acutal flow capacity of a given valve may be influenced by any of the following:

(a) fluid conditions close to or above the critical point

(b) liquid flashing to vapor and other phase changes that may occur causing a two-phase or multi-phase flow regime in the valve

(c) conditions in which decomposition reactions occur and the chemical composition of the resulting fluid cannot be definitively established

The User or his Designated Agent shall be responsible for establishing a procedure for sizing and or flow capacity conversion based on device geometry, as well as the change in fluid conditions and fluid properties during flow through the valve and all associated piping. This procedure shall address the effects of phase changes at particular points in the device as appropriate. If necessary, sizing may be determined on an empirical basis by actual capacity tests with the process in question at expected relieving conditions. The User shall be responsible for providing or approving the assumptions and calculations used in all flow capacity conversions.

KR-540 FLOW CAPACITY CERTIFICATION TESTING REQUIREMENTS FOR TEST FACILITIES

Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25 and Appendix 4. The tests shall be made under the supervision of, and certified by, an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5-year period.

KR-550 TEST DATA REPORTS

Flow capacity test Data Reports for each valve model, type, and size signed by the Manufacturer and the Authorized Observer witnessing the tests shall be submitted to an ASME designee for certification. Where changes are made in the design, flow capacity certification tests shall be repeated.

KR-560 CERTIFICATION OF FLOW CAPACITY OF PRESSURE RELIEF VALVES IN COMBINATION WITH RUPTURE DISK DEVICES

For each combination of pressure relief valve design and rupture disk device design, the pressure relief valve Manufacturer or the rupture disk device Manufacturer may have the flow capacity of the combination certified as prescribed in KR-561 through KR-563.

KR-561 Test Media and Test Pressures

The test media and test pressure requirements are the same as those stated in KR-501 and KR-502.

KR-562 Sizes of Test Units

The valve Manufacturer or the rupture disk device Manufacturer may submit for tests the smallest rupture disk device size with the equivalent size of pressure relief valve that is intended to be used as a combination device. The pressure relief valve to be tested shall have the largest orifice used in that particular pressure relief valve inlet size.

KR-563 Testing Method

Tests may be performed in accordance with the following:

(a) The rupture disk device and pressure relief combination to be tested shall be arranged to duplicate the combination assembly design.

(b) The test shall embody the minimum burst pressure of the rupture disk device design which is to be used in combination with pressure relief valve design. The stamped bursting pressure shall be between 90% and 100% of the stamped set pressure of the valve.

(c) The pressure relief valve (one valve) shall be tested for flow capacity as an individual valve, without the rupture disk device, at a pressure 10% above the valve set pressure. The rupture disk device shall then be installed ahead of the pressure relief valve and the disk burst to operate the valve. The flow capacity test shall be performed on the combination at 10% above the valve set pressure duplicating the individual pressure relief valve flow capacity test.

(d) Tests shall be repeated with two additional rupture disks of the same nominal rating, for a total of three rupture disks to be tested with the single valve. The results of the flow capacity tests shall fall within a range of ±10% of the average flow capacity of the three tests. Failure to meet this requirement shall be cause to require retest for determination of cause of the discrepancies.

(e) From the results of the tests, a combination flow capacity factor shall be determined. The combination flow capacity factor is the ratio of the average flow capacity determined by the combination tests to the flow capacity determined on the individual valve. The combination flow capacity factor shall be used as a multiplier to make appropriate changes in the ASME rated relieving flow capacity of the pressure relief valve in all sizes of the design. The value of the combination flow capacity factor shall not be greater than one. The combination flow capacity factor shall apply only to combinations of the same design of pressure relief valve and the same design of rupture disk device as those tested.

(f) The test laboratory shall meet the requirements of KR-540 and shall submit to an ASME designee the test results for approval of the combination flow capacity factor for certification.

KR-570 OPTIONAL TESTING OF RUPTURE DISK DEVICES AND PRESSURE RELIEF VALVES

KR-571 Larger Sizes

If desired, a valve Manufacturer or a rupture disk device Manufacturer may conduct tests in the same manner as outlined in KR-550 using a rupture disk device larger than the inlet of the pressure relief valve to determine a combination flow capacity factor applicable to larger sizes. If a greater combination flow capacity factor is established and can be certified by a test facility that meets the requirements of KR-540, it may be used for all disks larger than the combination tested, but shall not be greater than one.

KR-572 Higher Pressures

If desired, additional tests may be conducted at higher pressures in accordance with KR-560 to establish a maximum combination flow capacity factor for all pressures higher than the highest tested, but it shall be not greater than one.

PART KE
EXAMINATION REQUIREMENTS

ARTICLE KE-1
REQUIREMENTS FOR EXAMINATION PROCEDURES AND PERSONNEL QUALIFICATION

KE-100 GENERAL

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as modified by the requirements of this Article.

KE-101 Radiographic Examination

Radiographic examination shall be in accordance with Section V, Article 2, except that fluorescent screens are not permitted, the geometric unsharpness shall not exceed the limits of T-285, and the penetrameters of Table KE-101 shall be used in lieu of those shown in Table T-276.

KE-102 Ultrasonic Examination

Ultrasonic examination shall be in accordance with Section V, Article 5.

KE-103 Magnetic Particle Examination

Magnetic particle examination shall be in accordance with Section V, Article 7. If prods are used, the procedure shall include precautions that shall be taken to prevent arc strikes. This procedure shall also contain steps to be followed to remove arc strikes, which may occur so that all affected material has been removed. See KE-210.

KE-104 Liquid Penetrant Examination

Liquid penetrant examination shall be in accordance with Section V, Article 6.

KE-105 Nondestructive Examination Procedures

(a) All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate article of Section V for the particular examination method. Written procedures and records of demonstration of procedure capability and records of personnel qualification to these procedures shall be made available to the Inspector and included in the Manufacturer's Construction Records (see KS-320).

(b) Following any nondestructive examination in which examination materials are applied to the part, the part shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

KE-110 QUALIFICATION AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

KE-111 General

(a) Organizations performing and evaluating nondestructive examinations required by this Division shall use personnel qualified to the requirements of KE-112 through KE-115.

(b) When these services are subcontracted by the certificate holder (see KG-322), the certificate holder shall

TABLE KE-101
THICKNESS, PENETRAMETER DESIGNATIONS, ESSENTIAL HOLES, AND WIRE DIAMETERS (U.S. Customary Units)

Single Wall Material Thickness Range, in.	Penetrameter					
	Source Side			Film Side		
	Designation	Essential Hole	Wire Diameter, in.	Designation	Essential Hole	Wire Diameter, in.
Up to 1/4, incl.	8	2*T*	0.005	8	2*T*	0.005
Over 1/4 to 3/8	12	2*T*	0.008	10	2*T*	0.006
Over 3/8 to 1/2	15	2*T*	0.010	12	2*T*	0.008
Over 1/2 to 5/8	15	2*T*	0.010	12	2*T*	0.008
Over 5/8 to 3/4	17	2*T*	0.013	15	2*T*	0.010
Over 3/4 to 7/8	17	2*T*	0.013	15	2*T*	0.010
Over 7/8 to 1	20	2*T*	0.016	17	2*T*	0.013
Over 1 to 1 1/4	20	2*T*	0.016	17	2*T*	0.013
Over 1 1/4 to 1 3/8	25	2*T*	0.020	20	2*T*	0.016
Over 1 3/8 to 1 1/2	30	2*T*	0.025	25	2*T*	0.020
Over 1 1/2 to 2	35	2*T*	0.032	30	2*T*	0.025
Over 2 to 2 1/2	40	2*T*	0.040	35	2*T*	0.032
Over 2 1/2 to 3	40	2*T*	0.040	35	2*T*	0.032
Over 3 to 4	50	2*T*	0.050	40	2*T*	0.040
Over 4 to 6	60	2*T*	0.063	45	2*T*	0.040
Over 6 to 8	80	2*T*	0.100	50	2*T*	0.050
Over 8 to 10	100	2*T*	0.126	60	2*T*	0.063
Over 10 to 12	120	2*T*	0.160	80	2*T*	0.100
Over 12 to 16	160	2*T*	0.250	100	2*T*	0.126
Over 16 to 20	200	2*T*	0.320	120	2*T*	0.160

verify the qualification of personnel to the requirements of KE-112 through KE-115. All nondestructive examinations required by this subsection shall be performed by, and the results evaluated by, qualified nondestructive examination personnel.

(c) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

KE-112 Qualification Procedure

KE-112.1 Qualification. Personnel performing nondestructive examinations shall be qualified in accordance with SNT-TC-1A,[1] the ASNT Central Certification Program (ACCP),[1] or CP-189.[1] The Employer's[2] written practice shall identify the requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be required, as modified in KE-112.1(a) through (e).

(a) Qualification of Level III nondestructive examination personnel shall be by examination. The basic and method examinations of SNT-TC-1A may be prepared and administered by the Employer, ASNT, or an outside agency. The specific examination of SNT-TC-1A shall

[1] SNT-TC-1A, *Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing*; ACCP, *ASNT Central Certification Program*; and CP-189 are published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228-0518.

[2] *Employer* as used in this Article refers to a U3 certificate holder and organizations who provide subcontracted nondestructive examination services to organizations described above.

TABLE KE-101M
THICKNESS, PENETRAMETER DESIGNATIONS, ESSENTIAL HOLES, AND WIRE DIAMETERS (SI Units)

Single Wall Material Thickness Range, mm	Penetrameter					
	Source Side			Film Side		
	Designation	Essential Hole	Wire Diameter, mm	Designation	Essential Hole	Wire Diameter, mm
Up to 6.4, incl.	8	2*T*	0.13	8	2*T*	0.13
Over 6.4 to 9.5	12	2*T*	0.20	10	2*T*	0.15
Over 9.5 to 12.7	15	2*T*	0.25	12	2*T*	0.20
Over 12.7 to 15.9	15	2*T*	0.25	12	2*T*	0.20
Over 15.9 to 19.1	17	2*T*	0.33	15	2*T*	0.25
Over 19.1 to 22.2	17	2*T*	0.33	15	2*T*	0.25
Over 22.2 to 25.4	20	2*T*	0.41	17	2*T*	0.33
Over 25.4 to 31.8	20	2*T*	0.41	17	2*T*	0.33
Over 31.8 to 34.9	25	2*T*	0.51	20	2*T*	0.41
Over 34.9 to 38.1	30	2*T*	0.64	25	2*T*	0.51
Over 38.1 to 50.8	35	2*T*	0.81	30	2*T*	0.64
Over 50.8 to 63.5	40	2*T*	1.02	35	2*T*	0.81
Over 63.5 to 76.2	40	2*T*	1.02	35	2*T*	0.81
Over 76.2 to 101.6	50	2*T*	1.27	40	2*T*	1.02
Over 101.6 to 152.4	60	2*T*	1.60	45	2*T*	1.02
Over 152.4 to 203.2	80	2*T*	1.60	50	2*T*	1.27
Over 203.2 to 254	100	2*T*	2.54	60	2*T*	1.60
Over 254 to 304.8	120	2*T*	3.20	80	2*T*	2.54
Over 304.8 to 406.4	160	2*T*	6.35	100	2*T*	3.20
Over 406.4 to 508	200	2*T*	8.12	120	2*T*	4.06

be prepared and administered by the Employer or an outside agency. The Employer or an outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/ fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(b) The written practice and the procedures used for examination of personnel shall be referenced in the Employer's Quality Control System.

(c) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in SNT-TC-1A. The time of training and experience shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

(d) For visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in SNT-TC-1A. The use of equivalent type and size letters is permitted.

(e) A Level I individual shall be qualified to perform specified setups, calibrations, and tests, and to record and evaluate data by comparison with specific acceptance criteria defined in written instructions. The Level I individual shall implement these written NDE instructions under the guidance of a Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

KE-112.2 Qualification to Perform Other NDE Methods. For nondestructive examination methods not covered by the referenced qualification documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved. The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

KE-113 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels, I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations, the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's records in accordance with KE-115.

KE-114 Verification of Nondestructive Examination Personnel Certification

The certificate holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Manufacturers and Material Suppliers and subcontractors who provide nondestructive examination services to them.

KE-115 Records

Personnel qualification records identified in the referenced qualification documents shall be retained by the Employer. See additional requirements in KE-105.

ARTICLE KE-2
REQUIREMENTS FOR EXAMINATION AND REPAIR OF MATERIAL

KE-200 GENERAL REQUIREMENTS

(a) Pressure retaining material shall be examined by nondestructive methods applicable to the material and product form as required by the rules of this Article.

(b) The requirements of this Article for repair by welding, including examination of the repair welds, shall be met wherever repair welds are made to pressure retaining material.

(c) The requirements of this Article shall apply to both Material Manufacturer and Manufacturer.

KE-201 Examination After Quenching and Tempering

Ferritic steel products that have their properties enhanced by quenching and tempering shall be examined by the methods specified in this Article for each product form after the quenching and tempering phase of the heat treatment.

KE-210 GENERAL REQUIREMENTS FOR REPAIR OF DEFECTS

KE-211 Elimination of Defects by Blend Grinding

(a) Imperfections exceeding the acceptance criteria of KE-233.2 shall be considered defects. Such defects shall be removed or reduced to an acceptable sized imperfection. Defects may be removed by grinding or machining, provided the requirements of KE-211(a)(1) through (a)(4) are met.

(1) The remaining thickness of the section is not reduced below that required by Part KD, except as noted in KE-211(b).

(2) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(3) After defect elimination, the area is reexamined by the magnetic particle method in accordance with KE-233 or the liquid penetrant method in accordance with KE-233 to ensure that the imperfection has been removed or reduced to an acceptable size.

(4) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant test method.

(b) Reduction in thickness due to blend grinding, below the minimum required by Part KD, is permitted within the limits stated below.

(1) Repair cavity diameter:

$$COD = 0.2\sqrt{R_m t}$$

(2) Cavity depth below required thickness:

$$C_{depth} = 0.02\sqrt{R_m t}$$

KE-212 Repair by Welding

(a) Except for materials in which welding is prohibited or restricted in Part KM, the Material Manufacturer may repair the material by welding after the defects have been removed. For restricted materials, see Article KF-7.

(b) The permitted depth of repair is given separately in this Article by product form.

(c) Prior approval of the certificate holder shall be obtained for the repair.

KE-212.1 Defect Removal. The defect shall be removed by suitable mechanical, thermal cutting, or gouging methods and the cavity shall be prepared for repair. After thermal cutting, all slag and detrimental discoloration of material which has been molten shall be removed by mechanical means suitable for the material prior to weld repair. When thermal cutting is used, the effect on mechanical properties shall be taken into consideration. The surface to be welded shall be uniform and smooth. The cavity shall be examined by liquid penetrant or magnetic particle method (see KE-233).

KE-212.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with the requirements of Article KF-2 and Section IX, and meet the toughness requirements of Article KT-2.

KE-212.3 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

KE-212.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method (see KE-233). In addition, when the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, the repair weld shall be ultrasonically examined after repair in accordance with KE-102 and to the acceptance standards of KE-333.

KE-212.5 Heat Treatment After Repairs. The product shall be heat treated after repair in accordance with the heat treatment requirements of Article KF-4.

KE-213 Repairs of Cladding

The Material Manufacturer may repair defects in cladding by welding provided the requirements of KE-213(a) through (c) are met.

(a) The welding procedure and the welders or welding operators shall be qualified in accordance with Article KF-2 and Section IX.

(b) The defect shall be removed, and the cavity prepared for repair shall be examined by the liquid penetrant or magnetic particle method (see KE-233).

(c) The repaired area shall be examined by the liquid penetrant or magnetic particle method (see KE-233).

KE-214 Material Report Describing Defects and Repairs

Each defect repair shall be described in the Certified Material Test Report for each piece, including a chart which shows the location and size of the repair, the welding material identification, welding procedure, heat treatment, and examination results. The location of repairs shall be traceable to the completed vessel.

KE-220 EXAMINATION AND REPAIR OF PLATE

KE-221 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in KE-221(a) through (c).

(a) Ultrasonic examination shall be performed after rolling to size and after heat treatment, except postweld heat treatment.

(b) When radiographic examination of repair welds to plate is required, it shall be performed after postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of repair welds to plate shall be performed after final heat treatment (see KE-212.4).

KE-222 Examination Procedures for Subsurface Imperfections

All plates shall be examined by the straight beam ultrasonic method in accordance with SA-578, Standard Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications, as shown in Article 23 of Section V, except that the extent of examination and the acceptance standards to be applied are given in KE-222(a) and (b).

(a) Extent of Examination. One hundred percent of each major plate surface shall be covered by moving the search unit in parallel paths with not less than a 10% overlap. The location of all recordable indications as defined in Section V shall be documented.

(b) Acceptance Criteria

(1) Any area where one or more imperfections produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 1 in. (25 mm) shall be unacceptable.

(2) In addition, two or more imperfections smaller than described in KE-222(b)(1) shall be unacceptable if they are separated by a distance less than the diameter of the larger imperfection or they may be collectively encompassed by the circle described in KE-222(b)(1).

KE-223 Repair by Welding

The depth of the repair cavity shall not exceed one-third the nominal thickness of the plate and the repair shall be in accordance with KE-210.

KE-230 EXAMINATION AND REPAIR OF FORGINGS AND BARS

(a) Forgings and bars shall be examined by the ultrasonic method in accordance with KE-232, except configurations which do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods in accordance with Article 2 of Section V using the acceptance standards of KE-332. In addition, all external surfaces and accessible internal surfaces shall be examined by the magnetic particle method or liquid penetrant method (see KE-233).

(b) Forged flanges and fittings, such as elbows, tees, and couplings, shall be examined in accordance with the requirements of KE-240.

(c) Bar material used for bolting shall be examined in accordance with KE-260.

(d) Forgings and forged or rolled bars which are to be bored to form tubular products or fittings shall be examined in accordance with the requirements of KE-240 after boring.

KE-231 Time of Examination

Acceptance examination, including those for repair welds, shall be performed at the time of manufacture as required in KE-231(a) through (d).

(a) Ultrasonic examination may be performed at any time after forging [see KE-230(d)] and the maximum practical volume shall be examined after final heat treatment, excluding postweld heat treatment.

(b) Radiographic examination of repair welds, if required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination shall be performed in the finished condition.

(d) Forgings and rolled bars which are to be bored or turned to form tubular parts or fittings shall be examined after boring or turning, except for threading.

KE-232 Ultrasonic Examination

KE-232.1 Examination Procedure. All forgings in the rough forged or finished condition, and bars, shall be examined in accordance with one of the following specifications: SA-745, Standard Practice for Ultrasonic Examination of Austenitic Steel Forgings, or SA-388, Standard Practice for Ultrasonic Examination of Heavy Steel Forgings, as shown in Article 23 of Section V. Either contact, immersion, or water column coupling is permissible. The techniques of KE-232.1(a) through (d) are required, as applicable.

(a) All forgings and bars shall be examined by the ultrasonic method using the straight beam technique.

(b) Ring forgings and other hollow forgings shall, in addition, be examined using the angle beam technique in two circumferential directions, unless wall thickness or geometric configuration makes angle beam examination impractical.

(c) In addition to KE-232.1(a) and (b), ring forgings made to fine grain melting practices and used for vessel shell sections shall also be examined by the angle beam technique in two axial directions.

(d) Forgings may be examined by the use of alternative ultrasonic methods which utilize distance amplitude corrections, provided the acceptance standards are shown to be equivalent to those listed in KE-232.2.

KE-232.2 Acceptance Standards

(a) Straight Beam General Rule. A forging shall be unacceptable if the results of straight beam examinations show one or more reflectors which produce indications accompanied by a complete loss of back reflection not associated with or attributable to geometric configurations. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(b) Angle Beam Rule. A forging shall be unacceptable if the results of angle beam examinations show one or more reflectors which produce indications exceeding in amplitude the indication from the appropriate calibration notches (see KE-232.1).

KE-233 Magnetic Particle and Liquid Penetrant Examination

Surface examination of ferromagnetic materials shall be performed using a wet magnetic particle method. Nonferromagnetic material shall be examined using the liquid penetrant method. It shall be demonstrated that the inspections to be performed are capable of finding relevant surface defects as defined in KE-233.2(a).

KE-233.1 Evaluation of Indications

(a) For magnetic particle examinations, alternating current methods are prohibited. When utilizing magnetic particle examination, mechanical discontinuities at or near the surface will be indicated by the retention of the examination medium. However, all indications are not necessarily imperfections, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant to the detection of unacceptable discontinuities.

(b) When utilizing liquid penetrant examination, mechanical discontinuities at the surface will be indicated by bleeding out of the penetrant; however, localized surface imperfections, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications which are not relevant to the detection of imperfections. Any indication in excess of the KE-233.2 acceptance standards which is believed to be nonrelevant shall be regarded as a defect and shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask indications of defects are unacceptable.

(c) Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length less than three times the width.

KE-233.2 Acceptance Standards

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant.

(b) The relevant indications of KE-233.2(b)(1) through (b)(4) are unacceptable. More stringent acceptance criteria may be specified in the User's Design Specification. See KG-311.

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less, edge-to-edge

(4) ten or more rounded indications in any 6 in.^{2} (3 871 mm^2) of area whose major dimension is no more than 6 in. (152 mm), with the dimensions taken in the most unfavorable location relative to the indications being evaluated

KE-234 Repair by Welding

When repair by welding is not prohibited by Part KM or the product specification, the depth of repair is not limited except as by the product specification and shall be in accordance with KE-210.

KE-240 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED (WITHOUT FILLER METAL) TUBULAR PRODUCTS AND FITTINGS

KE-241 Required Examination

(a) Wrought seamless and welded (without filler metal) pipe and tubing shall be examined over the entire volume of the material in accordance with the applicable paragraph KE-241(a)(1), (a)(2), or (a)(3). Tubular products may require both outside and inside surface conditioning prior to examination.

(1) Pipe and tubing smaller than $2\frac{1}{2}$ in. (64 mm) O.D. shall be examined by the ultrasonic method in accordance with KE-242.1(a) in two opposite circumferential directions[1] and by the eddy current method in accordance with KE-244, provided the product is limited to sizes, materials, and thicknesses for which meaningful results can be obtained by eddy current examination. Each method shall be calibrated to the appropriate standard; that is, the ultrasonic method shall be calibrated to the axial notches or grooves of KE-242.2(b), and the eddy current method shall be calibrated to the circumferential notches and grooves as well as the radial hole of KE-244.2. As an alternative to the eddy current examination or when the eddy current examination does not yield meaningful results, an axial scan ultrasonic examination in two opposite axial directions in accordance with KE-242.1(b) shall be made.

(2) Pipe and tubing $2\frac{1}{2}$ in. (64 mm) O.D. through $6\frac{3}{4}$ in. (171 mm) O.D. shall be examined by the ultrasonic method in accordance with KE-242.1(a) in two opposite circumferential directions and in accordance with KE-242.1(b) in two opposite axial directions.

(3) Pipe and tubing larger than $6\frac{3}{4}$ in. (171 mm) O.D. shall be examined by the ultrasonic method in two opposite circumferential directions in accordance with KE-242.1(c) or the radiographic method in accordance with KE-243. Alternatively, for welded without filler metal pipe larger than $6\frac{3}{4}$ in. (171 mm) O.D., the plate shall be examined by the ultrasonic method in accordance with KE-220 prior to forming and the weld shall be examined by the radiographic method in accordance with KE-243. Radiographic examination of welds, including repair welds, shall be performed after final rolling and forming and may be performed prior to any required postweld heat treatment.

(b) Wrought seamless and welded without filler metal fittings (including pipe flanges and fittings machined from forgings and bars) shall be examined in accordance with the material specification and in addition by the magnetic particle method or the liquid penetrant method in accordance with KE-233 on all external surfaces and all accessible internal surfaces.

(c) Tubular products used for vessel nozzles shall be examined over the entire volume of material by either the ultrasonic method in two opposite circumferential directions in accordance with KE-242 or the radiographic method in accordance with KE-243, and shall be examined on all external and all accessible internal surfaces by either the magnetic particle method or the liquid penetrant method in accordance with KE-233.

KE-242 Ultrasonic Examination

KE-242.1 Examination Procedure for Pipe and Tubing. Independent channels or instruments shall be

[1] The direction of ultrasonic examinations referenced is the direction of sound propagation.

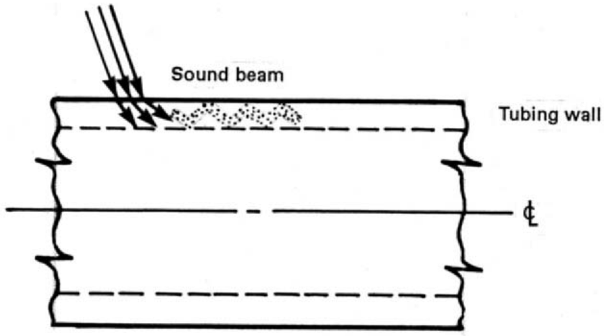


FIG. KE-242.1 AXIAL PROPAGATION OF SOUND IN TUBE WALL

employed for axial and circumferential scans.

(a) Circumferential Direction — 6¾ in. (171 mm) O.D. and Smaller. The procedure for ultrasonic examination of pipe and tubing in the circumferential direction shall be in accordance with SE-213, Standard Practice for Ultrasonic Inspection of Metal Pipe and Tubing, in Article 23 of Section V, except as required in KE-241(a)(1) and (2), and the requirements of this paragraph. The procedure shall provide a sensitivity which will consistently detect defects that produce indications equal to, or greater than, the indications produced by standard defects included in the reference specimens specified in KE-242.2.

(b) Axial Direction — 6¾ in. (171 mm) O.D. and Smaller. When required by KE-241, the ultrasonic examination of pipe and tubing shall include angle beam scanning in the axial direction. The procedure for the axial scans shall be in accordance with SE-213 in Section V, except that the propagation of sound in the tube or pipe wall shall be in the axial direction instead of the circumferential direction and as required in KE-241(a). Figure KE-242.1 illustrates the characteristic oblique entry of sound into the pipe or tube wall in the axial direction of ultrasonic energy propagation to detect transverse notches.

(c) Pipe and Tubing Larger Than 6¾ in. (171 mm) O.D. The procedure for ultrasonic examination of pipe and tubing larger than 6¾ in. (171 mm) O.D. shall be in accordance either with the requirements of Section II, SA-388 for angle beam scanning in the circumferential direction or with the requirements of Section V, SE-213, except as required in KE-241(a)(3). The reference standard shall be in accordance with KE-242.2.

(d) Acceptance Standards. Products with defects that produce indications in excess of the indications produced by the standard defects in the referenced specimen are unacceptable.

KE-242.2 Reference Specimens. The reference specimen shall be of the same nominal diameter and thickness, and of the same nominal composition and heat-treated condition, as the product which is being examined.

(a) For circumferential scanning, the standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $^1/_{16}$ in. (1.6 mm) for a square notch or U-notch, a width proportional to the depth for a V-notch, and depth not greater than the larger of 0.004 in. (0.10 mm) or 3% of the nominal wall thickness.

(b) For axial scanning in accordance with SE-213 in Section V, a transverse (circumferential) notch shall be introduced on the inner and outer surfaces of the standard. Dimensions of the transverse notch shall not exceed those of the longitudinal notch. The reference specimen may be the product being examined.

(c) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

KE-242.3 Checking and Calibration of Equipment. The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum

(a) at the beginning of each production run of a given size and thickness of given material

(b) after each 4 hr or less during the production run;

(c) at the end of the production run

(d) at any time that malfunctioning is suspected

If, during any check, it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

KE-243 Radiographic Examination

The radiographic examination shall be performed in accordance with Article 2 of Section V, as modified by KE-101, using the acceptance requirements of KE-332.

KE-244 Eddy Current Examination

The requirements for eddy current examination are given in KE-244.1 through KE-244.3.

KE-244.1 Examination Procedure. The procedure for eddy current examination shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen specified in KE-244.2. Products with defects that produce indications in excess of the reference standards are unacceptable unless the defects are eliminated or repaired in accordance with KE-246.

KE-244.2 Reference Specimen. The reference specimen shall be a piece of, and shall be processed in the same manner as, the product being examined. The standard defects shall be circumferential or tangential notches or grooves on the outside and the inside surfaces of the product and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $\frac{1}{16}$ in. (1.6 mm), a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness, and a radial hole having a nominal diameter of $\frac{1}{16}$ in. (1.6 mm) or less. The size of reference specimens shall be as specified in KE-242.2.

KE-244.3 Checking and Calibration of Equipment. The checking and calibration of examination equipment shall be the same as in KE-242.3.

KE-245 Time of Examination

Time of acceptance examination, including that of repair welds, shall be in accordance with KE-231.

KE-246 Repair by Welding

When repair by welding is not prohibited by Part KM or the product specification, the depth of repair is not limited except as by the product specification and shall be in accordance with KE-210.

KE-250 EXAMINATION AND REPAIR OF TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL

KE-251 Required Examination

(a) All welds shall be examined 100% by radiography in accordance with the method and acceptance requirements of the material specification and by a magnetic particle method or a liquid penetrant method (KE-233). When radiographic examination of welds is not specified in the material specification, the welds shall be examined by radiography in accordance with the requirements of Article 2 of Section V, as modified by KE-111 using the acceptance standards of KE-332. The radiographic film and a radiographic report showing film locations shall be provided with the Certified Material Test Report.

(b) Plate for these products shall be examined by ultrasonic methods in accordance with KE-220 or the finished product shall be examined in accordance with KE-242.

KE-252 Time of Examination

Acceptance examinations, including those for repair welds, shall be performed at the time of manufacture as specified in KE-252(a) through (c).

(a) Ultrasonic examination of plate shall be performed at the time as specified in KE-221, or, if the finished product is examined, the time of examination shall be after final rolling and forming.

(b) Radiographic examination of welds, including repair welds, shall be performed after final rolling and forming and may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of welds, including repair welds, shall be performed after heat treatment, except the examination may be performed prior to postweld heat treatment of P-No. 1 material.

KE-253 Repair by Welding

When repair by welding is not prohibited by Part KM, or the product specification, the depth of repair is not limited except as by the product specification and shall be in accordance with KE-210.

KE-260 EXAMINATION OF BOLTS, STUDS, AND NUTS

KE-261 Required Examination

(a) All bolting materials shall be visually examined.

(b) Nominal sizes greater than 1 in. (25 mm) shall be examined by either the magnetic particle or liquid penetrant method.

(c) Nominal sizes greater than 2 in. (51 mm) shall be examined by ultrasonic methods in accordance with KE-264 and KE-265.

KE-262 Visual Examination

The areas of threads, shanks, and heads of final machined parts shall be visually examined. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

KE-263 Magnetic Particle or Liquid Penetrant Examination

All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by the magnetic particle method or the liquid penetrant method in accordance with KE-233. Such examination shall be performed on the finished bolting after threading, or on the material stock at approximately the finished diameter before threading, and after heading, if this process is used. Any indications shall be unacceptable.

KE-264 Ultrasonic Examination for Sizes Greater Than 2 in. (51 mm)

All bolts, studs, and nuts greater than 2 in. (51 mm) nominal size shall be ultrasonically examined over the entire surface prior to threading in accordance with the requirements of KE-264.1 through KE-264.4.

KE-264.1 Ultrasonic Method. Examination shall be carried out by the straight beam, radial scan method.

KE-264.2 Examination Procedure. Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit not to exceed 1 in.^{2} (645 mm^2) in area.

KE-264.3 Calibration of Equipment. Calibration sensitivity shall be established by adjustment of the instrument so that the first back screen reflection is 75–90% of full screen height.

KE-264.4 Acceptance Standards. Any discontinuity which causes an indication in excess of 20% of the height of the first back reflection or any discontinuity which prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

KE-265 Ultrasonic Examination for Sizes Over 4 in. (102 mm)

In addition to the requirements of KE-264, all bolts, studs, and nuts over 4 in. (100 mm) nominal size shall be ultrasonically examined over an entire end surface before or after threading in accordance with the requirements of KE-265.1 through KE-265.4.

KE-265.1 Ultrasonic Method. Examination shall be carried out by the straight beam, longitudinal scan method.

KE-265.2 Examination Procedure. Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit not to exceed 0.5 in.^{2} (322 mm^2).

KE-265.3 Calibration of Equipment. Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A $\frac{3}{8}$ in. (10 mm) diameter × 3 in. (76 mm) deep flat bottom hole shall be drilled in one end of the bar and plugged to full depth. A distance amplitude correction curve shall be established by scanning from both ends of the test bar.

KE-265.4 Acceptance Standards. Any discontinuity which causes an indication in excess of that produced by the calibration hole in the reference specimen as corrected by the distance amplitude correction curve is not acceptable.

KE-266 Repair by Welding

Weld repair of bolts, studs, and nuts is not permitted.

ARTICLE KE-3
EXAMINATION OF WELDS AND ACCEPTANCE CRITERIA

KE-300 EXAMINATION OF WELDS AND WELD OVERLAY

Acceptance examinations of welds and weld overlay shall be performed at the times stipulated in KE-300(a) through (f) during fabrication and installation, except as otherwise specified in KE-310 and KE-400.

(a) All butt joints shall be ultrasonically examined after completion of all required heat treatment. Where ultrasonic examination cannot resolve embedded flaws in the performance demonstration block, or weld joint and/or vessel geometry prohibits ultrasonic examination, radiographic examination shall be performed.

(b) Magnetic particle or liquid penetrant examinations of welds including plate weld repair shall be performed after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment. The magnetic particle or liquid penetrant examination of welds at progressive states of welding may be performed before PWHT.

(c) The magnetic particle or liquid penetrant examination of weld surfaces that are to be covered with weld overlay shall be performed before the weld overlay is deposited. The magnetic particle or liquid penetrant examination of weld surfaces that are not accessible after a postweld heat treatment shall be performed prior to postweld heat treatment. These examinations may be performed before PWHT.

(d) Weld overlay shall be examined after completion of all required heat treatment by the magnetic particle or liquid penetrant methods.

(e) All of the joints in austenitic stainless steel and nonferrous material shall be examined by the liquid penetrant method after final postweld heat treatment, if any, is performed.

(f) Examination of weld joints when required in ferritic steels with tensile properties enhanced by quenching and tempering shall be made after all weld overlay has been deposited, and all required heat treatment has been performed.

KE-301 Requirements for Ultrasonic Examinations of Welds

(a) For welds in wrought product forms, both straight beam and angle beam examinations shall be required. Both examination methods shall include the volume of the weld and a minimum of 2 in. (51 mm) of the base metal on either side of the weld. The straight beam examination shall include the volume of the base metal through which subsequent shear waves shall pass. These examinations shall be performed in accordance with procedures agreed upon by the manufacturer and purchaser, but as a minimum shall meet the requirements of Section V, Article 4.

The entire weld volume shall be inspected per the requirements of Section V, Article 5 for the detection of volumetric defects such as gas porosity and slag inclusions, and planar defects near surfaces such as lack of penetration at the root. The weld volume shall also be inspected with a procedure capable of detecting planar defects such as sidewall lack of fusion.

For weld inspection in material thicker than 2 in. (51 mm), in addition to the basic calibration block side drilled holes and surface notches required by Section V, Article 4 (T-434.2.1), machined planar reflectors shall also be included so that their flat surfaces match the weld preparation angle (±10 deg). The reflecting surface of the machined planar reflectors in this specific calibration block shall reside no closer than 15% of the material thickness to any exterior surface and have the following reflecting area depending on material thickness, t:

Material Thickness, in. (mm)	Reflecting Area, in.^{2} (mm^2)	Diameter or Length, in. (mm)
2 (50) ≤ t < 4 (100)	0.25 (161)	$^9/_{16}$ (14)
4 (100) ≤ t < 6 (150)	0.37 (239)	$^{11}/_{16}$ (17)
6 (150) ≤ t < 8 (200)	0.44 (284)	$^3/_4$ (19)
8 (200) ≤ t < 10 (250)	0.60 (387)	$^7/_8$ (22)
t > 10 (250)	0.79 (510)	1 (25)

The weld fusion zone shall be inspected using the appropriate test procedure(s) and calibration(s). Indications greater than 20% of the ultrasonic response from the planar reflector shall be considered relevant and shall be investigated per KE-333. Alternatively, for time-of-flight method, sized flaws of at least the diameter or length shown in the above table shall be considered relevant and shall be investigated.

(b) Personnel shall demonstrate the ability of their procedures to locate planar flaws by conducting a performance demonstration on a performance demonstration (PD) block containing embedded planar flaws (see KE-302). A blind test is not required. The testing technique will be considered acceptable if the response from the embedded flaws exceeds 20% of the ultrasonic response from the planar reflector in the specific calibration block. Alternatively, for time-of-flight method, acceptable performance is defined as sized flaws demonstrated to be a flaw of at least the length identified for the embedded planar flaws. PD block flaw characterization data is given to the inspection personnel prior to the procedure demonstration.

(c) A performance demonstration does not need to be conducted for welds less than 2 in. (51 mm) in thickness.

KE-302 Requirements for Performance Demonstration Block

The PD block shall meet the following requirements.

(a) The PD block shall contain a minimum of three planar flaws. The primary weld preparation angle must be represented by at least two embedded flaws oriented within ±10 deg of the weld preparation angle. One flaw shall be located near the midpoint of the top one-third of the PD block (representing the O.D.), one flaw shall be located near mid-thickness of the PD block, and one flaw shall be located near the midpoint of the bottom one-third of the PD block (representing the I.D.).

(b) The material of the PD block shall meet the P-number requirements of Section V, Article 5.

(c) The thickness of the PD block shall be within ±25% of the actual final thickness of the thickest weld to be examined in the pressure vessel.

(d) The PD block flaw size shall be greater than 0.2 $in.^2$ (129 mm^2) reflecting area but no greater than 0.75 $in.^2$ (484 mm^2) reflecting area.

(e) The embedded planar flaws in the PD block may be natural or artificial and must be fully characterized in location, orientation (angular rotation in horizontal and vertical axis), and reflecting area.

KE-310 EXAMINATION OF WELD EDGE PREPARATION SURFACES

All weld edge preparation surfaces in materials 2 in. (51 mm) or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Weld repairs made to the weld edge preparation surfaces shall also be inspected by the magnetic particle or liquid penetrant method before the surface becomes inaccessible.

Indications shall be evaluated in accordance with the acceptance standards in KE-310(a), (b), and (c). The location of all relevant indications shall be documented.

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant.

(b) Laminar type indications are acceptable without repair if they do not exceed $\frac{1}{4}$ in. (6 mm) in length. The extent of all laminar type indications exceeding $\frac{1}{4}$ in. (6 mm) in length shall be determined by ultrasonic examination. Indications exceeding $\frac{1}{4}$ in. (6 mm) in length shall be repaired by welding to a depth of $\frac{3}{8}$ in. (10 mm) or the depth of the indication, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) Other nonlaminar relevant indications that are unacceptable are:

(1) any linear indications greater than $\frac{3}{16}$ in. (4.8 mm) long

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm)

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less, edge-to-edge

KE-320 TYPES OF WELDS AND THEIR EXAMINATION

KE-321 Welded Joint Categories

The term category as used herein defines the location of a joint in a vessel, but not the type of joint. The categories established by this paragraph are for use in this Division in specifying special requirements regarding joint type and degree of examination for certain welded pressure joints. Since these special requirements, which are based on service and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in categories. The joints included in each category are designated as joints of Categories A, B, C, and D below. Figure KE-321 illustrates typical joint locations included in each category.

(a) Category A Locations. Category A locations are longitudinal welded joints within the main shell, communicating chambers,[1] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat

[1] *Communicating chambers* are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure containing enclosure, e.g., sumps.

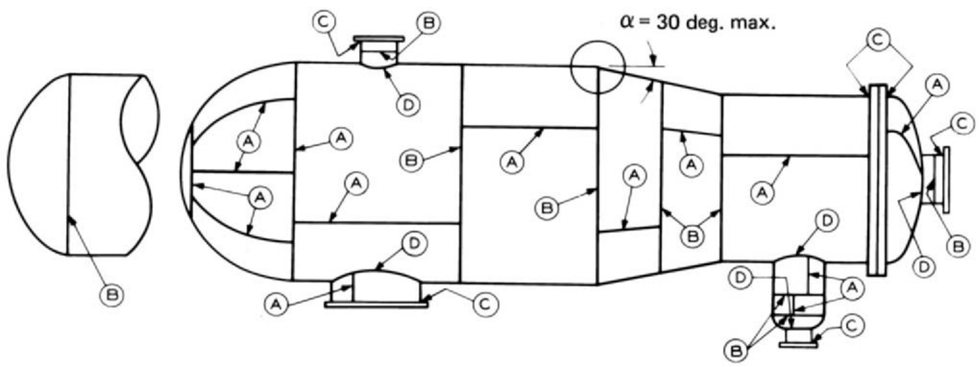


FIG. KE-321 ILLUSTRATION OF WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

head, or within the side plates[2] of a flat-sided vessel; and circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

(b) Category B Locations. Category B locations are circumferential welded joints within the main shell, communicating chambers, nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; and circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

(c) Category C Locations. Category C locations are welded joints connecting flanges, tubesheets, or flat heads to the main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers; and any welded joint connecting one side plate to another side plate of a flat-sided vessel.

(d) Category D Locations. Category D locations are welded joints connecting communicating chambers or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat-sided vessels; and nozzles at the small end of a transition in diameter and those joints connecting nozzles to communicating chambers.

KE-322 Weld Joints

The entire length of all Category A, B, C, and D weld joints shall be ultrasonically examined in accordance with KE-300. Where ultrasonic examination test results cannot be conclusively interpreted, radiographic examination of that area shall be carried out in accordance with KE-101. The external and accessible internal weld surfaces and adjacent base material for at least $\frac{1}{2}$ in. (13 mm) on each side of the weld shall be examined by either the magnetic particle or liquid penetrant method.

[2] *Side plates* of a flat-sided vessel are defined as any of the flat plates forming an integral part of the pressure containing enclosure.

KE-323 Weld Buildup Deposits at Openings for Nozzles, Branch, and Piping Connections

When weld buildup deposits are made to a surface, the weld buildup deposit, the fusion zone, and the parent metal beneath the weld buildup deposit shall be ultrasonically examined. See KE-333 for acceptance standards.

KE-324 Attachment Welds

Attachment welds made to pressure retaining material shall be examined by either the magnetic particle or liquid penetrant method. See KE-334 for acceptance standards.

KE-325 Welds for Membrane Seals

Membrane seal welds shall be examined by either the magnetic particle or liquid penetrant method.

KE-330 ACCEPTANCE STANDARDS

KE-331 General Requirements

Acceptance standards for welds shall be as stated in the following paragraphs, while the acceptance standards for material adjacent to the weld or beneath the weld or weld buildup shall be as stated in Article KE-2.

KE-332 Radiographic Acceptance Standards

Welds that are shown by radiography to have any of the following types of imperfections are unacceptable:

(a) any type of crack or zone of incomplete fusion or penetration

(b) any other linear indication which has a length greater than

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive (where t is the thickness of the thinner portion of the plate being welded)

(2) $t/3$ for t over $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

(c) internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt (such that radiographs can be interpreted); linear indications on the radiograph at either edge of such conditions shall be unacceptable as provided in KE-332(b)

(d) any group of aligned, rounded indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication

(e) rounded indications in excess of those shown as acceptable in Table KE-332 and Mandatory Appendix 6.

TABLE KE-332
RADIOGRAPHIC ACCEPTANCE STANDARDS FOR ROUNDED INDICATIONS (Examples Only)

Thickness t, in. (mm)	Maximum Size of Acceptable Rounded Indications, in. (mm)		Maximum Size of Nonrelevant Indication, in. (mm)
	Random	Isolated	
Less than $\frac{1}{8}$ (3)	$\frac{1}{4}\,t$	$\frac{1}{3}\,t$	$\frac{1}{10}\,t$
$\frac{1}{8}$ (3)	0.031 (0.8)	0.042 (1.1)	0.015 (0.4)
$\frac{3}{16}$ (5)	0.047 (1.2)	0.063 (1.6)	0.015 (0.4)
$\frac{1}{4}$ (6)	0.063 (1.6)	0.083 (2.1)	0.015 (0.4)
$\frac{5}{16}$ (8)	0.078 (2.0)	0.104 (2.6)	0.031 (0.8)
$\frac{3}{8}$ (9.5)	0.091 (2.3)	0.125 (3.2)	0.031 (0.8)
$\frac{7}{16}$ (11)	0.109 (2.8)	0.146 (3.7)	0.031 (0.8)
$\frac{1}{2}$ (13)	0.125 (3.2)	0.168 (4.3)	0.031 (0.8)
$\frac{9}{16}$ (14)	0.142 (3.6)	0.188 (4.8)	0.031 (0.8)
$\frac{5}{8}$ (16)	0.156 (4.0)	0.210 (5.3)	0.031 (0.8)
$\frac{11}{16}$ (17.5)	0.156 (4.0)	0.230 (5.8)	0.031 (0.8)
$\frac{3}{4}$ (19) to 2 (50), incl.	0.156 (4.0)	0.250 (6.4)	0.031 (0.8)
Over 2 (50)	0.156 (4.0)	0.375 (9.5)	0.063 (1.6)

KE-333 Ultrasonic Acceptance Standards

All indications which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such indications and evaluate them in terms of the acceptance standards given in KE-333(a) and (b).

(a) Where indications are interpreted to be cracks, lack of fusion, or incomplete penetration, they are unacceptable regardless of discontinuity or signal amplitude.

(b) Indications are unacceptable if the amplitude exceeds the reference level, or indications have lengths that exceed

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive (where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses)

(2) $t/3$ for t over $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

KE-334 Magnetic Particle and Liquid Penetrant Examination

Welds shall be examined by the magnetic particle or liquid penetrant methods in accordance with KE-233.

ARTICLE KE-4
FINAL EXAMINATION OF VESSELS

KE-400 SURFACE EXAMINATION AFTER HYDROTEST

All surfaces of pressure boundary components including internal and external surfaces and weld metal shall be examined by wet magnetic particle method (if ferromagnetic) or by liquid penetrant method (if nonmagnetic) over the entire surface of the vessel or component following all applicable heat treatment and autofrettage hydrotest, unless accessibility prevents meaningful interpretation and characterization of defects. Acceptance criteria shall be per KE-233.2.

KE-410 INSPECTION OF LINED VESSEL INTERIOR AFTER HYDROTEST

When the test fluid leaks behind the protective liner, there is danger that the fluid will remain in place when the vessel is put in service. In cases where the operating temperature of the vessel is above the boiling point of the test fluid, the vessel should be heated slowly for sufficient time to drive out all test fluid from behind the protective liner without damage to the liner. This heating operation shall be performed at the vessel manufacturing plant or at the plant where the vessel is being installed. After the test fluid is driven out, the lining should be repaired. Repetition of the examination, the heat treatment, or the hydrostatic test of the vessel after lining repairs is not required except when there is reason to suspect that the repair welds may have defects that penetrate into the base material, in which case the Inspector shall decide which one or more of these operations shall be repeated.

PART KT
TESTING REQUIREMENTS

ARTICLE KT-1
TESTING REQUIREMENTS

KT-100 SCOPE

The testing of vessels within the scope of this Division shall be performed in accordance with the rules in this Part.

KT-110 REQUIREMENTS FOR SAMPLE TEST COUPONS

KT-111 Obtaining Sample Test Coupons

When material is subjected to heat treatment during fabrication, the test specimens required by the applicable specification shall be obtained from sample coupons which have been heat treated in the same manner as the material, including such heat treatments as were applied by the Material Producer before shipment. The required tests shall be performed by either the material producer or Manufacturer (see KM-220).

KT-112 Heat Treating of Sample Test Coupons

The material used in a vessel or a component shall be represented by test specimens which have been subjected to the same manner of heat treatment, including postweld heat treatment, as the vessel. The kind and number of tests, and test results, shall be those required by the material specification. The Manufacturer shall specify the temperature, time, and cooling rates that the material will be subjected to during fabrication. Material from which the specimens are prepared shall be heated at the specified temperature within the tolerances established by the Manufacturer for use in actual fabrication. The total time at temperature shall be at least 80% of the total time at temperature during actual heat treatment of the product and may be performed in a single cycle. Simulation of postweld heat treatment may be applied to the test specimen blanks. Local heating such as flame or arc cutting, preheating, or welding shall not be considered as part of the heat treatment.

KT-113 Exception for Standard Pressure Parts

An exception to the requirements of KT-111 and KT-112 shall apply to standard items such as described in KM-102. These may be subjected to postweld heat treatment with the vessel or vessel part without the same treatment being required of the test specimens. This exception shall not apply to specially designed wrought fittings.

ARTICLE KT-2
IMPACT TESTING FOR WELDED VESSELS

KT-200 IMPACT TESTS

(a) For vessels of welded construction, the toughness of welds and heat-affected zones of procedure qualification test plates and vessel production test plates shall be determined as required in this Article.

(b) Test plates shall be subjected to heat treatment, including cooling rates and aggregate time at temperature or temperatures, essentially the same as established by the Manufacturer for use in actual manufacture. The total time at temperature shall be at least 80% of the total time at temperature during actual heat treatment of the product and may be performed in a single cycle.

(c) The test temperature for welds and heat-affected zones shall not be higher than for the base materials.

(d) Impact values shall be at least as high as those required for the base materials [see Table KM-234.2(a)].

KT-210 LOCATION AND ORIENTATION OF SPECIMENS

All weld impact specimens for both weld procedures and production tests shall comply with the following requirements:

(a) One set of weld metal impact specimens shall be taken across the weld with the notch in the weld metal. Each specimen shall be oriented so that the notch is normal to the surface of the material, and one face of the specimen shall be within $^1/_{16}$ in. (1.6 mm) of the surface of the material. When tests are made on material over $1^1/_2$ in. (38 mm) in thickness, two sets of impact specimens shall be taken from the weld, with one set located within $^1/_{16}$ in. (1.6 mm) of the surface of one side of the material, and one set taken as near as practical midway between the surface and the center of thickness of the opposite side as described above.

(b) One set of heat-affected zone impact specimens shall be taken across the weld and of sufficient length to locate, after etching, the notch in the affected zone. The notch shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone material as possible in the resulting fracture.

KT-220 IMPACT TESTS FOR WELDING PROCEDURE QUALIFICATIONS

Impact tests shall be required on weld and heat-affected zones for all welding procedure qualifications.

KT-221 Variables for Impact Testing Procedures

See Section IX, QW-250.

KT-222 Thickness Qualified When Lower Critical Temperature Is Exceeded

For test plates or pipe receiving a postweld heat treatment in which the lower critical temperature is exceeded, the maximum thickness qualified is the thickness of the test plate or pipe.

KT-230 IMPACT TEST OF PRODUCTION TEST PLATES

Impact tests of welds and heat-affected zones shall be made in accordance with KT-210 for each qualified welding procedure used on each vessel. Test plates shall be taken from one of the heats of material used for the vessel production for Category A and B weld joints and shall be welded as an extension to the end of the production weld joint where practical, welded immediately prior to the start of production, or welded concurrently with the production weld, utilizing welding materials and procedures which are to be used on the production joint. If test plates are welded concurrently with the production weld, the welding equipment shall be of the same type as used for production and the location of the test plate welding shall be immediately adjacent to the production welding. In addition, the following requirements shall apply.

(a) If automatic or semiautomatic welding is performed, a test plate shall be made in each position employed in the vessel welding.

(b) If manual welding is to be employed in the horizontal flat position only, a test plate shall be made in the

flat position. A vertical test plate with the major portions of the layers of welds deposited in the vertical upward position shall be used to qualify the welding procedure when welds are made in any other position. The vertically welded test plate will qualify the manual welding in all positions.

(c) Impact tests shall be valid only if the thickness of the vessel test plate meets the requirements of QW-451.1 (including Notes) of Section IX, except that, if the thickness is less than $\frac{5}{8}$ in. (16 mm), the thickness of the test material shall be the minimum thickness qualified.

KT-240 BASIS FOR REJECTION

If the vessel test plate fails to meet the impact requirements, the welds represented by the test plate shall be unacceptable. Reheat treatment in accordance with Part KM and retesting are permitted.

ARTICLE KT-3
HYDROSTATIC TESTS

KT-300 SCOPE

Each completed vessel shall be subjected to a hydrostatic test pressure which, at every point in the vessel, is within the range specified in KT-310. Vessels designed for vacuum conditions do not require an additional external pressure hydrotest.

04 **KT-301 Layered Vessels**

See additional requirements for hydrotest of layered, and wire-wound vessels in Articles KF-8 and KF-9.

KT-302 Nonmetallic Lined Vessels

Vessels which are to be lined with a nonmetallic material shall be pressure tested before the application of such lining.

KT-303 Autofrettaged Vessels

Autofrettaged vessels may be exempt from hydrostatic testing. See KT-340.

KT-310 LIMITS OF HYDROSTATIC TEST PRESSURE

KT-311 Lower Limit

The test pressure shall not be less than 1.25 times the design pressure to be marked on the vessel, multiplied by the lowest ratio (for materials of which the vessel is constructed) of the specified yield strength value S_y for the test temperature of the vessel to the specified yield strength value S_y for the design temperature.

KT-312 Upper Limit

Except for the provision in KT-312.3, the test pressure shall not exceed the limits in KT-312.1 or KT-312.2, as applicable.

KT-312.1 For Single Wall Vessels

$$P_t = S_y \ln(Y)$$

where

D_O = outside diameter
D_I = inside diameter
S_y = specified yield strength at test temperature
Y = D_O/D_I diameter ratio

KT-312.2 For Layered Vessels

$$P_t = \sum S_{yi} \ln(Y_i)$$

where S_{yi} and Y_i are the specified yield strength and diameter ratio for each individual layer.

KT-312.3 Pressures Beyond Code Limit. If the hydrostatic test pressure exceeds the value determined as prescribed in KT-312.1 or KT-312.2, as applicable, the suitability and integrity of the vessel shall be evaluated by the Designer and the results of this evaluation shall be included with the Manufacturer's Design Report.

KT-320 FLUID MEDIA FOR HYDROSTATIC TESTS[1]

Only fluid which is liquid at the hydrotest temperature and pressure and is not corrosive to the vessel parts shall be used for the hydrostatic test. The Manufacturer shall consider the effect of increase in fluid viscosity with pressure. To minimize the risk of brittle fracture, the test temperature shall be a minimum of 30°F (17°C) higher than the material impact test temperature, but below the boiling point of the pressurized fluid. The test pressure shall not be applied until the vessel and the pressurizing fluid are within 10°F (5.6°C) of each other.

KT-330 TEST PROCEDURE

(a) The test pressure shall be increased in increments of not more than 20% of the test pressure. The pressure

[1] To decrease the pressure energy of the fluid during hydrostatic test, filler bars may be inserted into vessels. Safety precautions should be scaled according to the test location, fluid properties, and the pressure energy contained in the vessel under test.

shall be stabilized at each increment and maintained without the aid of the pump. If the pressure drops more than 5% at any increment, the pressure shall be released to a safe level. Following the release of the hydrostatic test pressure to a safe level, examination for leakage shall be made of all joints, connections, and regions of high stress, such as head knuckles, regions around openings, and thickness transition sections. The examination shall be made immediately after pressure is released and shall be witnessed by the Inspector. Any evidence of leaks shall be investigated and leaks corrected, after which the vessel shall be retested in accordance with these requirements.

(b) After the test pressure has been maintained without the aid of the pump for a minimum of 5 min, the pressure shall be reduced to the design pressure. A thorough inspection for leakage shall be conducted in accordance with KT-330(a). If no leaks are found or if leaks are found to be from a fitting or other attachment, external to the vessel itself, the test may be accepted as satisfactory.

KT-340 EXEMPTION FOR AUTOFRETTAGED VESSELS

Autofrettaged vessels may be exempt from hydrostatic testing if all the following conditions are met:

(a) the vessel, when autofrettaged, is in its final assembled form

(b) no access ports or nozzles will be cut or attached after the autofrettage

(c) the heads, closures, seal carriers, or other sealing members but not necessarily the seals that will be used in the completed vessel are used as sealing members during the autofrettage process

(d) the autofrettage pressure equals or exceeds the requirements of KT-311 as limited by KT-312

ARTICLE KT-4
PRESSURE TEST GAGES AND TRANSDUCERS

KT-400 TYPE AND NUMBER OF GAGES OR TRANSDUCERS

At least two pressure test gages or transducers shall be used in testing high pressure vessels. All pressure gages and transducer readouts shall be readily visible to the operator controlling the pressure applied.

KT-410 PRESSURE RANGE OF TEST GAGES AND TRANSDUCERS

Dial reading pressure gages used in testing shall have dials graduated over a range of not less than 1.5 and not greater than 4 times the pressure being tested. The transducers used shall have a range not less than 1.5 times and not greater than 4 times the pressure being tested.

KT-420 CALIBRATION OF TEST GAGES AND TRANSDUCERS

All gages or transducers shall be calibrated against a standard deadweight tester or a calibrated master gage at least every 6 months or at any time there is reason to believe that they are in error.

PART KS
MARKING, STAMPING, REPORTS, AND RECORDS

ARTICLE KS-1
CONTENTS AND METHOD OF STAMPING

KS-100 REQUIRED MARKING FOR VESSELS

Each pressure vessel to which the ASME U3 symbol is applied shall be marked with the following:

(a) The official ASME U3 symbol, as shown in Fig. KS-100, shall be stamped on vessels certified in accordance with this Division.

(b) Name or identifying acronym of Manufacturer of the pressure vessel as it is shown on the Certificate of Authorization, preceded by "Certified by." Trademark is not considered to be sufficient identification for vessels or parts constructed to this Division. See Nonmandatory Appendix C.

(c) Manufacturer's serial number (MFG SER). Also, as applicable, Canadian Registration Number (CRN), National Board Registration Number (NB or NATL BD).

(d) Design pressure in either psi or MPa at coincident design metal temperature in either °F, if pressure is in psi, or °C, if MPa are used for pressure.

NOTE: When a vessel is specified to operate at more than one pressure and temperature condition, such values of coincident pressure and design temperature shall be added to the required markings.

(e) Minimum design metal temperature, °F (°C), in accordance with KG-311.4(c).

(f) Year built.

04 *(g)* Construction type:

HT = heat treated
PS = prestressed (autofrettaged or shrink fitted)
WL = welded layered
M = monobloc (solid wall)
F = forged
W = welded
UQT = quenched and tempered
WW = wire wound

FIG. KS-100 OFFICIAL SYMBOL FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD

KS-101 Methods of Marking Vessels With Two or More Independent Chambers

One of the following arrangements shall be used in marking vessels having two or more independent pressure chambers designed for the same or different operating conditions. Each detachable chamber shall be marked to identify it positively with the combined unit.

KS-101.1 If Markings Are Grouped in One Location. The markings may be grouped in one location on the vessel provided they are arranged to indicate clearly the data applicable to each chamber, including the maximum differential pressure for the common elements, when this pressure is less than the higher pressure in the adjacent chambers.

KS-101.2 If Each Independent Chamber Is Marked. The complete required marking may be applied to each independent pressure chamber, provided additional marking, such as name of principal chamber (e.g., process chamber, jacket, tubes) is used to indicate clearly to which chamber the data apply.

KS-110 APPLICATION OF STAMP

The ASME U3 symbol shall be applied by the Manufacturer only with the approval of the Inspector, and after the hydrostatic test has been satisfactorily made and all other required inspection and testing have been satisfactorily completed. Such application of the ASME U3 symbol, together with final certification in accordance with the rules of this Division, shall confirm that all applicable requirements of this Division and the User's Design Specification have been fulfilled.

KS-120 PART MARKING

(a) Parts of pressure vessels for which Partial Data Reports are required shall be marked by the Parts Manufacturer with the following:

(1) the appropriate ASME symbol stamp shown in Fig. KS-100 above the word "PART"

(2) the name of the manufacturer of the part, preceded by the words "Certified by"

(3) the manufacturer's serial number assigned to the part

(4) design pressure(s), psi (MPa), and coincident design metal temperature(s), °F (°C) [see KG-311.4(a) and (b)]

(5) minimum design metal temperature, °F (°C), at the maximum design pressure, psi (MPa)

(b) The requirements for part marking in accordance with KS-120(a)(4) and (a)(5) do not apply for the following conditions:

(1) for parts for which the Parts Manufacturer does not prepare a Manufacturer's Design Report

(2) for overpressure relief devices, which are covered in Part KR

04 *(c)* When pressure part weldments are supplied to the vessel Manufacturer by a subcontractor that possesses a certificate of authorization for a U or U2 stamp [see KG-420(c)], and the subcontractor submits to the Manufacturer Partial Data Reports, Form U-2, U-2A, or A-2, as appropriate.

KS-130 APPLICATION OF MARKINGS

Markings required in KS-100 through KS-120 shall be applied by one of the following methods.

KS-130.1 Nameplate. A separate corrosion-resistant nameplate, at least 0.15 in. thick, shall be permanently attached to the vessel or to an intervening support bracket. The attachment weld to the vessel shall not adversely affect the integrity of the vessel. Attachment by welding shall not be permitted on materials enhanced by heat treatment or on vessels that have been prestressed.

(a) Only the ASME Code symbol need be stamped on the nameplate.

(b) All other data may be stamped, etched, or engraved on the nameplate. See KS-132.

KS-130.2 Directly on Vessel Shell. Markings shall be stamped, with low stress type stamps, directly on the vessel, located on an area designated as a low stress area by the Designer (see KG-330) in the Manufacturer's Design Report (see KG-323). Markings made directly on the vessel shall not be made by the electro-etch method.

KS-130.3 Permanently Attached Tag. When the surface area of small parts is too small to permit the attachment of a nameplate or bracket, or by stamping directly on the part, the required markings shall be located on a permanently attached tag, subject to the prior agreement of the Inspector and the User. The method of attachment shall be described in the Manufacturer's Design Report.

KS-130.4 Adhesive Attachment. Nameplates may be attached with pressure-sensitive acrylic adhesive systems in accordance with Mandatory Appendix 5.

KS-131 Duplicate Nameplate

A duplicate nameplate may be attached on the support, jacket, or other permanent attachment to the vessel. All data on the duplicate nameplate, including the ASME U3 symbol, shall be cast, etched, engraved, or stamped. This marking need not be witnessed by the Inspector. The duplicate nameplate shall be marked "DUPLICATE." The use of duplicate nameplates, and the casting of the ASME symbol on the duplicate nameplate, shall be controlled as described in the Manufacturer's Quality Control System.

KS-132 Size and Arrangements of Characters

(a) The data shall be in characters not less than $^5\!/_{16}$ in. (8 mm) high and shall be arranged substantially as shown in Fig. KS-132.

(b) Where space limitations do not permit the requirements of KS-132(a) to be met, such as for parts with outside diameters of $3\frac{1}{2}$ in. (89 mm) or smaller, the

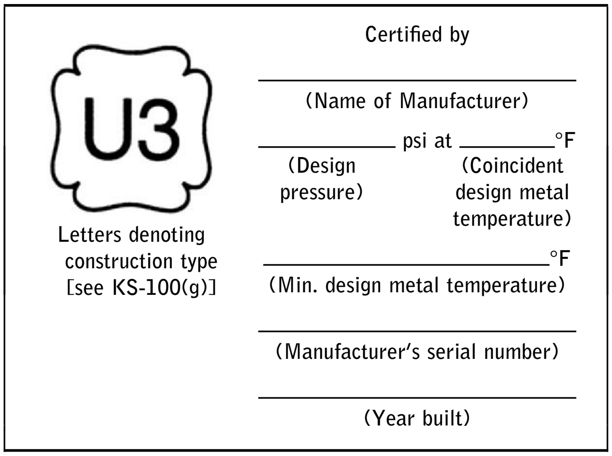


FIG. KS-132 FORM OF STAMPING
(U.S. Customary Units)

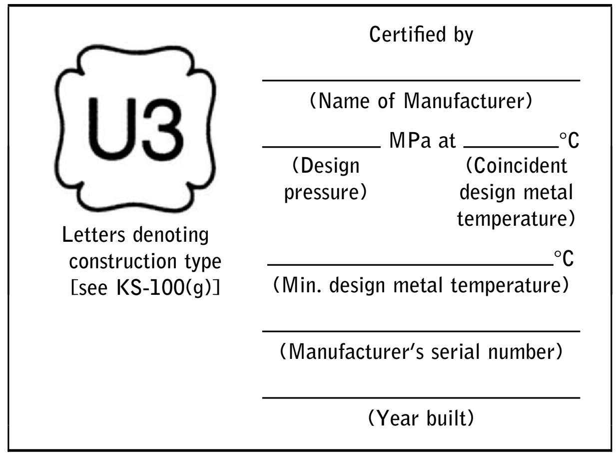


FIG. KS-132M FORM OF STAMPING
(SI Units)

required character size to be stamped directly on the vessel may be $\frac{1}{8}$ in. (3.2 mm).

KS-140 ATTACHMENT OF NAMEPLATE OR TAG

If all or part of the data is marked on the nameplate or tag before it is attached to the vessel, the Manufacturer shall ensure that the nameplate with the correct marking has been attached to the vessel to which it applies as described in his Quality Control System. The Inspector shall verify that this has been done.

ARTICLE KS-2
OBTAINING AND USING CODE STAMPS

KS-200 CODE STAMPS BEARING OFFICIAL SYMBOL

A Certificate of Authorization to use the Code U3 or UV3 (see Nonmandatory Appendix C) symbols shown in Fig. KS-100 and Fig. KR-401 will be granted by the Society pursuant to the provisions of the following paragraphs. Stamps for applying the Code symbol shall be obtained from the Society.

KS-210 APPLICATION FOR AUTHORIZATION

(a) Any organization desiring a Certificate of Authorization shall apply to the Boiler and Pressure Vessel Committee of the Society, on forms issued by the Society,[1] specifying the stamp desired and the scope of Code activities to be performed.

(b) When an organization intends to build Code items in plants in more than one geographical area, either separate applications for each plant or a single application listing the addresses of all such plants shall be submitted. Each application shall identify the accredited Authorized Inspection Agency providing Code inspection at each plant. A separate Certificate of Authorization will be prepared and a separate fee charged by the Society for each plant.

(c) Each applicant shall agree that each Certificate of Authorization and each Code symbol stamp are at all times the property of the Society, that they will be used in accordance with the rules and regulations of this Division of the Code, and that they will be promptly returned to the Society upon demand, or when the applicant discontinues the Code activities covered by this certificate, or when the Certificate of Authorization has expired and no new certificate has been issued. The holder of a Code symbol stamp shall not allow any other organization to use it.

[1] The application forms and related information and instructions may be obtained by writing to the Secretary, ASME Boiler and Pressure Vessel Committee, Three Park Avenue, New York, NY 10016-5990.

KS-220 ISSUANCE OF AUTHORIZATION

(a) Authorization to use the Code symbol stamps may be granted or withheld by the Society in its absolute discretion. If authorization is granted and the proper administrative fee paid, a Certificate of Authorization evidencing permission to use any such symbol, expiring on the triennial anniversary date thereafter, will be forwarded to the applicant. Each such certificate will identify the Code symbol to be used and the type of shop operations, field operations, or both for which authorization is granted (see Nonmandatory Appendix C). The certificate will be signed by the Chairman of the Boiler and Pressure Vessel Committee and the Director of Accreditation.

(b) Six months prior to the date of expiration of any such certificate, the applicant shall apply for a renewal of such authorization and the issuance of a new certificate.

(c) The Society reserves the absolute right to cancel or refuse to renew such authorization, returning, pro rata, fees paid for the unexpired term.

(d) The Boiler and Pressure Vessel Committee may at any time make such regulations concerning the issuance and use of Code symbol stamps as it deems appropriate, and all such regulations shall become binding upon the holders of valid Certificates of Authorization.

KS-230 INSPECTION AGREEMENT

(a) As a condition of obtaining and maintaining a Certificate of Authorization to use the U3 Code symbol stamp, the Manufacturer shall have in force at all times an inspection contract or agreement with an accredited Authorized Inspection Agency as defined in KG-431 to provide inspection services. This inspection agreement is a written agreement between the Manufacturer and the inspection agency which specifies the terms and conditions under which the inspection services are to be furnished and which states the mutual responsibilities of the Manufacturer and the Authorized Inspectors. A certificate holder shall notify the Society whenever his agreement with an accredited Authorized Inspection Agency is canceled or changed to another accredited Authorized Inspection Agency.

(b) Neither Manufacturers nor Assemblers of pressure relief valves are required to have an inspection agreement with an accredited Authorized Inspection Agency.

KS-240 QUALITY CONTROL SYSTEM

Any Manufacturer or Assembler holding or applying for a Certificate of Authorization to use the U3 or UV3 stamp shall demonstrate a Quality Control System to establish that all Code requirements shall be met. The Quality Control System of UV3 stamp holders shall include duties of a Certified Individual, as required by this Division. (See KR-410.)

KS-250 EVALUATION FOR AUTHORIZATION AND REAUTHORIZATION

(a) Before issuance or triennial renewal of a Certificate of Authorization for use of the U3 stamp, the Manufacturer's facilities and organization are subject to a joint review by a representative of his inspection agency and an individual certified as an ASME designee who is selected by the concerned legal jurisdiction. A written description or checklist of the Quality Control System which identifies what documents and what procedures the Manufacturer will use to produce a Code item shall be available for review.

(b) A written report to the Society shall be made jointly by the jurisdiction and the accredited Authorized Inspection Agency employed by the Manufacturer to do his Code inspection. This report is then reviewed by the Subcommittee on Boiler and Pressure Vessel Accreditation, which will either issue a Certificate of Authorization or notify the applicant of deficiencies revealed by the review. In the latter case, the applicant will be given an opportunity to explain or correct these deficiencies.

(c) Certificates of Authorization will be endorsed to indicate the scope of activity authorized. Authorization may include field operations if the review team determines that these operations are adequately described in the Quality Control Manual and this determination is accepted by the Society.

(d) Before issuance or renewal of a Certificate of Authorization for use of the UV3 stamp, the valve Manufacturer's or Assembler's facilities and organization are subject to a review by an ASME designee. A written description or checklist of the Quality Control System, which identifies the documents and procedures the Manufacturer or Assembler will use to produce Code pressure relief valves, shall be available for review. The ASME designee shall make a written report to the Society, where the Subcommittee on Boiler and Pressure Vessel Accreditation will act on it as described above.

(e) The purpose of the review by an ASME designee is to evaluate the applicant's Quality Control System and its implementation. The applicant shall demonstrate sufficient administrative and fabrication functions of the system to show that he has the knowledge and ability to produce the Code items covered by his Quality Control System. Fabrication functions may be demonstrated using current work, a mock-up, or a combination of the two.

(f) The Manufacturer may at any time make changes in the Quality Control System concerning the methods of achieving results, subject to acceptance by the Authorized Inspector. For Manufacturers and Assemblers of "UV3" stamped pressure relief valves, such acceptance shall be by the ASME designated organization.

(g) For those areas where there is no jurisdiction or where a jurisdiction does not choose to select an ASME designee to review a Manufacturer's facility, that function shall be performed by an ASME designee selected by ASME. Where the jurisdiction is the Manufacturer's inspection agency, the joint review and joint report shall be made by the jurisdiction and the ASME designee.

KS-260 CODE CONSTRUCTION BEFORE RECEIPT OF CERTIFICATE OF AUTHORIZATION

When used to demonstrate his Quality Control System, a Manufacturer may start fabricating Code items before receipt of a Certificate of Authorization to use a Code symbol stamp under the following conditions:

(a) the fabrication is done with the participation of the Authorized Inspector and is subject to his acceptance

(b) the activity is in conformance with the applicant's Quality Control System

(c) the item is stamped with the appropriate Code symbol and certified once the applicant receives his Certificate of Authorization from the Society

ARTICLE KS-3
REPORT FORMS AND MAINTENANCE OF RECORDS

KS-300 MANUFACTURER'S DATA REPORTS

(a) A Data Report shall be completed (Form K-1) by the Manufacturer and the Inspector for each pressure vessel to be marked with the Code symbol.

(1) For sample report forms and guidance in preparing Data Reports, see Nonmandatory Appendix A.

(2) A Data Report shall be filled out on Form K-1 or Form K-3 by the Manufacturer and shall be signed by the Manufacturer and the Inspector for each pressure vessel marked with the Code U3 symbol. Same-day production of vessels may be reported on a single form provided all of the following requirements are met:

(a) vessels must be identical

(b) vessels must be manufactured for stock or for the same user or his designated agent

(c) serial numbers must be in uninterrupted sequence

(d) the Manufacturer's written Quality Control System includes procedures to control the development, distribution, and retention of the Data Reports

The number of lines on the Data Report used to describe multiple components (e.g., nozzles, shell courses) may be increased or decreased as necessary to provide space to describe each component. If addition of lines used to describe multiple components results in the Data Report exceeding one page, space must be provided for the Manufacturer and Authorized Inspector to initial and date each of the additional pages. Horizontal spacing for information on each line may be altered as necessary. All information must be addressed; however, footnotes described in the remarks block are acceptable, e.g., for multiple cases of "none" or "not applicable."

(3) Size shall be standard size, 8.5 in. × 11 in. (A4, 210 mm × 297 mm), white bond paper.

(4) Forms may be reprinted, typed, or computer generated.

(5) Forms shall not contain advertising slogans, logos, or other commercial matter. Use only black ink.

(6) Method of completing the Data Report shall be consistent. The report shall be typed or handwritten using legible printing. Handwritten additions or corrections shall be initialed and dated by the Manufacturer's representative and the Authorized Inspector.

(7) Samples of the Manufacturer's Data Reports that the Manufacturer will use shall be submitted to the Inspector for review and approval before use.

(b) The Manufacturer shall

(1) furnish a copy of the Manufacturer's Data Report to the User and to the Inspector

(2) submit a copy of the Manufacturer's Data Report to the appropriate enforcement authority in the jurisdiction in which the vessel is to be installed where required by law

KS-301 Partial Data Reports

(a) The Parts Manufacturer shall indicate under "Remarks" whether or not he has performed any or all of the design functions. For guidance in preparing Partial Data Reports, see Nonmandatory Appendix A.

(b) Partial Data Reports for pressure vessel parts requiring examination under this Division, which are furnished to the Manufacturer responsible for the completed vessel, shall be executed by the Parts Manufacturer's Inspector in accordance with this Division (see KG-322). The vessel shall not be stamped until the Authorized Inspector has reviewed and accepted all Partial Data Reports pertinent to the vessel. All Partial Data Reports, Forms U-2, U-2A, A2, and K-2, as appropriate, shall be attached to the Manufacturer's Data Report, Form K-1. 04

KS-302 Replacement Parts

Partial Data Reports for those parts of a pressure vessel which are furnished by a Parts Manufacturer to the User of an existing Code vessel, as replacement parts, shall be executed on Form K-2 by the Parts Manufacturer and his Inspector in accordance with the requirements of this Division. A copy of the Parts Manufacturer's Partial Data Report shall be furnished to the User or his designated Agent and a copy shall be maintained in accordance with KS-320.

KS-310 MAINTENANCE OF RADIOGRAPHS

A complete set of radiographs as described in T-291 and T-292 of Article 2 of Section V, for each vessel or vessel part, shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector. Reports of examinations shall be included in the Manufacturer's Construction Records (see KS-320).

KS-320 MAINTENANCE OF RECORDS

The Manufacturer shall furnish to the User the records listed below:

(a) User's Design Specification complete with all reference documents (KG-311)

(b) Manufacturer's Data Report (KS-300)

(c) Manufacturer's Design Report (KG-323)

(d) Manufacturer's Construction Records:

(1) as-built drawings

(2) materials certifications, all Material Test Reports, record of repairs

(3) Welding Procedures (KF-216)

(4) weld repair reports (KF-245)

(5) NDE Examination Procedures, Records of Procedure Qualification, and Records of Personnel Qualifications (KE-105)

(6) record of all heat treatments (these records may be either the actual heat treatment charts or a certified summary description of heat treatment time and temperature)

(7) prestressing procedures and verification data

(8) NDE reports and as-built sketches showing all relevant NDE indications

(9) record of nonconformances and disposition

MANDATORY APPENDICES

MANDATORY APPENDIX 1
NOMENCLATURE

04 1-100 NOMENCLATURE

A = interference pressure factor (KD-811)
= actual discharge area of relief device (KR-531)
= nozzle or opening reinforcement area (H-120)
A_B = cross-sectional area of a vessel normal to the vessel axis through female threads (E-210)
A_b = total cross-sectional area of the bolts per clamp lug (G-300)
A_C = cross-sectional area of a closure normal to the vessel axis through female threads (E-210)
A_c = cross-sectional area of closure (E-210)
= total cross-sectional area of the clamp (G-300)
A_{c1} = partial clamp area (G-300)
A_{c2} = partial clamp area (G-300)
A_{c3} = partial clamp area (G-300)
A_{cs} = cross-sectional area (KD-502)
A_g = gap area (Fig. KF-826)
A_m = required cross-sectional area of the bolts per clamp (G-300)
A_{m1} = cross-sectional area of the bolts, gasket seating (G-300)
A_{m2} = cross-sectional area of the bolts, operating (G-300)
A_o = outside diameter of the hub (G-300)
A_{or} = outside bearing diameter of the hub (G-300)
A_3 = lesser of A_{3a} and A_{3b} (G-300)
A_{3a} = hub longitudinal shear area based on straight shear (G-300)
A_{3b} = hub longitudinal shear area based on 45 deg conical (G-300)
A_5 = minimum clamp cross-sectional area, radial–tangential (G-300)
A_{5b} = maximum clamp bolt hole cutout area (G-300)
A_{5i} = individual clamp bolt hole cutout area (G-300)
A_6 = minimum clamp cross-sectional area, tangential–longitudinal (G-300)
A_{6b} = maximum clamp bolt hole cutout area (G-300)
A_{6i} = individual clamp bolt hole cutout area (G-300)
A_7 = clamp lip longitudinal shear area, lesser of A_{7a} and A_{7b} (G-300)
A_{7a} = clamp lip longitudinal shear area, straight shear surface (G-300)
A_{7b} = clamp lip longitudinal shear area, 45 deg conical (G-300)
B = inside diameter of hub (G-300)
B_c = radial distance from connection centerline to center of bolts (G-300)
C = fatigue crack growth coefficient (Table KD-430)
= relief valve factor for specific heat ratio (KR-531)
= coefficient based on geometry of a blind end (E-120)
= diameter of effective clamp–hub reaction circle (G-300)
C_{depth} = cavity depth below required thickness (KE-211)
C_g = effective clamp gap (G-300)
C_i = inside bearing diameter of clamp (G-300)
C_{ir} = inside bearing diameter of clamp with corner radius (G-300)
C_n = inside diameter of neck of the clamp (G-300)
C_r = thread factor (E-210)

C_t = effective clamp thickness (G-300)
C_w = clamp width (G-300)
C_6 = tangential bending stress moment arm (G-300)
COD = repair cavity diameter (KE-211)
CP = collapse pressure (KD-1212, KD-1222, KD-1241, KD-1243, KD-1253)
$CTOD$ = crack tip opening displacement [KM-250, D-600(b)(2)]
CVN = Charpy V-notch impact strength (D-600, KM-250)
D = any referenced diameter in a cylinder or sphere (KD-502, KD-802)
D_I = diameter at inside surface (KD-502, KD-802, KD-811, KD-911)
D_{if} = diameter at interface of layers (KD-802, KD-811, KD-911)
D_n = diameter of outside surface of layer *n*, (KD-802)
D_O = outside diameter (KD-502, KD-802, KD-811, KD-822, KD-911)
D_{op} = diameter of opening in a blind end (E-110)
D_p = elastic–plastic interface diameter in autofrettage (KD-502)
= pitch diameter of thread (E-210)
D_w = outside diameter of winding (KD-911)
D_Z = autofrettage depth (KD-502, KD-522)
E = Young's modulus, material property
E_I = inner layer Young's modulus (KD-802)
E_O = outer layer Young's modulus (KD-802)
F = peak stress (KD-210, KD-220, Fig. KD-230)
= gap value (KF-826)
= reinforcing area reduction factor for axis angle (H-120)
F_b = correction factor for the Bauschinger effect (KD-502, KD-522.2, KD-523)
F_c = permissible layer gap factor (KD-802)
F_l = force in the longitudinal direction (KD-502)
F_n = load on thread *n* (E-210)
F_T = total load on threads (E-210)
F_1 = magnification factor for calculating stress intensity of internal radial–circumferential cracks (D-403)
F_2 = magnification factor for calculating stress intensity of internal radial–circumferential cracks (D-403)
F_3 = magnification factor for calculating stress intensity of internal radial–circumferential cracks (D-403)
F_4 = magnification factor for calculating stress intensity of internal radial–circumferential cracks (D-403)
G = material property (KD-430)
= gasket load reaction diameter (G-300)
H = specific stiffness (D-405)
= total end force on hub for operating or assembly (G-300)
H_D = hydrostatic end force on bore area (G-300)
H_e = total hydrostatic end force (G-300)
H_G = difference between hub preload and required forces (G-300)
H_m = gasket seating requirements (G-300)
H_p = joint-contact surface compression load (G-300)
H_T = difference between total hydrostatic end force and on bore (G-300)
H_2 = correction factor for bending stress (D-401)
I = material property (KD-430)
I_c = moment of inertia of clamp (G-300)
I_h = moment of inertia of hub shoulder (G-300)
I_5 = minimum clamp moment of inertia in any radial–tangential plane (G-300)
I_{5b} = maximum reduction clamp moment of inertia bolt holes (G-300)
I_6 = minimum clamp moment of inertia in any tangential–longitudinal plane (G-300)
I_{6b} = maximum reduction clamp moment of inertia bolt holes (G-300)
J_{Ic} = critical stress intensity for plane stress (KM-250, D-600)
K = stress concentration factor (Fig. KD-230)
= 0.73 times transition radius r_2 (H-142)
K_D = relief device discharge coefficient (KR-523, Fig. KR-523.3, KR-531)
K_I = stress intensity factors in a crack (KD-420, KD-440)
$K_{I\max}$ = maximum stress intensity factor in a crack (KD-430)
$K_{I\min}$ = minimum stress intensity factor in a crack (KD-430)
K_{Ires} = residual stress intensity in a crack (KD-420, KD-430)
K_{Ic} = critical stress intensity factor for crack (KM-250)
= fracture toughness (KD-401)
K_{IREF} = crack tip stress intensity factor (D-405)
K_N = wire design factor (KD-932)
K_n = greater of 2.6 or $(K_s)^{4.3}$ (KD-1262)
K_r = surface roughness factor (KD-322)
K_S = wire design factor (KD-932)
K_{SL} = wire design factor (KD-932)
K_{SS} = wire design factor (KD-932)
K_s = greater of 1.25 or $K_{sa}K_{sf}K_{sc}K_{st}K_{ss}$ (KD-1262)
K_{sa} = factor for size of highly stressed fatigue area (KD-1262)

K_{sc} = factor for fatigue curves at varying temperatures (KD-1262)
K_{sf} = factor for fatigue surface finish (KD-1262)
K_{ss} = factor for statistical variation in fatigue tests (KD-1262)
K_{st} = factor for fatigue test temperature (KD-1262)
K_{th} = threshold stress intensity (KD-430)
K_{TN} = test life ratio (KD-1262)
K_{TS} = test stress ratio (KD-1262)
= length along nozzle with thickness t_n plus transition (H-142)
L_a = distance from clamp bolt centerline to where clamp lug joins body (G-300)
L_d = design fatigue life (KD-330)
L_h = clamp lug height (G-300)
L_T = length of wire pieces in fatigue test (KD-932.3)
L_W = average distance between wire cracks (KD-932.3)
L_w = clamp lug width (G-300)
L_1 = measured length of vessel at test pressure
M = molecular weight (KR-523.3, KR-531)
= correction factor for membrane stress (D-401)
= mean flexibility of vessel body and end closure (E-210)
M_D = moment due to H_D (G-300)
M_F = offset moment (G-300)
M_G = moment due to H_G (G-300)
M_H = reaction moment at hub neck (G-300)
M_o = total rotational moment on hub (G-300)
M_p = pressure moment (G-300)
M_R = radial clamp equilibrating moment (G-300)
M_T = moment due to H_T (G-300)
M_5 = clamp longitudinal stress bending moment (G-300)
M_6 = clamp tangential stress bending moment (G-300)
N = number of layers (KD-802)
N_D = design number of alternating stress cycles (KD-932, KD-1262)
N_f = design limit number of alternating stress cycles (KD-320)
N_H = outside diameter of hub neck (G-300)
N_i = allowable number of cycles for vessel service life (KD-330)
N_p = design operating cycles to one-fourth critical crack depth (KD-440)
N_T = number of test cycles (KD-1262)
$N_{T\min}$ = minimum number of test cycles (KD-1262)
P = design pressure (KD-802, G-300)
= set pressure of relief device (KR-520)
= fluid pressure acting in a crack (D-401)
P_A = maximum autofrettage pressure (KD-502)
P_B = back pressure on relief device (KR-523)
P_b = bending stress (KD-220, Fig. KD-230)
P_D = design pressure (KD-250)
P_{if} = interface pressure (KD-802)
P_L = local membrane stress (KD-210, KD-220)
P_m = general membrane stress (KD-220)
P_n = pressure at layer interface (KD-802)
P_T = cyclic test loading (KD-1262)
P_t = hydrostatic test pressure (KD-824, KT-312)
Q = secondary membrane plus bending stress (KD-220, Fig. KD-230)
= reaction shear force at hub neck (G-300)
Q_c = percent of theoretical circumferential growth measured on outside (KD-802)
= acceptance criteria (KD-822, KD-823)
R_c = corner radius (E-110)
R_f = final centerline radius of formed head (KF-602)
R_g = outside radius of layer below gap (Fig. KF-826)
R_I = radius to inside surface of innermost layer (KF-826)
R_K = stress intensity factor ratio (KD-430)
R_m = radius of midsurface of head or shell (KD-231, KD-721, KE-211)
R_O = outside radius of vessel (KF-826)
R_o = original centerline radius of formed plate (KF-602)
S = stress intensity (KD-210)
= slope of flow test data for relief valves (KR-522)
S_a = allowable fatigue strength (KD-120)
= allowable bolt stress, room temperature (G-300)
S_{a10^n} = stress intensity at design load (KD-1262)
S'_a = allowable amplitude of alternating stress (KD-312.4)
S_{aD} = design stress, allowable (KD-1262)
S_{alt} = alternating stress intensity (KD-302)
S_b = allowable bolt stress, design temperature (G-300)
S_{eq} = equivalent calculated alternating stress intensity (KD-312.4)
S_u = ultimate tensile strength (Table U-2 in Section II, Part D)
$S_w(x)$ = stress in wire (KD-911)
S_y = yield strength (KD-120, KD-1254)
S_{yact} = actual yield stress (KD-1254)
S_{yms} = actual yield strength per material specification (KD-1254)
S_{YAC} = yield stress for clamp material, room temperature (G-300)

S_{YAH} = yield stress for hub material, room temperature (G-300)
S_{YOC} = yield stress for clamp material, design temperature (G-300)
S_{YOH} = yield stress for hub material, design temperature (G-300)
S_1 = hub longitudinal stress on outside hub neck (G-300)
S_2 = maximum Lamé hoop stress at hub bore (G-300)
S_3 = hub shear stress at shoulder (G-300)
S_4 = hub radial stress in hub neck (G-300)
S_5 = clamp longitudinal stress at clamp body inner diameter (G-300)
S_6 = clamp tangential stress at clamp body outer diameter (G-300)
S_7 = maximum shear stress in clamp lips (G-300)
S_8 = clamp lip bending stress (G-300)
S_9 = clamp lug bending stress (G-300)
S_{10} = maximum clamp lug shear stress (G-300)
S_{11} = effective bearing stress between clamp and hub (G-300)
T = absolute temperature
= thickness (KM-201, KM-210, KM-211.1)
= maximum heat-treated thickness (KM-211)
= thickness of hub shoulder (G-300)
T_c = critical temperature (KD-1262)
= clamp lip thickness below outside edge hub (G-300)
T_h = hub shoulder thickness below inside edge hub (G-300)
T_t = test temperature (KD-1262)
U = cumulative usage factor (KD-330)
V_{REF} = longitudinal crack displacement (D-405)
W = mass flow of any gas or vapor (KR-523.3, KR-531)
= total design bolt load (G-300)
W_a = rated air flow for relief device (KR-531)
W_c = total effective clamping preload on one lip (G-300)
W_{m1} = minimum operating bolt load (G-300)
W_{m2} = minimum gasket seating bolt load (G-300)
W_T = theoretical mass flow (KR-523.3)
X_b = basic clamp dimension to neutral axis (G-300)
X_i = average radial distance from bolt cutout area (G-300)
X_5 = modified clamp dimension to neutral axis (G-300)
X_6 = modified clamp dimension to neutral axis (G-300)
Y = wall ratio or D_O/D_I of a shell (KD-250, KD-502)
= weld offset (Fig. KD-830.2)
Y_i = ratio of outside diameter to inside diameter of inner layer (KD-802)
Y_o = ratio of outside diameter to inside diameter of outer layer (KD-802)
Z = D_O/D, where D can be any point in the wall (KD-250)
= compressibility factor (KR-531)
= clamp–hub taper angle (G-300)
a = crack depth (D-401)
b = length of gap between layers (KF-826)
d = diameter in given plane of finished opening (H-120)
d_{op} = maximum opening diameter (E-110, Fig. E-110)
d_S = root diameter of a stud (KD-615)
e = constant = 2.718
e_b = radial distance from bolts to centroid of clamp (G-300)
e_m = actual circumferential growth (KD-802, KD-822, KD-824, KF-827)
e_{th} = theoretical circumferential expansion (KD-802, KD-822, KD-824)
f = hub stress correction factor (G-300)
$\overline{g}$ = radial distance from hub inside diameter to centroid hub shoulder ring (G-300)
g_0 = thickness of hub at small end (G-300)
g_1 = thickness of hub at neck (G-300)
g_2 = height of hub shoulder (G-300)
h = distance from flange face to end of skirt [Fig. KD-830.3, sketch (c)]
= gap between two layers (KF-826)
h_D = radial distance clamp–hub reaction circle to H_D (G-300)
h_G = radial distance clamp–hub reaction circle to H_G (G-300)
h_n = hub neck length (G-300)
h_T = radial distance clamp–hub reaction circle to H_T (G-300)
h_2 = average thickness of hub shoulder (G-300)
k = C_p/C_v ratio of specific heats
= combination loading factor (Fig. KD-230)
ℓ = length of required taper (Fig. KD-1121)
= surface length of crack (D-401)
ℓ_c = effective clamp lip length (G-300)
= circumferential separation of nozzle centerlines (H-101)
ℓ_ℓ = longitudinal separation of nozzle centerlines (H-101)
ℓ_m = effective clamp lip moment arm (G-300)
m = crack growth rate exponent (KD-430, Table KD-430)
= gasket factor (G-300)

n = number of layer (KD-802)
= number of fully engaged threads (E-210)
n_i = number of applied alternating stress cycles (KD-330)
r = radius between flat head and shell (Fig. KD-830.3, KD-1112)
= clamp or hub cross section corner radius (G-300)
= inside radius of nozzle (H-142)
r_c = clamp inside corner radius (G-300)
r_h = hub outside corner radius (G-300)
r_m = mean radius of nozzle (H-142)
r_2 = transition radius inside nozzle to vessel wall (H-142)
t = distance between highly stressed surface and the nearest quenched surface (KM-211.2)
= wall thickness, nominal vessel thickness (KD-220, KD-802, H-142)
t_b = thickness of blind end (E-110)
t_H = thickness of head at joint (Fig. KD-830.2)
t_L = thickness of layer at joint (Fig. KD-830.2)
t_n = thickness of layer n (KD-802)
= nominal thickness of nozzle wall less corrosion allowance (Fig. KD-830.6)
= thickness of nozzle wall (Fig. KD-1130)
t_p = thickness of attached pipe wall (H-142)
t_r = minimum wall thickness without opening (H-120)
t_{rn} = required thickness of seamless nozzle wall (Fig. KD-1122)
t_S = shell thickness (Fig. KD-830.2)
t_w = thickness of vessel wall (E-110)
x = diameter at any point (KD-911)
x_1 = any diameter of cylinder (KD-911)
x_2 = any diameter of winding (KD-911)
y = radial offset in buttwelding of unequal section thicknesses (Fig. KD-1121)
α = shape factor (KD-210, Fig. KD-230, KD-240)
= angle, maximum angle (Fig. KE-321)
= maximum rake angle (E-110)
α_r = thermal expansion of reinforcing metal (H-150)
α_v = thermal expansion of vessel wall (H-150)
β = factor in equivalent alternating stress intensity (KD-312)
= factor = 0.2 (KD-932)
Δ = difference, increment
ΔK = range of stress intensity factor (KD-430)
$\overline{\Delta s}$ = average relative standard deviation of fatigue strength (KD-932.3)
ΔT = operating temperature range (H-150)
δ = any difference, diametral interference (KD-802)
ϵ_m = average tangential strain, autofrettaged outside diameter (KD-502)
ϵ_p = average tangential strain, autofrettaged bore (KD-502)
μ = viscosity
= friction angle (G-300)
ν = Poisson's ratio (KD-802); also sometimes viscosity
ν_i = inner layer Poisson's ratio (KD-802)
ν_o = outer layer Poisson's ratio (KD-802)
π = constant = 3.14159
ρ = mass density (KR-523)
Σ = summation
σ = normal or principal stresses, with various subscripts
σ_{AD} = value of σ_{tRA} at $D = D_I$ (KD-502)
σ_{CD} = residual tangential stress at bore, including the Bauschinger effect (KD-502)
σ_{nm} = associated mean stress (KD-302.2)
σ_R = radial stress component at radius r (KD-802)
σ_{rR} = radial stress at bore, including the Bauschinger effect (KD-522)
σ_{tr} = residual tangential stress (KD-802)
σ_{rr} = residual radial stress (KD-802)
σ_{rRA} = first approximation of residual radial stress after autofrettage (KD-522)
σ_t = tangential stress component at radius r (KD-802)
σ_{tR} = residual tangential stress, including the Bauschinger effect (KD-522)
σ_{tRA} = first approximation of residual tangential stress after autofrettage (KD-522)
τ = shear stresses, with various subscripts
Φ = flaw shape parameter (D-401)
ϕ = clamp shoulder angle (G-300)

MANDATORY APPENDIX 2
QUALITY CONTROL SYSTEM

04 2-100 GENERAL

The Manufacturer or Assembler shall have and maintain a Quality Control System which will establish that all Code requirements, including material, design, fabrication, examination (by the Manufacturer or Assembler), and inspection of vessels and vessel parts (by the Inspector), will be met. The Quality Control System of UV3 stamp holders shall include duties of a Certified Individual, as required by this Division. The Certified Individual authorized to provide oversight may also serve as the Certificate Holder's authorized representative responsible for signing data reports or certificates of conformance. Provided that Code requirements are suitably identified, the system may include provisions for satisfying any requirements by the Manufacturer, Assembler, or user which exceed minimum Code requirements and may include provisions for quality control of non-Code work. In such systems, the Manufacturer of vessels and vessel parts may make changes in parts of the system which do not affect the Code requirements without securing acceptance by the Inspector (see KG-300). Before implementation, revisions to Quality Control Systems of Manufacturers and Assemblers of pressure relief valves shall have been found acceptable by an ASME designee if such revisions affect Code requirements.

The system that the Manufacturer or Assembler uses to meet the requirements of this Division must be one suitable for his own circumstances. The necessary scope and detail of the system shall depend on the complexity of the work[1] performed and on the size and complexity of the Manufacturer's organization.[2] A written description of the system the Manufacturer or Assembler will use to produce a Code item shall be available for review. Depending upon the circumstances, the description may be brief or voluminous.

The written description may contain information of a proprietary nature relating to the Manufacturer's processes. Therefore, the Code does not require any distribution of this information except for the Inspector's or ASME designee's copy as covered by 2-123(c) and 2-124(c). It is intended that information learned about the system in connection with the evaluation will be treated as confidential and that all loaned descriptions will be returned to the Manufacturer or Assembler upon completion of the evaluation.

2-110 OUTLINE OF FEATURES TO BE INCLUDED IN THE WRITTEN DESCRIPTION OF THE QUALITY CONTROL SYSTEM

The following is a guide to some of the features which should be covered in the written description of the Quality Control System and is equally applicable to both shop and field work.

(a) See Article KE-1.

(b) The complexity of the work includes factors such as design simplicity versus complexity, the types of materials and welding procedures used, the thickness of materials, the types of nondestructive examinations applied, and whether heat treatments are applied.

(c) The size and complexity of the Manufacturer's or Assembler's organization includes factors such as the number of employees, the experience level of employees, the number of vessels produced, and whether the factors defining the complexity of the work cover a wide or narrow range.

2-111 AUTHORITY AND RESPONSIBILITY

The authority and responsibility of those in charge of the Quality Control System shall be clearly established. Persons performing quality control functions shall have sufficient and well-defined responsibility, the authority, and the organizational freedom to identify quality control problems and to initiate, recommend, and provide solutions.

[1] The complexity of the work includes factors such as design simplicity versus complexity, the types of materials and welding procedures used, the thickness of materials, the types of nondestructive examinations applied, and whether heat treatments are applied.

[2] The size and complexity of the organization includes factors such as the number of employees, the experience level of employees, the number of Code items produced, and whether the factors defining the complexity of the work cover a wide or narrow range.

2-112 ORGANIZATION

An organization chart showing the relationship between management and engineering, purchasing, manufacturing, field construction, inspection, and quality control is required to reflect the actual organization. The purpose of this chart is to identify and associate the various organizational groups with the particular function for which they are responsible. The Code does not intend to encroach on the Manufacturer's or Assembler's right to establish, and from time to time to alter, whatever form of organization the Manufacturer or Assembler considers appropriate for its Code work.

2-113 DRAWINGS, DESIGN CALCULATIONS, AND SPECIFICATION CONTROL

The Manufacturer's or Assembler's Quality Control System shall provide procedures which will assure that the latest applicable drawings, design calculations, specifications, and instructions, required by the Code, as well as authorized changes, are used for manufacture, examination, inspection, and testing. The system shall insure that authorized changes are included, when appropriate, in the User's Design Specification and/or in the Manufacturer's Design Report.

2-114 MATERIAL CONTROL

The Manufacturer or Assembler shall include a system of receiving control which will insure that the material received is properly identified and has documentation including required material certifications or material test reports to satisfy Code requirements as ordered. The system material control shall insure that only the intended material is used in Code construction.

2-115 EXAMINATION AND INSPECTION PROGRAM

The Manufacturer's or Assembler's Quality Control System shall describe the fabrication operations, including examination, sufficiently to permit the Inspector or ASME designee to determine at what stages specific inspections are to be performed.

2-116 CORRECTION OF NONCONFORMITIES

There shall be a system agreed upon with the Inspector for correction of nonconformities. A nonconformity is any condition which does not comply with the applicable rules of this Division. Nonconformities must be corrected or eliminated in some way before the completed component can be considered to comply with this Division.

2-117 WELDING

The Quality Control System shall include provisions for indicating that welding conforms to requirements of Section IX as supplemented by this Division.

2-118 NONDESTRUCTIVE EXAMINATION

The Quality Control System shall include provisions for identifying nondestructive examination procedures the Manufacturer or Assembler will apply to conform with the requirements of this Division.

2-119 HEAT TREATMENT

The Quality Control System shall provide controls to ensure that heat treatments as required by the rules of this Division are applied. Means shall be indicated by which the Inspector or ASME designee can satisfy himself that these Code heat treatment requirements are met. This may be by review of furnace time– temperature records or by other methods as appropriate.

2-120 CALIBRATION OF MEASUREMENT AND TEST EQUIPMENT

The Manufacturer or Assembler shall have a system for the calibration of examination, measuring, and test equipment used in fulfillment of requirements of this Division.

2-121 RECORDS RETENTION

The Manufacturer or Assembler shall have a system for the maintenance of Data Reports and records as required by this Division.

2-122 SAMPLE FORMS

The forms used in this Quality Control System and any detailed procedures for their use shall be available for review. The written description shall make necessary references to these forms.

2-123 INSPECTION OF VESSELS AND VESSEL PARTS

(a) Inspection of vessels and vessel parts shall be by the Inspector as defined in Article KG-4.

(b) The written description of the Quality Control System shall include reference to the Inspector.

(c) The Manufacturer shall make available to the Inspector, at the Manufacturer's plant or construction site, a current copy of the written description of the Quality Control System.

(d) The Manufacturer's Quality Control System shall provide for the Inspector at the Manufacturer's plant to have access to the User's Design Specification, the Manufacturer's Design Report, and all drawings, calculations, specifications, procedures, process sheets, repair procedures, records, test results, and any other documents as necessary for the Inspector to perform his duties in accordance with this Division. The Manufacturer may provide such access either to his own files of such documents or by providing copies to the Inspector.

2-124 INSPECTION OF PRESSURE RELIEF VALVES

(a) Inspection of pressure relief valves shall be by a designated representative of ASME, as described in KR-331.

(b) The written description of the Quality Control System shall include reference to the ASME designee.

(c) The valve Manufacturer or Assembler shall make available to the ASME designee, at the Manufacturer's or Assembler's plant, a current copy of the written description of the applicable Quality Control System.

(d) The valve Manufacturer's or Assembler's Quality Control System shall provide for the ASME designee to have access to all drawings, calculations, specifications, procedures, process sheets, repair procedures, records, test results, and any other documents as necessary for the designee to perform his duties in accordance with this Division. The Manufacturer may provide such access either to his own files of such documents or by providing copies to the designee.

MANDATORY APPENDIX 3
SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL COMMITTEE

3-100 INTRODUCTION

The ASME Boiler and Pressure Vessel Committee and its Subcommittees, Subgroups, and Working Groups meet regularly to consider revisions of the Code rules, new Code rules as dictated by technological development, Code Cases, and Code interpretations. This Appendix provides guidance to Code users for submitting technical inquiries to the Committee. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code interpretations.

Code Cases may be issued by the Committee when the need is urgent. Code Cases clarify the intent of existing Code requirements or provide alternative requirements. Code Cases are written as a question and a reply, and are usually intended to be incorporated into the Code at a later date. Code interpretations provide the meaning of or the intent of existing rules in the Code and are also presented as a question and a reply. Both Code Cases and Code interpretations are published by the Committee.

The Code rules, Code Cases, and Code interpretations established by the Committee are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers or constructors to choose any method of design or any form of construction that conforms to the Code rules.

As an alternative to the requirements of this Appendix, members of the Committee and its Subcommittees, Subgroups, and Working Groups may introduce requests for Code revisions or additions, Code Cases, and Code interpretations at their respective Committee meetings or may submit such requests to the Secretary of a Subcommittee, Subgroup, or Working Group.

Inquiries that do not comply with the provisions of this Appendix or that do not provide sufficient information for the Committee's full understanding may result in the request being returned to the inquirer with no action.

3-200 INQUIRY FORMAT

Submittals to the Committee shall include:

(a) Purpose. Specify one of the following:

(1) revision of present Code rule(s)

(2) new or additional Code rule(s)

(3) Code Case

(4) Code interpretation

(b) Background. Provide the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda, paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) Presentations. The inquirer may desire or be asked to attend a meeting of the Committee to make a formal presentation or to answer questions from the Committee members with regard to the inquiry. Attendance at a Committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the Committee.

3-300 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following:

(a) Proposed Revision(s) or Addition(s). For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code, marked up with the proposed revision. For additions, provide the recommended wording referenced to the existing Code rules.

(b) Statement of Need. Provide a brief explanation of the need for the revision(s) or addition(s).

(c) Background Information. Provide background information to support the revision(s) or addition(s) including any data or changes in technology that form the basis for the request that will allow the Committee

to adequately evaluate the proposed revision(s) or addition(s). Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision(s) or addition(s), and identify paragraphs in the Code that reference the paragraphs that are to be revised or added.

3-400 CODE CASES

Requests for Code Cases shall provide a *Statement of Need* and *Background Information* similar to that defined in 3-300(b) and 3-300(c), respectively, for Code revisions or additions. The proposed Code Case should identify the Code Section and Division and be written as a *Question* and a *Reply* in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code Edition(s) and Addenda to which the proposed Code Case applies.

3-500 CODE INTERPRETATIONS

Requests for Code interpretations shall provide the following:

(a) Inquiry. Provide a condensed and precise question, omitting superfluous background information and, when possible, composed in such a way that a "yes" or a "no" *Reply,* possibly with brief provisos, is acceptable. The question should be technically and editorially correct.

(b) Reply. Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be "yes" or "no," possibly with brief provisos.

(c) Background Information. Provide any background information that will assist the Committee in understanding the proposed *Inquiry* and *Reply.*

3-600 SUBMITTALS

Submittals to and responses from the Committee shall meet the following:

(a) Submittal. Inquiries from Code users shall preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, and fax number, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Three Park Avenue
New York, NY 10016-5990

(b) Response. The Secretary of the ASME Boiler and Pressure Vessel Committee or of the appropriate Subcommittee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the Code Committee.

MANDATORY APPENDIX 4
ACCEPTANCE OF TESTING LABORATORIES AND AUTHORIZED OBSERVERS FOR CAPACITY CERTIFICATION OF PRESSURE RELIEF DEVICES

4-100 SCOPE

These rules cover the requirements for ASME acceptance of testing laboratories and Authorized Observers for conducting capacity certification tests of pressure relief valves.

4-200 TEST FACILITIES AND SUPERVISION

The tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and the qualifications of the Authorized Observer shall be subject to the acceptance of ASME on recommendation of a representative from an ASME-designated organization. Acceptance of the testing facility is subject to review within each 5-year period. The testing laboratory shall have available for reference a copy of ASME PTC 25 and this Division.

4-300 ACCEPTANCE OF TESTING FACILITY

Before a recommendation is made to the ASME Boiler and Pressure Vessel Committee on the acceptability of a testing facility, a representative from an ASME- designated organization shall review the applicant's Quality Control System and testing facility and shall witness test runs. Before a favorable recommendation can be made to the Committee, the testing facility must meet all applicable requirements of ASME PTC 25. Uncertainty in final flow measurement results shall not exceed ±2%. To determine the uncertainty in final flow measurements, the results of flow tests on an object tested at the applicant's testing laboratory will be compared to flow test results on the same object tested at a designated ASME-accepted testing laboratory.

4-400 QUALITY CONTROL SYSTEM

The applicant shall prepare a Quality Control Manual describing his Quality Control System which will clearly establish the authority and responsibility of those in charge of the Quality Control System. The manual shall include a description of the testing facility, testing arrangements, pressure, size and capacity limitations, and the testing medium used. An organization chart showing the relationship among the laboratory personnel is required to reflect the actual organization.

The Quality Control Manual shall include as a minimum the applicable requirements of this Division and ASME PTC 25, including but not limited to a description of the Quality Control Manual and document control, the procedure to be followed when conducting tests, the methods by which test results are to be calculated, how test instruments and gages are to be calibrated and the frequency of their calibration, and methods of identifying and resolving nonconformities. Sample forms shall be included. If testing procedure specifications or other similar documents are referenced, the Quality Control Manual shall describe the methods of their approval and control.

4-500 TESTING PROCEDURES

(a) Flow tests shall be conducted at the applicant's facility, including the testing of one or more valves and other flow devices (nozzle orifice or other object with a fixed flow path) in accordance with the methods specified by this Division and ASME PTC 25. The flow and pressure capability of a designated ASME-accepted testing laboratory shall be consistent with the flow and pressure ranges of the device being tested. Flow tests of devices

made at a lower pressure shall not be extrapolated to a higher pressure. A representative from an ASME-designated organization will observe the procedures and methods of tests, and the recording of results.

(b) Rupture disks may be certified as to burst pressure provided the test stand has enough volume to provide a complete burst. Flow coefficient (C_D, K, L_{EQ}, percent open area) may be established at a lower pressure using any suitable fluid.

(c) For relief valves intended for use with supercritical fluids relieving at or above the critical point, tests shall be conducted on both liquid and vapor. A designated ASME-accepted testing laboratory shall measure and report the stem lift at the stated capacity for both liquid and vapor.

Provided the above tests are found acceptable, a representative from an ASME-designated organization will submit a report to the Society recommending the laboratory be accepted for the purpose of conducting capacity certification tests. If a favorable recommendation cannot be given, a representative from an ASME-designated organization will provide, in writing to the Society, the reasons for such a decision.

4-600 AUTHORIZED OBSERVERS

A representative from an ASME-designated organization shall review and evaluate the experience and qualifications of persons who wish to be designated as Authorized Observers. Following such review and evaluation, a representative from an ASME-designated organization shall make a report to the Society. If a favorable recommendation is not made, full details shall be provided in the report.

Persons designated as Authorized Observers by the ASME Boiler and Pressure Vessel Committee shall supervise capacity certification tests only at testing facilities specified by the Committee.

MANDATORY APPENDIX 5
ADHESIVE ATTACHMENT OF NAMEPLATES

5-100 SCOPE

(a) The rules in this Appendix cover minimum requirements for the use of adhesive systems for the attachment of nameplates, limited to

(1) the use of pressure-sensitive acrylic adhesives which have been preapplied by the nameplate manufacturer to a nominal thickness of at least 0.005 in. (0.13 mm) and which are protected with a moisture-stable liner

(2) use for vessels with design temperatures within the range of −40°F to 300°F (−40°C to 149°C), inclusive

(3) application to clean, bare metal surfaces, with attention being given to removal of antiweld spatter compound which may contain silicone

(4) use of prequalified application procedures as outlined in 5-200

(5) use of the preapplied adhesive within an interval of 2 years after adhesive application

5-200 NAMEPLATE APPLICATION PROCEDURE QUALIFICATION

(a) The Manufacturer's Quality Control System (see Mandatory Appendix 2) shall define that written procedures, acceptable to the Inspector, for the application of adhesive-backed nameplates shall be prepared and qualified.

(b) The application procedure qualification shall include the following essential variables, using the adhesive and nameplate manufacturers' recommendations where applicable:

(1) description of the pressure-sensitive acrylic adhesive system employed, including generic composition.

(2) the qualified temperature range [the cold box test temperature shall be −40°F (−40°C) for all applications].

(3) materials of nameplate and substrate when the mean coefficient of expansion at design temperature of one material is less than 85% of that for the other material.

(4) finish of the nameplate and substrate surfaces.

(5) the nominal thickness and modulus of elasticity at application temperature of the nameplate when nameplate preforming is employed. A change of more than 25% in the quantity: [(nameplate nominal thickness)^2 × nameplate modulus of elasticity at application temperature] will require requalification.

(6) the qualified range of preformed nameplate and companion substrate contour combinations when preforming is employed.

(7) cleaning requirements for the substrate.

(8) application temperature range and application pressure technique.

(9) application steps and safeguards.

(c) Each procedure used for nameplate attachment by pressure-sensitive acrylic adhesive systems shall be qualified for outdoor exposure in accordance with Standard UL-969, Marking and Labeling Systems, with the following additional requirements:

(1) Width of nameplate test strip shall not be less than 1 in.

(2) Nameplates shall have an average adhesion of not less than 8 lb/in. (1.4 N/mm) of width after all exposure conditions, including low temperature.

(d) Any change in 5-200(b) shall require requalification.

(e) Each lot or package of nameplates shall be identified with the adhesive application date.

MANDATORY APPENDIX 6
ROUNDED INDICATIONS CHARTS ACCEPTANCE STANDARD FOR RADIOGRAPHICALLY DETERMINED ROUNDED INDICATIONS IN WELDS

6-100 APPLICABILITY OF THESE STANDARDS

These standards are applicable to ferritic, austenitic, and nonferrous materials, in cases where radiography is required.

6-110 TERMINOLOGY

(a) Rounded Indications. Indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included. The indication may be from any source in the weld, such as porosity, slag, or tungsten.

(b) Aligned Indications. A sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.

(c) Thickness, t. t is the thickness of the weld, excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

6-120 ACCEPTANCE CRITERIA

(a) Image Density. Density within the image of the indication may vary and is not a criterion for acceptance or rejection.

04 *(b) Relevant Indications (See Table KE-332 for Examples).* Only those rounded indications which exceed the following dimensions shall be considered relevant:

(1) $\frac{1}{10}t$ for t less than $\frac{1}{8}$ in. (3.2 mm)

(2) $\frac{1}{64}$ in. (0.4 mm) for t $\frac{1}{8}$ in. (3.2 mm) to $\frac{1}{4}$ in. (6 mm), inclusive

(3) $\frac{1}{32}$ in. (0.8 mm) for t greater than $\frac{1}{4}$ in. (6 mm) to 2 in. (51 mm), inclusive

(4) $\frac{1}{16}$ in. (1.6 mm) for t greater than 2 in. (51 mm)

(c) Maximum Size of Rounded Indications (See Table KE-332 for Examples). The maximum permissible size of any indication shall be $\frac{1}{4}t$ or $\frac{5}{32}$ in. (4 mm), whichever is smaller, except that an isolated indication separated from an adjacent indication by 1 in. (25 mm) or more may be $\frac{1}{3}t$ or $\frac{1}{4}$ in. (6 mm), whichever is less. For t greater than 2 in. (51 mm), the maximum permissible size of an isolated indication shall be increased to $\frac{3}{8}$ in. (10 mm).

(d) Aligned Rounded Indications. Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$ (see Fig. 6-1). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Fig. 6-2.

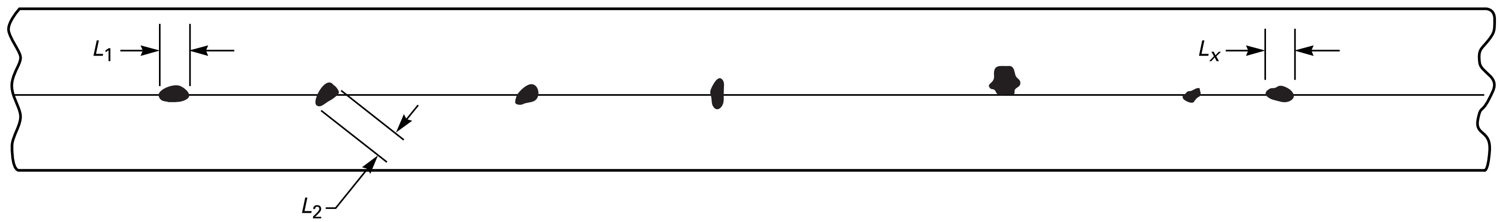
(e) Spacing. The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

(f) Rounded Indications Charts. The rounded indications as determined from the radiographic film shall not exceed that shown in the charts.

The charts in Figs. 6-3.1 through 6-3.6 illustrate various types of assorted, randomly dispersed and clustered rounded indications for different weld thicknesses greater than $\frac{1}{8}$ in. (3.2 mm). These charts represent the maximum acceptable concentration limits for rounded indications.

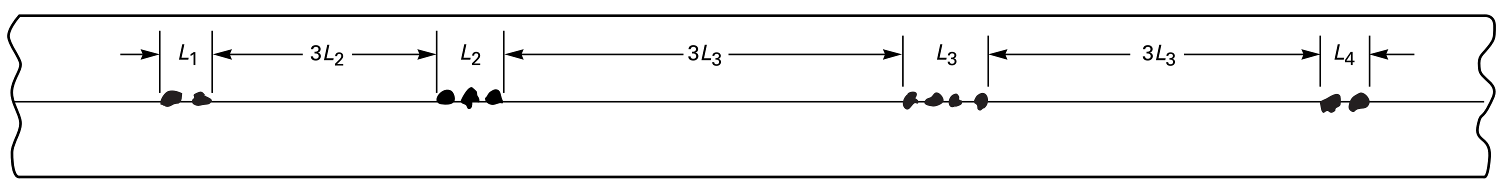
The chart for each thickness range represents full-scale 6 in. (152 mm) radiographs, and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph, but are typical of the concentration and size of indications permitted.

(g) Clustered Indications. The illustrations for clustered indications show up to four times as many indications in a local area as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in. (25 mm) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in. (25 mm) in a 6 in. (152 mm) length of weld.



The sum of L_1 to L_x shall be less than t in a length of $12t$.

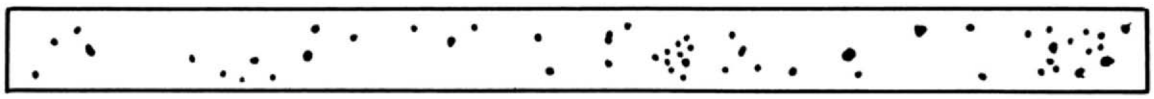
FIG. 6-1 ALIGNED ROUNDED INDICATIONS



The sum of the group lengths shall be less than t in a length of $12t$.

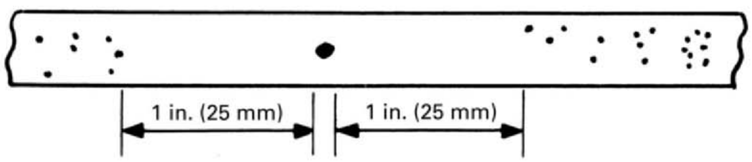
Maximum Group Length	Minimum Group Spacing
L = $^1/_4$ in. (6 mm) for t less than $^3/_4$ in. (19 mm) L = $^1/_3$ t for t $^3/_4$ in. (19 mm) to $2^1/_4$ in. (57 mm) L = $^3/_4$ in. (19 mm) for t greater than $2^1/_4$ in. (57 mm)	$3L$ where L is the length of the longest adjacent group being evaluated.

FIG. 6-2 GROUPS OF ALIGNED ROUNDED INDICATIONS

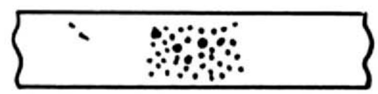


RANDOM ROUNDED INDICATIONS

Typical concentration and size permitted
in any 6 in. (150 mm) length of weld



ISOLATED INDICATION
Maximum size per Table KE-332



CLUSTER

FIG. 6-3.1 CHARTS FOR t 1⁄8 in. (3 mm) TO 1⁄4 in. (6 mm), INCLUSIVE

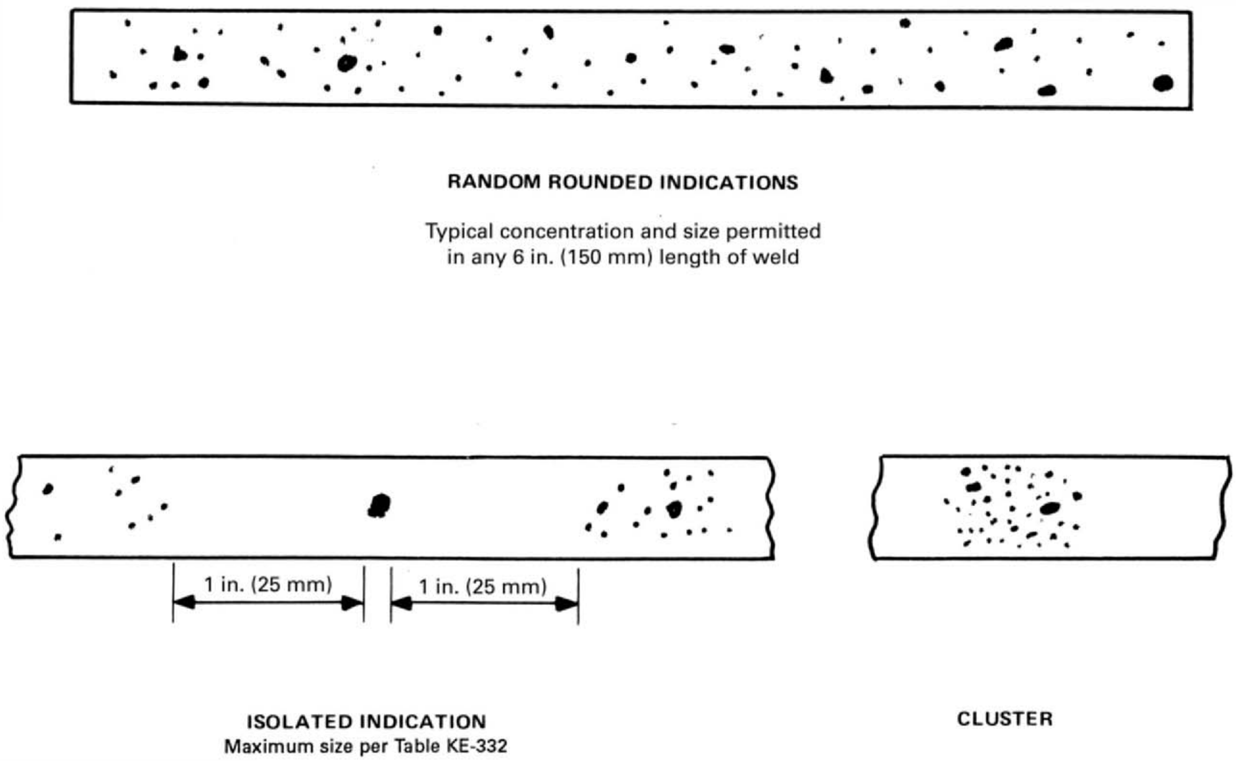
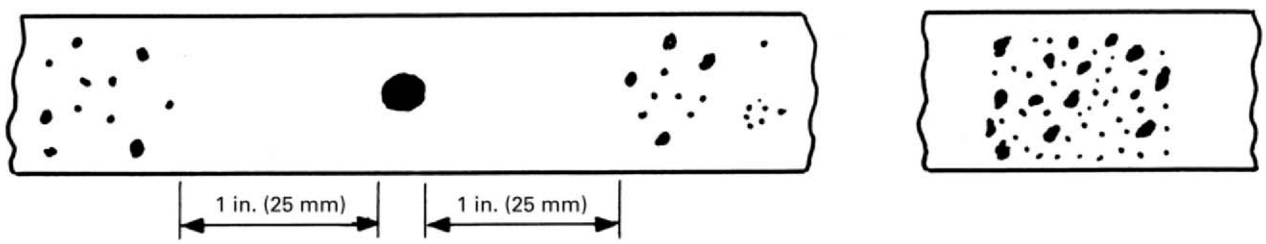


FIG. 6-3.2 CHARTS FOR t OVER $\frac{1}{4}$ in. (6 mm) TO $\frac{3}{8}$ in. (10 mm), INCLUSIVE

RANDOM ROUNDED INDICATIONS

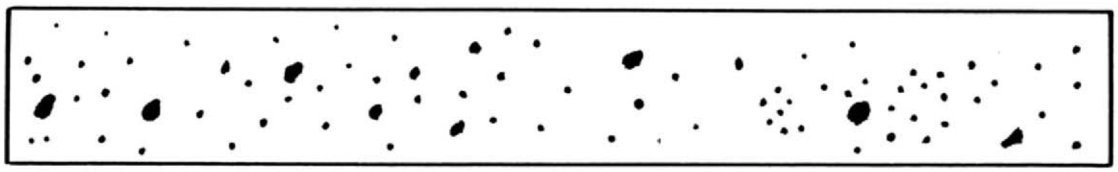
Typical concentration and size permitted
in any 6 in. (150 mm) length of weld



ISOLATED INDICATION
Maximum size per Table KE-332

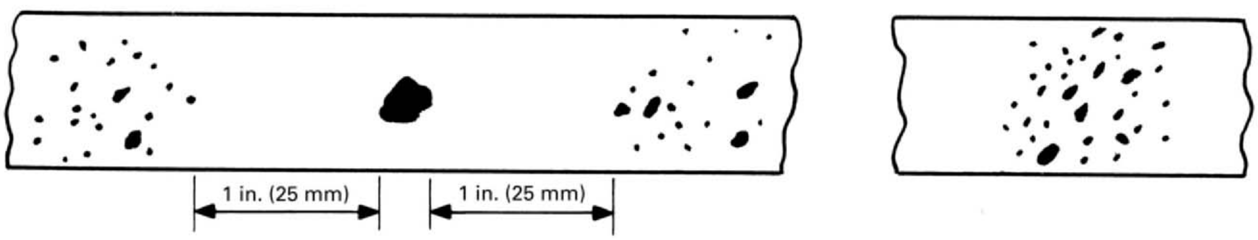
CLUSTER

FIG. 6-3.3 CHARTS FOR t OVER $^3\!/_8$ in. (10 mm) TO $^3\!/_4$ in. (19 mm), INCLUSIVE



RANDOM ROUNDED INDICATIONS

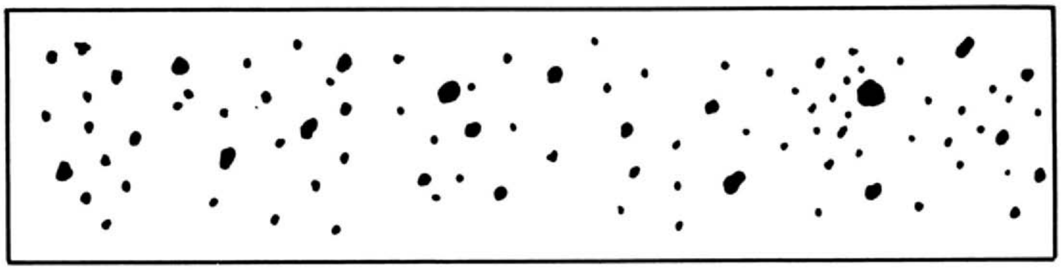
Typical concentration and size permitted
in any 6 in. (150 mm) length of weld



ISOLATED INDICATION
Maximum size per Table KE-332

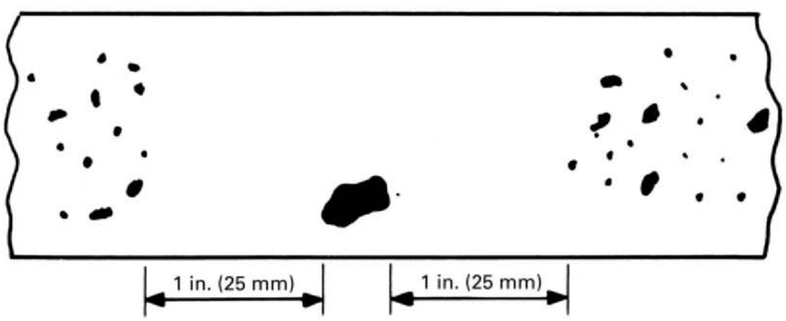
CLUSTER

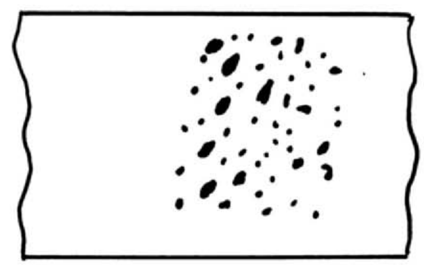
FIG. 6-3.4 CHARTS FOR t OVER $\frac{3}{4}$ in. (19 mm) TO 2 in. (50 mm), INCLUSIVE



RANDOM ROUNDED INDICATIONS

Typical concentration and size permitted
in any 6 in. (150 mm) length of weld

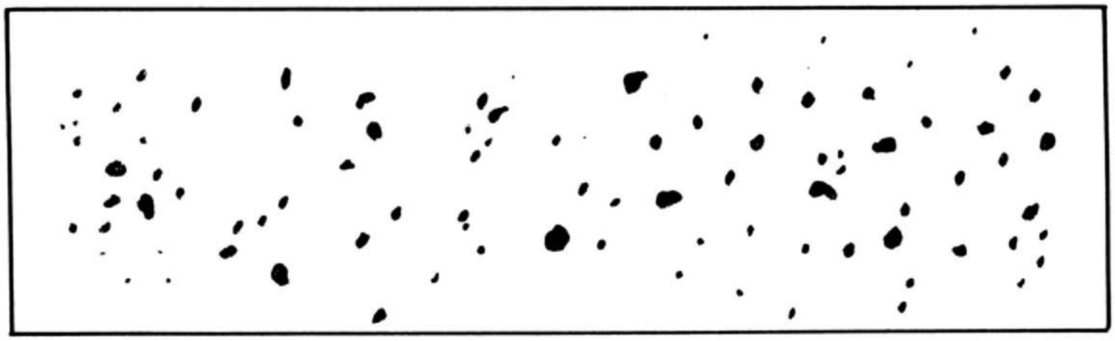




ISOLATED INDICATION
Maximum size per Table KE-332

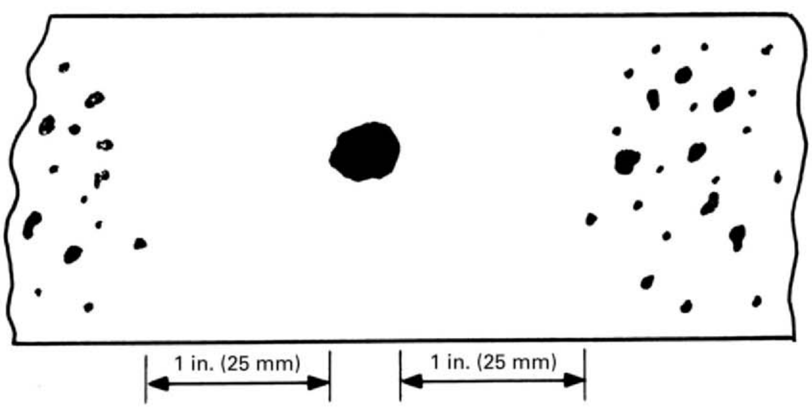
CLUSTER

FIG. 6-3.5 CHARTS FOR t OVER 2 in. (50 mm) TO 4 in. (100 mm), INCLUSIVE

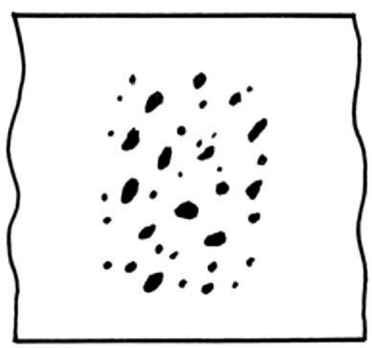


RANDOM ROUNDED INDICATIONS

Typical concentration and size permitted
in any 6 in. (150 mm) length of weld



ISOLATED INDICATION
Maximum size per Table KE-332



CLUSTER

FIG. 6-3.6 CHARTS FOR t OVER 4 in. (100 mm)

MANDATORY APPENDIX 7 04
STANDARD UNITS FOR USE IN EQUATIONS

TABLE 7-1
STANDARD UNITS FOR USE IN EQUATIONS

Quantity	U.S. Customary Units	SI Units
Linear dimensions (e.g., length, height, thickness, radius, diameter)	inches (in.)	millimeters (mm)
Area	square inches (in.^{2})	square millimeters (mm^2)
Volume	cubic inches (in.^{3})	cubic millimeters (mm^3)
Section modulus	cubic inches (in.^{3})	cubic millimeters (mm^3)
Moment of inertia of section	inches^4 (in.^{4})	millimeters^4 (mm^4)
Mass (weight)	pounds mass (lbm)	kilograms (kg)
Force (load)	pounds force (lbf)	newtons (N)
Bending moment	inch-pounds (in.-lb)	newton-millimeters (N·mm)
Pressure, stress, stress intensity, and modulus of elasticity	pounds per square inch (psi)	megapascals (MPa)
Energy (e.g., Charpy impact values)	foot-pounds (ft-lb)	joules (J)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Absolute temperature	Rankine (R)	kelvin (K)
Fracture toughness	ksi square root inches (ksi$\sqrt{\text{in.}}$)	MPa square root meters (MPa$\sqrt{\text{m}}$)
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

NONMANDATORY APPENDICES

NONMANDATORY APPENDIX A
GUIDE FOR PREPARING MANUFACTURER'S DATA REPORTS

A-100 INTRODUCTION

(a) The instructions in this Appendix provide general guidance to the Manufacturer in preparing Data Reports as required in KS-300.

(b) Manufacturer's Data Reports required by this Division are for use with this Division only. They are not intended for use with special construction that requires and receives approval by jurisdictional authorities under the laws, rules, and regulations of the respective state, province, or municipality in which the vessel is to be installed.

(c) The instructions for completing the Data Reports are identified by circled numbers corresponding to numbers on the sample forms in this Appendix (see Forms K-1, K-2, and K-3, and Table A-100.1).

(d) Where more space is needed than has been provided on the form for any item, insert the words "See Remarks" and then enter the data in the "Remarks" area or in the Supplement.

(e) It is not intended that these Data Reports replace in any way the required Manufacturer's Design Report (KG-323) or the Manufacturer's construction records (KG-325). It is intended that the Data Reports be used for identifying the vessel, retrieval of records, and certification of compliance with this Division, and with the User's Design Specification, by the Manufacturer and by the Inspector.

FORM K-1 MANUFACTURER'S DATA REPORT FOR HIGH PRESSURE VESSELS
As Required by the Provisions of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 3

1. Manufactured and certified by ______ 1 ______
(name and address of Manufacturer)

2. Manufactured for ______ 2 ______
(name and address of purchaser)

______

3. Location of installation ______ 3 ______
(name and address)

4. Type ______ 4 ______ ______ 5 ______ ______ 6 ______ ______ 7 ______ ______
(horizontal/vertical) (Mfr.'s serial no.) (CRN) (National Board No.) (year built)

Drawing no. ______ 8 ______ Prepared by ______ 9 ______

5. User's Design Specification on file at ______ 10 ______

Certified by ______ 10 ______ P.E. state ______ 11 ______ Reg. no. ______

6. Manufacturer's Design Report on file at ______ 10 ______

Certified by ______ 10 ______ P.E. state ______ 11 ______ Reg. no. ______

7. Material ______ 12 ______ Impact tested at ______ °F

8. ASME Boiler and Pressure Vessel Code, Section VIII, Division 3 ______ 13 ______ ______ 13 ______ ______ 14 ______
(year) (Addenda date) (Code Case no.)

9. Service ______ 15 ______

10. Restrictions and warnings ______ 16 17 ______

______ 18 ______ cycles at ______ psig at ______ °F ______

11. Construction ______ 19 20 21 22 23 ______

Prestress method ______ 24 ______

12. Size and configuration ______ 25 ______ ______ 26 ______ ______ 27 ______ ______
(I.D.) (length) (thickness) (cylindrical, spherical, other)

______

13. Supports and attachments ______ 28 ______

14. Design pressure ______ 29 ______ psi at maximum coincident metal temperature ______ 30 ______ °F

Maximum metal temperature ______ 30 ______ °F at ______ 30 ______ psi

Minimum design metal temperature ______ 31 ______ °F at ______ 31 ______ psi

15. Test pressure ______ 32 ______ psi ______ 32 ______ at ______ 32 ______ °F
(pneum./hydro./combination)

Performed in the ______ 32 ______ position ______
(horiz./vertical) [fluid(s) used in test]

16. Closures ______ 33 ______
(describe)

17. Connections, or provisions, for overpressure relief ______ 34 ______

FORM K-1 (Back)

18. Nozzles and connections

Purpose (Inlet, Outlet, Drain)	Quantity	Diameter or Size	Type	Material	Nominal Thickness	Reinforcement Material	How Attached	Location
34 35 36		35	35 37	12	27			36

19. Manufacturer's Partial Data Reports, properly identified and signed by commissioned Inspectors, have been furnished for the following components: ______ 38 ______

20. Remarks: ______ 16 ______

39

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Boiler and Pressure Vessel Code, Section VIII, Division 3.

U3 Certificate of Authorization no. ______ expires ______ , 19 ______ .

Date ______ Co. name ______ 39 (Manufacturer) ______ Signed ______ 39 (representative) ______

40

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______ and employed by ______ of ______ , have inspected the pressure vessel described in this Manufacturer's Data Report on ______ , 19______ , and state that, to the best of my knowledge and belief, the Manufacturer has constructed this part in accordance with ASME Code, Section VIII, Division 3. By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______ Signed ______ 40 (Authorized Inspector) ______ Commissions ______ 41 [Nat'l. Bd. (incl. endorsements), state, prov., and no.] ______

39

CERTIFICATE OF FIELD ASSEMBLY COMPLIANCE

We certify that the field assembly construction of all parts of this vessel conforms with the requirements of SECTION VIII, Division 3 of the ASME BOILER AND PRESSURE VESSEL CODE.

U3 Certificate of Authorization no. ______ expires ______ , 19 ______ .

Date ______ Co. name ______ 39 (Assembler that certified and constructed field assembly) ______ Signed ______ 39 (representative) ______

42

CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______ and employed by ______ of ______ , have compared the statements in this Manufacturer's Data Report with the described pressure vessel and state that parts referred to as data items ______ , not included in the certificate of shop inspection, have been inspected by me and that, to the best of my knowledge and belief, the Manufacturer has constructed and assembled this part in accordance with the ASME Code, Section VIII, Division 3. The described vessel was inspected and subjected to a hydrostatic test of ______ 42 ______ psi. By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______ Signed ______ 42 (Authorized Inspector) ______ Commissions ______ 41 [Nat'l. Bd. (incl. endorsements), state, prov., and no.] ______

FORM K-1M MANUFACTURER'S DATA REPORT FOR HIGH PRESSURE VESSELS
As Required by the Provisions of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 3

1. Manufactured and certified by ______ 1 ______
(name and address of Manufacturer)

2. Manufactured for ______ 2 ______
(name and address of purchaser)

3. Location of installation ______ 3 ______
(name and address)

4. Type ___ 4 ___ (horizontal/vertical) ___ 5 ___ (Mfr.'s serial no.) ___ 6 ___ (CRN) ___ 7 ___ (National Board No.) ______ (year built)

Drawing no. ___ 8 ___ Prepared by ___ 9 ___

5. User's Design Specification on file at ___ 10 ___

Certified by ___ 10 ___ P.E. state ___ 11 ___ Reg. no. ______

6. Manufacturer's Design Report on file at ___ 10 ___

Certified by ___ 10 ___ P.E. state ___ 11 ___ Reg. no. ______

7. Material ___ 12 ___ Impact tested at ______ °C

8. ASME Boiler and Pressure Vessel Code, Section VIII, Division 3 ___ 13 ___ (year) ___ 13 ___ (Addenda date) ___ 14 ___ (Code Case no.)

9. Service ___ 15 ___

10. Restrictions and warnings ___ 16 17 ___

___ 18 ___ cycles at ______ MPa at ______ °C ______

11. Construction ___ 19 20 21 22 23 ___

Prestress method ___ 24 ___

12. Size and configuration ___ 25 ___ (I.D.) ___ 26 ___ (length) ___ 27 ___ (thickness) ______ (cylindrical, spherical, other)

13. Supports and attachments ___ 28 ___

14. Design pressure ___ 29 ___ MPa at maximum coincident metal temperature ___ 30 ___ °C

Maximum metal temperature ___ 30 ___ °C at ___ 30 ___ MPa

Minimum design metal temperature ___ 31 ___ °C at ___ 31 ___ MPa

15. Test pressure ___ 32 ___ MPa ___ 32 ___ (pneum./hydro./combination) at ___ 32 ___ °C

Performed in the ___ 32 ___ (horiz./vertical) position ______ [fluid(s) used in test]

16. Closures ___ 33 ___ (describe)

17. Connections, or provisions, for overpressure relief ___ 34 ___

FORM K-1M (Back)

18. Nozzles and connections

Purpose (Inlet, Outlet, Drain)	Quantity	Diameter or Size	Type	Material	Nominal Thickness	Reinforcement Material	How Attached	Location
34 35 36		35	35 37	12	27			36

19. Manufacturer's Partial Data Reports, properly identified and signed by commissioned Inspectors, have been furnished for the following components: ______ 38 ______

20. Remarks: ______ 16 ______

39

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Boiler and Pressure Vessel Code, Section VIII, Division 3.

U3 Certificate of Authorization no. ______ expires ______ , 19 ______ .

Date ______ Co. name ______ 39 ______ (Manufacturer) Signed ______ 39 ______ (representative)

40

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______ and employed by ______ of ______ , have inspected the pressure vessel described in this Manufacturer's Data Report on ______ , 19______ , and state that, to the best of my knowledge and belief, the Manufacturer has constructed this part in accordance with ASME Code, Section VIII, Division 3. By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______ Signed ______ 40 ______ (Authorized Inspector) Commissions ______ 41 ______ [Nat'l. Bd. (incl. endorsements), state, prov., and no.]

39

CERTIFICATE OF FIELD ASSEMBLY COMPLIANCE

We certify that the field assembly construction of all parts of this vessel conforms with the requirements of SECTION VIII, Division 3 of the ASME BOILER AND PRESSURE VESSEL CODE.

U3 Certificate of Authorization no. ______ expires ______ , 19 ______ .

Date ______ Co. name ______ 39 ______ (Assembler that certified and constructed field assembly) Signed ______ 39 ______ (representative)

42

CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______ and employed by ______ of ______ , have compared the statements in this Manufacturer's Data Report with the described pressure vessel and state that parts referred to as data items ______ , not included in the certificate of shop inspection, have been inspected by me and that, to the best of my knowledge and belief, the Manufacturer has constructed and assembled this part in accordance with the ASME Code, Section VIII, Division 3. The described vessel was inspected and subjected to a hydrostatic test of ______ 42 ______ MPa. By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______ Signed ______ 42 ______ (Authorized Inspector) Commissions ______ 41 ______ [Nat'l. Bd. (incl. endorsements), state, prov., and no.]

FORM K-2 MANUFACTURER'S PARTIAL DATA REPORT FOR HIGH PRESSURE VESSELS
A Part of a Pressure Vessel Fabricated by One Manufacturer for Another Manufacturer
As Required by the Provisions of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 3

1. Manufactured and certified by ______ 1 ______
(name and address of Manufacturer)

2. Manufactured for ______ 2 ______
(name and address of purchaser)

______

3. Location of installation ______ 3 ______
(name and address)

4. Type ______ 4 ______ ______ 5 ______ ___ 6 ___ ______ 7 ______ ______
(horizontal/vertical) (Mfr.'s serial no.) (CRN) (National Board No.) (year built)

Drawing no. ______ 8 ______ Prepared by ______ 9 ______

5. User's Design Specification on file at ______ 10 ______
Certified by ______ 10 ______ P.E. state ___ 11 ___ Reg. no. ______

6. Manufacturer's Design Report on file at ______ 10 ______
Certified by ______ 10 ______ P.E. state ___ 11 ___ Reg. no. ______

7. Material ______ 12 ______ Impact tested at ______ °F

8. ASME Boiler and Pressure Vessel Code, Section VIII, Division 3 ___ 13 ___ ______ 13 ______ ______ 14 ______
(year) (Addenda date) (Code Case no.)

9. Constructed to ______ 8 ______ ______ 9 ______ ______
(drawing no.) (prepared by) (description of part inspected)

10. Construction ______ 19 20 21 23 ______
Prestress method ______ 24 ______

11. Size and configuration ______ 25 ______ ______ 26 ______ ______
(I.D.) (length) (cylindrical, spherical, other)

______

12. Supports and attachments ______ 28 ______ °F

13. Design pressure ___ 29 ___ psi at maximum coincident metal temperature ______ 30 ______ °F
Maximum metal temperature ______ 30 ______ °F at ______ 30 ______ psi
Minimum design metal temperature ______ 31 ______ °F at ______ 31 ______ psi

14. Test pressure ______ 32 ______ psi ______ 32 ______ at ______ 32 ______ °F
(pneum./hydro./combination)

Performed in the ______ 32 ______ position ______
(horiz./vertical) [fluid(s) used in test]

15. Remarks: ______ 16 ______

______

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FORM K-2 (Back)

39

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Boiler and Pressure Vessel Code, Section VIII, Division 3.

Certificate of Authorization no. ____________ expires ______________ .

Date ____________ Co. name ______ 39 ______ (Manufacturer) Signed ______ 39 ______ (representative)

40

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ____________ and employed by ____________ of ____________ , have inspected the pressure vessel described in this Manufacturer's Partial Data Report on ____________ , ______ , and state that, to the best of my knowledge and belief, the Manufacturer has constructed this part in accordance with ASME Code, Section VIII, Division 3. By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this Manufacturer's Partial Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ____________ Signed ______ 40 ______ (Authorized Inspector) Commissions ______ 41 ______ [Nat'l. Bd. (incl. endorsements), state, prov., and no.]

39

CERTIFICATE OF FIELD ASSEMBLY COMPLIANCE

We certify that the field assembly construction of all parts of this vessel conforms with the requirements of SECTION VIII, Division 3 of the ASME BOILER AND PRESSURE VESSEL CODE.

Certificate of Authorization no. ____________ expires ____________ .

Date ____________ Co. name ______ 39 ______ (Assembler that certified and constructed field assembly) Signed ______ 39 ______ (representative)

42

CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ____________ and employed by ____________ of ____________ have compared the statements in this Manufacturer's Partial Data Report with the described pressure vessel and state that parts referred to as data items ____________ , not included in the certificate of shop inspection, have been inspected by me and that, to the best of my knowledge and belief, the Manufacturer has constructed and assembled this part in accordance with the ASME Code, Section VIII, Division 3. The described vessel was inspected and subjected to a hydrostatic test of ______ 42 ______ psi. By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this Manufacturer's Partial Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ____________ Signed ______ 42 ______ (Authorized Inspector) Commissions ______ 41 ______ [Nat'l. Bd. (incl. endorsements), state, prov., and no.]

FORM K-2M MANUFACTURER'S PARTIAL DATA REPORT FOR HIGH PRESSURE VESSELS
A Part of a Pressure Vessel Fabricated by One Manufacturer for Another Manufacturer
As Required by the Provisions of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 3

1. Manufactured and certified by ______ 1 ______
   (name and address of Manufacturer)

2. Manufactured for ______ 2 ______
   (name and address of purchaser)

3. Location of installation ______ 3 ______
   (name and address)

4. Type ______ 4 ______ ______ 5 ______ ______ 6 ______ ______ 7 ______ ____________
   (horizontal/vertical) (Mfr.'s serial no.) (CRN) (National Board No.) (year built)

   Drawing no. ______ 8 ______ Prepared by ______ 9 ______

5. User's Design Specification on file at ______ 10 ______
   Certified by ______ 10 ______ P.E. state ______ 11 ______ Reg. no. ____________

6. Manufacturer's Design Report on file at ______ 10 ______
   Certified by ______ 10 ______ P.E. state ______ 11 ______ Reg. no. ____________

7. Material ______ 12 ______ Impact tested at ______ ˚C

8. ASME Boiler and Pressure Vessel Code, Section VIII, Division 3 ______ 13 ______ ______ 13 ______ ______ 14 ______
   (year) (Addenda date) (Code Case no.)

9. Constructed to ______ 8 ______ ______ 9 ______ ____________
   (drawing no.) (prepared by) (description of part inspected)

10. Construction ______ 19 20 21 23 ______
    Prestress method ______ 24 ______

11. Size and configuration ______ 25 ______ ______ 26 ______ ____________
    (I.D.) (length) (cylindrical, spherical, other)

12. Supports and attachments ______ 28 ______ ˚C

13. Design pressure ______ 29 ______ MPa at maximum coincident metal temperature ______ 30 ______ ˚C
    Maximum metal temperature ______ 30 ______ ˚C at ______ 30 ______ MPa
    Minimum design metal temperature ______ 31 ______ ˚C at ______ 31 ______ MPa

14. Test pressure ______ 32 ______ MPa ______ 32 ______ at ______ 32 ______ ˚C
    (pneum./hydro./combination)

    Performed in the ______ 32 ______ position ____________
    (horiz./vertical) [fluid(s) used in test]

15. Remarks: ______ 16 ______

FORM K-2M (Back)

39

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Boiler and Pressure Vessel Code, Section VIII, Division 3.

Certificate of Authorization no. ____________ expires ________________ .

Date ______________ Co. name ______ 39 ______ (Manufacturer) Signed ______ 39 ______ (representative)

40

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______________________ and employed by ______________________ of ____ , have inspected the pressure vessel described in this Manufacturer's Partial Data Report on _________________ , _____ , and state that, to the best of my knowledge and belief, the Manufacturer has constructed this part in accordance with ASME Code, Section VIII, Division 3. By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this Manufacturer's Partial Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______________ Signed ______ 40 ______ (Authorized Inspector) Commissions ______ 41 ______ [Nat'l. Bd. (incl. endorsements), state, prov., and no.]

39

CERTIFICATE OF FIELD ASSEMBLY COMPLIANCE

We certify that the field assembly construction of all parts of this vessel conforms with the requirements of SECTION VIII, Division 3 of the ASME BOILER AND PRESSURE VESSEL CODE.

Certificate of Authorization no. ______________ expires ____________ .

Date ______________ Co. name ______ 39 ______ (Assembler that certified and constructed field assembly) Signed ______ 39 ______ (representative)

42

CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ____________________ and employed by ______________________ of ______________________________ have compared the statements in this Manufacturer's Partial Data Report with the described pressure vessel and state that parts referred to as data items ____________________________________ , not included in the certificate of shop inspection, have been inspected by me and that, to the best of my knowledge and belief, the Manufacturer has constructed and assembled this part in accordance with the ASME Code, Section VIII, Division 3. The described vessel was inspected and subjected to a hydrostatic test of ________ 42 ________ MPa. By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this Manufacturer's Partial Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______________ Signed ______ 42 ______ (Authorized Inspector) Commissions ______ 41 ______ [Nat'l. Bd. (incl. endorsements), state, prov., and no.]

FORM K-3 MANUFACTURER'S DATA REPORT SUPPLEMENTARY SHEET
As Required by the Provisions of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 3

1. Manufactured and certified by ______ 1 43 ______
(name and address of Manufacturer)

2. Type ______ 4 43 ______ (horiz., vert., tank, etc.) ______ 5 43 ______ (Mfr.'s serial no.) ______ 6 43 ______ (CRN) ______ 8 43 ______ (drawing) ______ 7 43 ______ (Nat'l. Bd. No.) ______ (year built)

Data Report Item Number	Remarks
43	44

Date ______ Company name ______ 40 43 ______ (Manufacturer) Signed ______ 40 43 ______ (representative)

Date ______ Signed ______ 40 43 ______ (Authorized Inspector) Commissions ______ 41 43 ______ [Natl. Board (incl. endorsements), state, prov., and no.]

TABLE A-100.1
INSTRUCTIONS FOR THE PREPARATION OF MANUFACTURER'S DATA REPORTS

Applies to Form			Note No.	Instruction
K-1	K-2	K-3		
X	X	X	1	Name and street address of Manufacturer, as shown on Manufacturer's ASME Code Certificate of Authorization.
X	X	. . .	2	Name and address of purchaser.
X	X	. . .	3	Name of user and address where vessel is to be installed.
X	X	X	4	Type of vessel, such as horizontal or vertical, separator, heat exchanger, reactor, storage, etc.
X	X	X	5	An identifying Manufacturer's serial number marked on the vessel (or vessel part) (see KS-120).
X	X	X	6	Canadian registration number where applicable.
X	X	X	7	Where applicable, National Board Number from Manufacturer's Series of National Board Numbers. National Board Number shall not be used for owner-inspected vessels.
X	X	X	8	Indicate drawing numbers, including revision numbers, that cover general assembly and list materials. For Canadian registration, also include the number of the drawing approved by Provincial authorities.
X	X	. . .	9	Organization that prepared drawing.
X	X	. . .	10	To be completed by the Manufacturer to show the disposition of the User's Design Specification and the Manufacturer's Design Report, and to identify the registered Professional Engineers who certify them.
X	X	. . .	11	State of the U.S.A. or province of Canada, as applicable.
X	X	. . .	12	Show the complete ASME specification number and grade of the actual material used in the vessel part. Material is to be as designated in Section VIII, Division 3. Exceptions: A specification number for a material not identical to an ASME specification may be shown *only* if such material meets the criteria in the Foreword of this Division. When material is accepted through a Code Case, the applicable Case number shall be shown.
X	X	. . .	13	Issue date of Section VIII, Division 3 and Addenda under which vessel or vessel part was manufactured.
X	X	. . .	14	All Code Case numbers when vessel is manufactured according to any Cases.
X	. . .	. . .	15	Describe contents or service of the vessel.
X	X	. . .	16	Additional comments, including any Code restrictions on the vessel or any unusual Code or jurisdictional requirements that have been met, such as those noted in 17, 18, 20, 21, and 32. Indicate corrosion or erosion allowance.
X	. . .	. . .	17	Show need for start-up or shutdown temperature and/or controlled rate of heating or cooling, maximum temperature of any part.
X	. . .	. . .	18	Show results of fatigue analysis, number of cycles, limitations, or restrictions.
X	X	. . .	19	Type of longitudinal joint in cylindrical section, or any joint in a sphere (e.g., Type No. 1 butt or seamless).
X	X	. . .	20	When heat treatment is performed by the Manufacturer, give temperature and time. Explain any special cooling procedure and other pertinent heating during fabrication.
X	X	. . .	21	Indicate examination applied. Methods, location, and results should be included under Remarks.
X	. . .	. . .	22	Type of welding used in girth joints in the cylindrical section (see 19).
X	X	. . .	23	For jacketed vessels, explain type of jacket closures used and Code stamping.
X	X	. . .	24	Prestress, method, verification, etc.

TABLE A-100.1 (CONT'D) INSTRUCTIONS FOR THE PREPARATION OF MANUFACTURER'S DATA REPORTS

Applies to Form			Note	
K-1	K-2	K-3	No.	Instruction
X	X	. . .	25	Indicate inside diameter.
X	X	. . .	26	The shell length shall be shown as the overall length between closure or transition section welds or joints for a shell of a single diameter. In other cases, define length as appropriately descriptive.
X	. . .	. . .	27	Thickness is the nominal thickness of the material used in the fabrication of the vessel. It includes corrosion allowance.
X	X	. . .	28	Indicate provisions for support of the vessel and any attachments for superimposed equipment.
X	X	. . .	29	Show design pressure for which vessel is constructed (see KG-311). Other internal or external pressures with coincident temperatures shall be listed where applicable.
X	X	. . .	30	Show maximum coincident metal temperatures permitted for vessel at the design pressures.
X	X	. . .	31	Show minimum design metal temperature at coincident pressure. List if more than one set.
X	X	. . .	32	Show hydrostatic or other tests made with specified test pressure at top of vessel in the test position that applies (pneumatic, hydrostatic, or combination test pressure). Indicate if vessel was tested in the vertical position.
X	. . .	. . .	33	Bolts used to secure removable head(s), closures, or seals of vessel.
X	. . .	. . .	34	Indicate nozzle or other opening which is designated for pressure relief (see Part KR).
X	. . .	. . .	35	Show other nozzles and openings by size, type, and purpose. See 37.
X	. . .	. . .	36	Show opening designated for inspection. Show location.
X	. . .	. . .	37	Data entries with descriptions acceptable to Inspector. Abbreviations, coded identification, or reference to Code figure and sketch number may be used to define any generic name. For ASME B16.5 flanges, the class should be identified. Flange facing and attachment to neck is not required. Some typical abbreviations: Flanged fabricated nozzle — Cl. 300 flg Long weld neck flange — Cl. 300 lwn Weld end fabricated nozzle — w.e.
X	. . .	. . .	38	To be completed when one or more parts of the vessel are furnished by others and certified on Data Report Form K-2 as required by KS-301. The part manufacturer's name and serial number should be indicated.
X	X	. . .	39	Certificate of compliance block is to show the name of the Manufacturer as shown on Manufacturer's ASME Code Certificate of Authorization. This should be signed in accordance with organizational authority defined in the Quality Control System (see Appendix 2).
X	X	X	40	To be completed by the Manufacturer and signed by the Authorized Inspector who performs the shop inspection or signs Form K-1 for the completed vessel. Attach any applicable K-2 forms.
X	X	X	41	The Inspector's National Board Commission Number must be shown when the vessel is stamped "National Board." Otherwise, show only Inspector's state or province commission number.
X	X	. . .	42	This certificate is for the Authorized Inspector to sign for any field construction or assembly work (see 41 for National Board Commission Number requirements). Indicate the method used to pressure test the vessel.
. . .	. . .	X	43	Fill in information identical to that shown on the Data Report to which this is supplementary.
. . .	. . .	X	44	Fill in information for which there was insufficient space for a specific item on the Data Report Form as identified by the notation "See attached Form K-3" on the Data Report. Identify the information by the applicable Data Report Item Number.

FORM K-4 MANUFACTURER'S OR ASSEMBLER'S CERTIFICATE OF CONFORMANCE FOR PRESSURE RELIEF VALVES

As Required by the Provisions of the ASME Code Rules, Section VIII, Division 3

1. Manufactured (or assembled) by ______ 1 ______

2. Table of Code symbol stamped items:

I.D. #	Date	Cert. #	Qty.	Type	Size (NPS)	Set Pressure	Capacity	Test Fluid	Date Code	CI Name	CI Signature
2	3	4	5	6	7	8	9	10	11	12	13

3. Remarks ______ 14 ______

CERTIFICATE OF SHOP COMPLIANCE

By the signature of the Certified Individual (CI) noted above, we certify that the statements made in this report are correct and that all details for design, material, construction, and workmanship of the pressure relief valves conform with the requirements of Section VIII, Division 3 of the ASME Boiler and Pressure Vessel Code.

UV3 Certificate of Authorization No. ______ 15 ______ Expires ______ 16 ______

Date ______ 17 ______ Signed ______ 18 ______ Name ______ 18 ______

(responsible representative) (Manufacturer or Assembler)

TABLE A-100.2
SUPPLEMENTARY INSTRUCTIONS FOR THE PREPARATION OF MANUFACTURER'S OR ASSEMBLER'S CERTIFICATE OF CONFORMANCE FORM K-4

Note No.	Instruction
1	Name and address of Manufacturer or Assembler.
2	Pressure relief valve Manufacturer's or Assembler's unique number, such as serial number, work order number, or lot number.
3	The date of completion of production of the pressure relief valve.
4	The NB Certification Number.
5	The quantity of identical valves for this line item.
6	The Manufacturer's Design or Type Number as marked on the nameplate.
7	The inlet size of the pressure relief valve (NPS).
8	The nameplate set pressure of the pressure relief valve.
9	The nameplate capacity of the pressure relief valve.
10	The fluid used for testing the pressure relief valve.
11	The year built or the pressure relief valve Manufacturer's or Assembler's date code.
12	The name of the Certified Individual.
13	The signature of the Certified Individual. Required for each line item.
14	Include any applicable remarks (referencing the identification number) that may pertain, such as identification of a Code Case that requires marking on the device.
15	The number of the pressure relief valve Manufacturer's Certificate of Authorization.
16	Expiration date of the pressure relief valve Manufacturer's Certificate of Authorization.
17	Date signed by the pressure relief valve Manufacturer or Assembler's authorized representative.
18	The Certificate of Compliance block is to show the name of the Manufacturer or Assembler as shown on his/her ASME Code Certificate of Authorization. This shall be signed in accordance with organizational authority defined in the Quality Control System (see Mandatory Appendix 2).

NONMANDATORY APPENDIX B
REQUALIFICATION

B-100 EXTENDING ALLOWED CYCLIC LIMITS WHILE IN OPERATION

(a) It is recognized that the fatigue and fracture analyses of Articles KD-3 and KD-4, respectively, define only the minimum cyclic potential of a high pressure vessel.

(b) Article KD-3 is applicable only as long as the pressure vessel remains in as-new condition; however, the results of the analysis may not be valid if inservice deterioration occurs.

(c) Further, Article KD-4 requires assuming an initial material flaw size which may not exist when a pressure vessel is first manufactured.

(d) To accommodate the potentially restrictive limits described above and at the same time provide realistic guidance to users of high pressure vessels, ASME HPS, High Pressure Systems, includes such guidance governing periodic requalification examinations. Such requalification, however, is outside the scope of this Division.

NONMANDATORY APPENDIX C
GUIDE TO INFORMATION APPEARING ON CERTIFICATE OF AUTHORIZATION (SEE FIG. C-1)

ITEM	DESCRIPTION
1	a. The name of the Manufacturer or Assembler; this description could include "doing business as" (DBA) or an abbreviation of the name. b. The full street address, city, state or province, country, and zip code.
2	This entry describes the scope and limitations, if any, on use of the Code symbol stamps, as illustrated below. **U3 Code Symbol Stamp** 1. Manufacture of pressure vessels at the above location only. 2. Manufacture of pressure vessels at the above location only. (This authorization does not cover welding or brazing.) 3. Manufacture of pressure vessels at the above location and field sites controlled by that location. 4. Manufacture of pressure vessels at the above location and field sites controlled by that location. (This authorization does not cover welding or brazing.) 5. Manufacture of pressure vessels at field sites controlled by the above location. 6. Manufacture of pressure vessels at field sites controlled by the above location. (This authorization does not cover welding or brazing.) **UV3 Code Symbol Stamp** 1. Manufacture of pressure vessel pressure relief valves at the above location only. 2. Manufacture of pressure vessel pressure relief valves at the above location only. (This authorization does not cover welding or brazing.) 3. Assembly of pressure vessel pressure relief valves at the above location. (This authorization does not cover welding or brazing.)
3	The date authorization was granted by the Society to use the indicated Code symbol stamp.
4	The date authorization to use the Code symbol stamp will expire.
5	A unique certificate number assigned by the Society.
6	Code symbol granted by the Society, i.e., U3 pressure vessels, UV3 pressure relief valves.
7, 8	The signatures of the current chair and director.

The American Society of Mechanical Engineers

CERTIFICATE OF AUTHORIZATION

This certificate accredits the named company as authorized to use the indicated symbol of the American Society of Mechanical Engineers (ASME) for the scope of activity shown below in accordance with the applicable rules of the ASME Boiler and Pressure Vessel Code. The use of the code symbol and the authority granted by this Certificate of Authorization are subject to the provisions of the agreement set forth in the application. Any construction stamped with this symbol shall have been built strictly in accordance with the provisions of the ASME Boiler and Pressure Vessel Code.

SAMPLE

COMPANY ①

SCOPE ②

AUTHORIZED ③

EXPIRES ④

CERTIFICATE NUMBER ⑤

SYMBOL ⑥

⑦

CHAIRMAN OF THE BOILER
AND PRESSURE VESSEL COMMITTEE

⑧

DIRECTOR, ASME ACCREDITATION

FIG. C-1 SAMPLE CERTIFICATE OF AUTHORIZATION

NONMANDATORY APPENDIX D
FRACTURE MECHANICS CALCULATIONS

D-100 SCOPE

Linear elastic fracture mechanics provides the relationships among the applied stress, the fracture toughness of the material, and the critical crack size.

This Appendix provides engineering methods for the calculation of the stress intensity factor K_I for various postulated crack geometries in thick-walled vessels.

D-200 CRACK LOCATION AND STRESSING

D-201 Internal Radial–Longitudinal Cracks

Figure D-200 shows some locations on a pressure vessel where fatigue cracks may develop. Cracks of type *A* develop in the main cylinder in the radial– longitudinal plane. The opening stresses are the hoop stresses and the pressure in the crack. These cracks tend to develop in a semielliptical shape with an aspect ratio a/ℓ, where a is the maximum crack depth and ℓ is the surface length.

D-202 Cracks Initiating at Internal Cross Bores

When connections between a vessel and piping or accessories are made through a radial hole (cross bore), fatigue cracks tend to develop in the radial–longitudinal plane. In Fig. D-200, crack *B* is shown developing from both sides of the cross bore; this is often the case, but the growth may not be symmetric. Calculation of the opening stress field is complicated by the stress concentration due to the hole, and the pressure in the crack should be considered.

D-203 Internal Radial–Circumferential Cracks

Cyclic loading may lead to fatigue cracking and fast fracture in the threads of a high pressure vessel using a threaded closure. These fatigue cracks usually initiate at the root of the first loaded thread because of uneven load distribution along the length of the thread and the stress concentration at the thread root. These fatigue cracks usually propagate in the radial–circumferential plane (see crack *C* in Fig. D-200). Usually, the high pressure fluid does not act on the faces of this crack. The longitudinal (opening) stress field has a very steep gradient due to the stress concentration at the thread root.

D-204 Internal Cracks at Blind End Closures

Fatigue cracks may develop on the inside surface of the vessel at the stress concentration associated with blind end closures (see crack *D* in Fig. D-200).

D-205 Crack Initiating at External Surfaces

Fatigue cracks may also develop on the outside surface of high pressure vessels due to the combination of stress concentrations, tensile residual stresses, and/ or environmental effects. See cracks *E* and *F* in Fig. D-200.

D-300 CRACK ORIENTATION AND SHAPE

(a) It is assumed that planar cracks develop at highly stressed points of the vessel. The following assumptions on initial crack orientation and shape to be used in fatigue crack propagation calculations are not intended for the areas of a weld in welded vessels.

(b) Surface cracks of type *A* may be assumed to be semielliptical with an aspect ratio a/ℓ equal to $\frac{1}{3}$.

(c) Surface cracks at cross bores, type *B*, may be assumed to be quarter circular or semicircular (see Fig. D-300).

(d) Surface cracks at the root of threads, type *C*, should be assumed to be annular even if the end closure has interrupted threads. This annular (ring) crack is shown in Fig. D-200.

(e) The planes in which cracks of types *A*, *B*, and *C* are assumed to propagate are as defined in Fig. D-200.

(f) Surface cracks of type *D* should be assumed to be annular. The plane of propagation of type *D* cracks should be determined by stress analysis. Cracks will usually propagate in a plane normal to the direction of the maximum range of tensile stress.

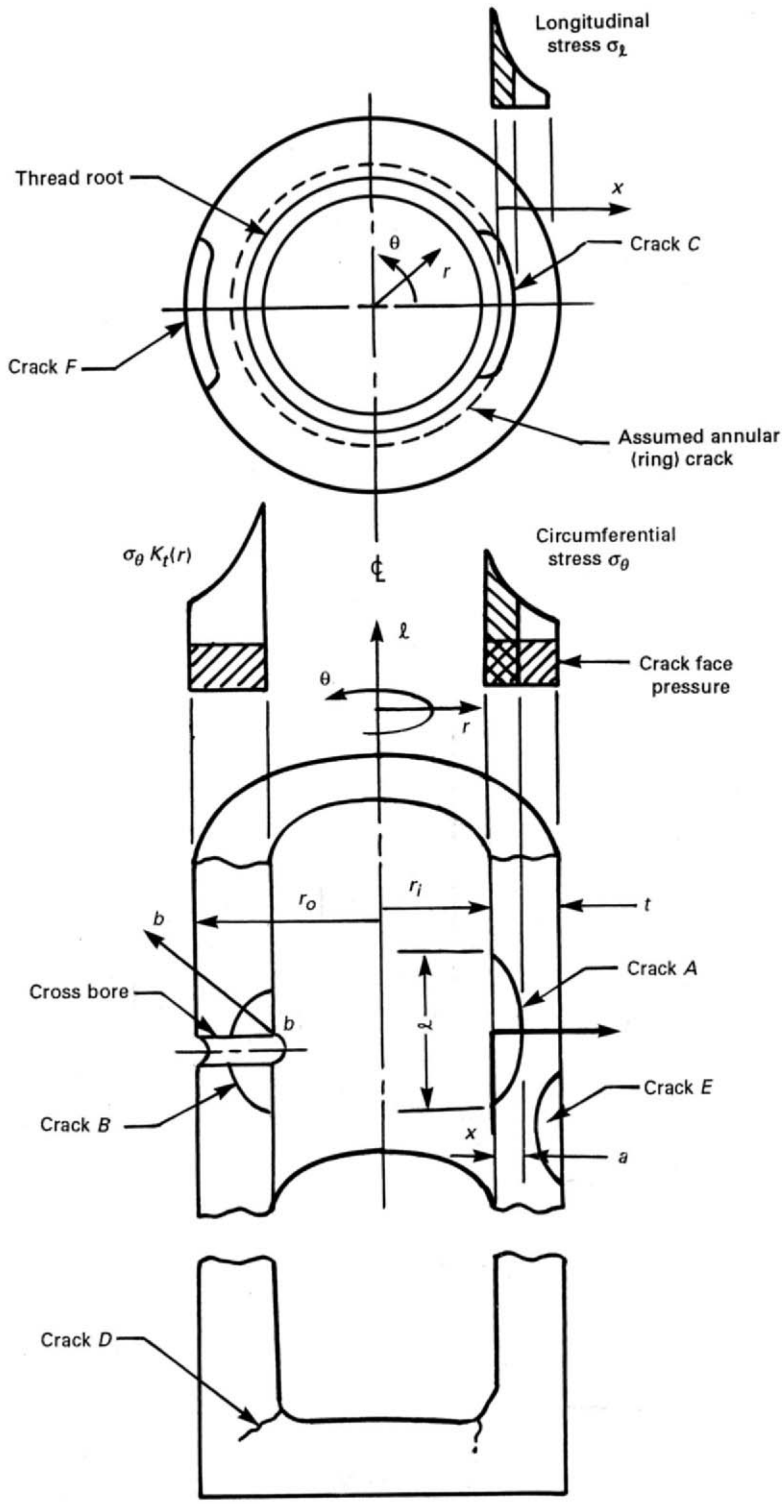


FIG. D-200 TYPICAL CRACK TYPES

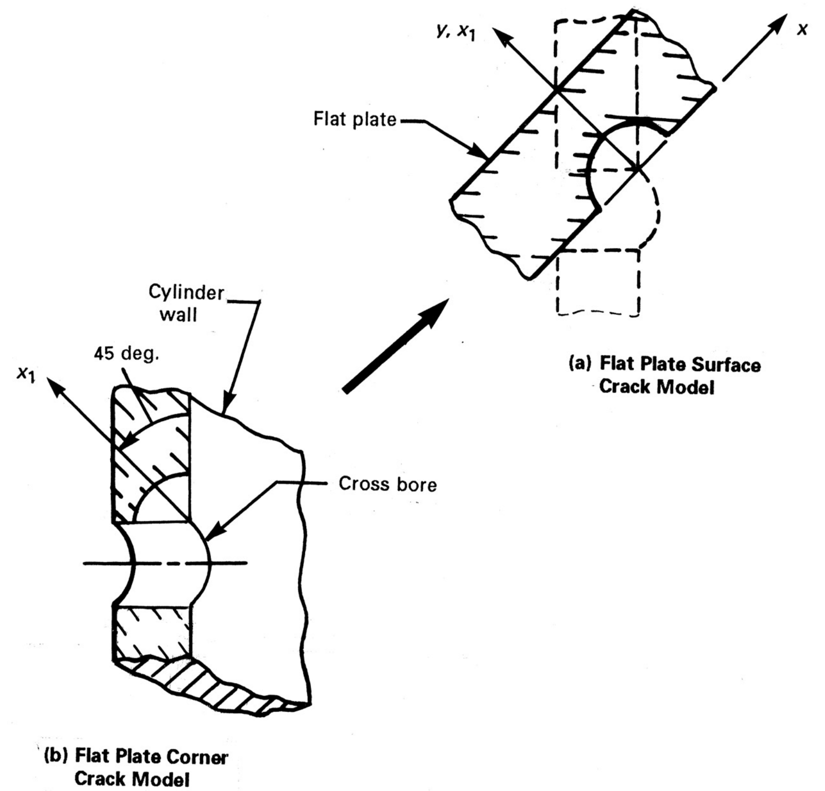


FIG. D-300 IDEALIZATIONS OF A CRACK PROPAGATING FROM A CROSS-BORE CORNER

The potential change in crack aspect ratio during crack growth should be considered in the calculation.

(g) External surface cracks, type *E*, should be assumed to be semielliptical and cracks of type *F* may be assumed to be either semielliptical or annular.

D-400 METHODS FOR DETERMINING STRESS INTENSITY FACTOR

(a) Section XI, Article A-3000, of the ASME Boiler and Pressure Vessel Code provides a method for calculating stress intensity factors K_I from a cubic polynomial fit of the stress distribution determined from stress analysis of the uncracked component. This method is not suitable for determining K_I for cracks of type *C* because of the severe stress gradient at the root of the thread. It may not be suitable for cracks of types *B*, *D*, *E*, and *F* if the stress gradients due to local stress concentrations are too steep to obtain a reasonable fit of the stress distribution over the critical crack depth. It is suitable for determining K_I for cracks of type *A* if the procedures outlined in D-401 are followed. The method given in D-401 may also be used to calculate the stress intensity factors due to thermal stresses. Paragraph D-402 outlines how the method given in D-401 can be used for cracks of type *B* in a well-radiused cross bore.

(b) More sophisticated techniques for determining K_I are described for crack type *C* in D-403(a).

(c) The weight function technique described in D-405 can be used for all crack types.

D-401 Stress Intensity Factors for Internal Radial–Longitudinal Cracks 04

This method may be used to calculate stress intensity factors for cracks of type *A*. The same method is also valid for the calculation of stress intensity factors due to thermal gradients and due to residual stresses. This method is based on Section XI, Article A-3000 [see D-700(a)]. It may be used to calculate stress intensity factors at the deepest point on the crack front and at a point near the free surface.

For a surface flaw, the stresses normal to the plane of the flaw at the flaw location are represented by a polynomial fit over the flaw depth by the following relationship:

$$\sigma = A_0 + A_1\,(x/a) + A_2\,(x/a)^2 + A_3\,(x/a)^3 \qquad (1)$$

where

A_0, A_1, A_2, A_3 = constants
a = crack depth, in. (mm)
x = distance through the wall measured from the flawed surface, in. (mm)

Coefficients A_0 through A_3 shall provide an accurate representation of stress over the flaw plane for all values of flaw depths, $0 \leq x/a \leq 1$, covered by the analysis. Stresses from all sources shall be considered.

Stress intensity factors for surface flaws shall be calculated using the cubic polynomial stress relation given by Eq. (2):

$$K_I = [(A_0 + A_p)\, G_0 + A_1G_1 + A_2G_2 + A_3G_3] \sqrt{\pi a/Q} \qquad (2)$$

where

A_0, A_1, A_2, A_3 = coefficients from Eq. (1) that represent the stress distribution over the flaw depth, $0 \leq x/a \leq 1$. When calculating K_I as a function of flaw depth, a new set of coefficients A_0 through A_3 shall be determined for each new value of flaw depth.
A_p = internal vessel pressure p, ksi (MPa), if the pressure acts on the crack surfaces. $A_p = 0$ for other flaws.
G_0, G_1, G_2, G_3 = free surface correction factors from Tables D-401.1 and D-401.2
Q = flaw shape parameter using Eq. (3)
a = flaw depth, in. (mm)

$$Q = 1 + 4.593\,(a/\ell)^{1.65} - q_y \qquad (3)$$

where

ℓ = major axis of the flaw, in. (mm)
a/ℓ = flaw aspect ratio $0 \leq a/\ell \leq 0.5$
q_y = plastic zone correction factor calculated using the following equation:

$$q_y = \left\{ [(A_0 + A_p)\, G_0 + A_1G_1 + A_2G_2 + A_3G_3]/S_y \right\}^2/6$$

For fatigue crack growth calculations, q_y may be set equal to zero.

D-401.1 Alternate Method

(a) If the distribution of stresses normal to the crack surface can be accurately represented by a single equation of the form of Eq. (1) over the entire range of crack depths of interest, the following method may be used to calculate the distribution of K_I over this crack depth.

The stress distribution is represented by

$$\sigma = A_0' + A_1'(x/t) + A_2'(x/t)^2 + A_3'(x/t)^3 \qquad (4)$$

For each value of a/t, the values of A_i' are converted to A_i values as follows:

$$A_0 = A_0'$$

$$A_1 = A_1'(a/t)$$

$$A_2 = A_2'(a/t)^2$$

$$A_3 = A_3'(a/t)^3$$

These A_i values are then used in Eq. (2) to calculate K_I.

(b) For a plain cylinder remote from any discontinuity, and for diameter ratios between 1.2 and 3.0, the values of A_i' for calculating K_I due to pressure only may be calculated from the following equations [see D-700(b)].

$$A_0'/P = (Y^2 + 1)/(Y^2 - 1)$$

$$A_1'/P = 1.051 - 2.318Y + 0.3036Y^2 - 0.004417Y^3$$

$$A_2'/P = -1.7678 + 0.9497Y + 0.9399Y^2 - 0.2056Y^3$$

$$A_3'/P = -0.2798 + 1.3831Y - 1.2603Y^2 + 0.2138Y^3$$

D-402 Stress Intensity Factors for Cracks Initiating at Cross Bores

The stress intensity factors for cracks of type B may be calculated using the method given in D-401, provided that the intersection of the cross bore with the bore of the main cylinder is radiused at least one-fourth of the diameter of the cross bore. See D-700(c). The values of stresses to be used to obtain the polynomial fit in Eq. (1) of D-401 are determined as follows:

(a) Elastic stress analysis may be used to determine the stress field in the vicinity of the uncracked cross bore. This elastic analysis is used to obtain the direct stresses acting normal to the plane of the assumed crack. The distribution of these stresses along line $b-b$ in Fig. D-200 shall be used to obtain the polynomial fit in Eq. (1) of D-401. As shown in Fig. D-200, the cross bore corner crack is assumed to be equivalent to a semicircular crack ($a/\ell = 0.5$) in a plane with the line $b-b$ as the axis of symmetry.

(b) If residual stresses have been introduced, such as by autofrettaging the main cylinder, the K due to residual stresses may be calculated using the polynomial fitting technique in D-401 with the simplifying assumption that the tangential residual stress distribution in the main cylinder acts along line $b-b$.

TABLE D-401.1
COEFFICIENTS G_0 THROUGH G_3 FOR SURFACE CRACK AT DEEPEST POINT

		Flaw Aspect Ratio a/ℓ					
Coefficient	a/t	0.0	0.1	0.2	0.3	0.4	0.5
Uniform	0.00	1.1208	1.0969	1.0856	1.0727	1.0564	1.0366
G_0	0.05	1.1461	1.1000	1.0879	1.0740	1.0575	1.0373
	0.10	1.1945	1.1152	1.0947	1.0779	1.0609	1.0396
	0.15	1.2670	1.1402	1.1058	1.0842	1.0664	1.0432
	0.20	1.3654	1.1744	1.1210	1.0928	1.0739	1.0482
	0.25	1.4929	1.2170	1.1399	1.1035	1.0832	1.0543
	0.30	1.6539	1.2670	1.1621	1.1160	1.0960	1.0614
	0.40	2.1068	1.3840	1.2135	1.1448	1.1190	1.0772
	0.50	2.8254	1.5128	1.2693	1.1757	1.1457	1.0931
	0.60	4.0420	1.6372	1.3216	1.2039	1.1699	1.1058
	0.70	6.3743	1.7373	1.3610	1.2237	1.1868	1.1112
	0.80	11.991	1.7899	1.3761	1.2285	1.1902	1.1045
Linear	0.00	0.7622	0.6635	0.6826	0.7019	0.7214	0.7411
G_1	0.05	0.7624	0.6651	0.6833	0.7022	0.7216	0.7413
	0.10	0.7732	0.6700	0.6855	0.7031	0.7221	0.7418
	0.15	0.7945	0.6780	0.6890	0.7046	0.7230	0.7426
	0.20	0.8267	0.6891	0.6939	0.7067	0.7243	0.7420
	0.25	0.8706	0.7029	0.7000	0.7094	0.7260	0.7451
	0.30	0.9276	0.7193	0.7073	0.7126	0.7282	0.7468
	0.40	1.0907	0.7584	0.7249	0.7209	0.7338	0.7511
	0.50	1.3501	0.8029	0.7454	0.7314	0.7417	0.7566
	0.60	1.7863	0.8488	0.7671	0.7441	0.7520	0.7631
	0.70	2.6125	0.8908	0.7882	0.7588	0.7653	0.7707
	0.80	4.5727	0.9288	0.8063	0.7753	0.7822	0.7792
Quadratic	0.00	0.6009	0.5078	0.5310	0.5556	0.5815	0.6084
G_2	0.05	0.5969	0.5086	0.5313	0.5557	0.5815	0.6084
	0.10	0.5996	0.5109	0.5323	0.5560	0.5815	0.6085
	0.15	0.6088	0.5148	0.5340	0.5564	0.5815	0.6087
	0.20	0.6247	0.5202	0.5364	0.5571	0.5815	0.6089
	0.25	0.6475	0.5269	0.5394	0.5580	0.5817	0.6093
	0.30	0.6775	0.5350	0.5430	0.5592	0.5820	0.6099
	0.40	0.7651	0.5545	0.5520	0.5627	0.5835	0.6115
	0.50	0.9048	0.5776	0.5632	0.5680	0.5869	0.6144
	0.60	1.1382	0.6027	0.5762	0.5760	0.5931	0.6188
	0.70	1.5757	0.6281	0.5907	0.5874	0.6037	0.6255
	0.80	2.5997	0.6513	0.6063	0.6031	0.6200	0.6351
Cubic	0.00	0.5060	0.4246	0.4480	0.4735	0.5006	0.5290
G_3	0.05	0.5012	0.4250	0.4482	0.4736	0.5006	0.5290
	0.10	0.5012	0.4264	0.4488	0.4736	0.5004	0.5290
	0.15	0.5059	0.4286	0.4498	0.4737	0.5001	0.5289
	0.20	0.5152	0.4317	0.4511	0.4738	0.4998	0.5289
	0.25	0.5292	0.4357	0.4528	0.4741	0.4994	0.5289
	0.30	0.5483	0.4404	0.4550	0.4746	0.4992	0.5291
	0.40	0.6045	0.4522	0.4605	0.4763	0.4993	0.5298
	0.50	0.6943	0.4665	0.4678	0.4795	0.5010	0.5316
	0.60	0.8435	0.4829	0.4769	0.4853	0.5054	0.5349
	0.70	1.1207	0.5007	0.4880	0.4945	0.5141	0.5407
	0.80	1.7614	0.5190	0.5013	0.5085	0.5286	0.5487

GENERAL NOTE: Interpolations in a/t and a/ℓ are permitted.

TABLE D-401.2
COEFFICIENTS G_0 THROUGH G_3 FOR SURFACE CRACK AT FREE SURFACE

		Flaw Aspect Ratio a/ℓ					
Coefficient	a/t	0.0	0.1	0.2	0.3	0.4	0.5
Uniform G_0	0.00	. . .	0.5450	0.7492	0.9024	1.0297	1.1406
	0.05	. . .	0.5514	0.7549	0.9070	1.0330	1.1427
	0.10	. . .	0.5610	0.7636	0.9144	1.0391	1.1473
	0.15	. . .	0.5738	0.7756	0.9249	1.0479	1.1545
	0.20	. . .	0.5900	0.7908	0.9385	1.0596	1.1641
	0.25	. . .	0.6099	0.8095	0.9551	1.0740	1.1763
	0.30	. . .	0.6338	0.8318	0.9750	1.0913	1.1909
	0.40	. . .	0.6949	0.8881	1.0250	1.1347	1.2278
	0.50	. . .	0.7772	0.9619	1.0896	1.1902	1.2746
	0.60	. . .	0.8859	1.0560	1.1701	1.2585	1.3315
	0.70	. . .	1.0283	1.1740	1.2686	1.3401	1.3984
	0.80	. . .	1.2144	1.3208	1.3871	1.4361	1.4753
Linear G_1	0.00	. . .	0.0725	0.1038	0.1280	0.1484	0.1665
	0.05	. . .	0.0744	0.1075	0.1331	0.1548	0.1740
	0.10	. . .	0.0771	0.1119	0.1387	0.1615	0.1816
	0.15	. . .	0.0807	0.1169	0.1449	0.1685	0.1893
	0.20	. . .	0.0852	0.1227	0.1515	0.1757	0.1971
	0.25	. . .	0.0907	0.1293	0.1587	0.1833	0.2049
	0.30	. . .	0.0973	0.1367	0.1664	0.1912	0.2128
	0.40	. . .	0.1141	0.1544	0.1839	0.2081	0.2289
	0.50	. . .	0.1373	0.1765	0.2042	0.2265	0.2453
	0.60	. . .	0.1689	0.2041	0.2280	0.2466	0.2620
	0.70	. . .	0.2121	0.2388	0.2558	0.2687	0.2791
	0.80	. . .	0.2714	0.2824	0.2887	0.2931	0.2965
Quadratic G_2	0.00	. . .	0.0254	0.0344	0.0423	0.0495	0.0563
	0.05	. . .	0.0264	0.0367	0.0456	0.0538	0.0615
	0.10	. . .	0.0276	0.0392	0.0491	0.0582	0.0666
	0.15	. . .	0.0293	0.0419	0.0527	0.0625	0.0716
	0.20	. . .	0.0313	0.0450	0.0565	0.0669	0.0764
	0.25	. . .	0.0338	0.0484	0.0605	0.0713	0.0812
	0.30	. . .	0.0368	0.0521	0.0646	0.0757	0.0858
	0.40	. . .	0.0445	0.0607	0.0735	0.0846	0.0946
	0.50	. . .	0.0552	0.0712	0.0834	0.0938	0.1030
	0.60	. . .	0.0700	0.0842	0.0946	0.1033	0.1109
	0.70	. . .	0.0907	0.1005	0.1075	0.1132	0.1183
	0.80	. . .	0.1197	0.1212	0.1225	0.1238	0.1252
Cubic G_3	0.00	. . .	0.0125	0.0158	0.0192	0.0226	0.0261
	0.05	. . .	0.0131	0.0172	0.0214	0.0256	0.0297
	0.10	. . .	0.0138	0.0188	0.0237	0.0285	0.0332
	0.15	. . .	0.0147	0.0206	0.0261	0.0314	0.0365
	0.20	. . .	0.0159	0.0225	0.0285	0.0343	0.0398
	0.25	. . .	0.0173	0.0245	0.0310	0.0371	0.0429
	0.30	. . .	0.0190	0.0267	0.0336	0.0399	0.0459
	0.40	. . .	0.0234	0.0318	0.0390	0.0454	0.0515
	0.50	. . .	0.0295	0.0379	0.0448	0.0509	0.0565
	0.60	. . .	0.0380	0.0455	0.0513	0.0564	0.0611
	0.70	. . .	0.0501	0.0549	0.0587	0.0621	0.0652
	0.80	. . .	0.0673	0.0670	0.0672	0.0679	0.0687

GENERAL NOTE: Interpolations in a/t and a/ℓ are permitted.

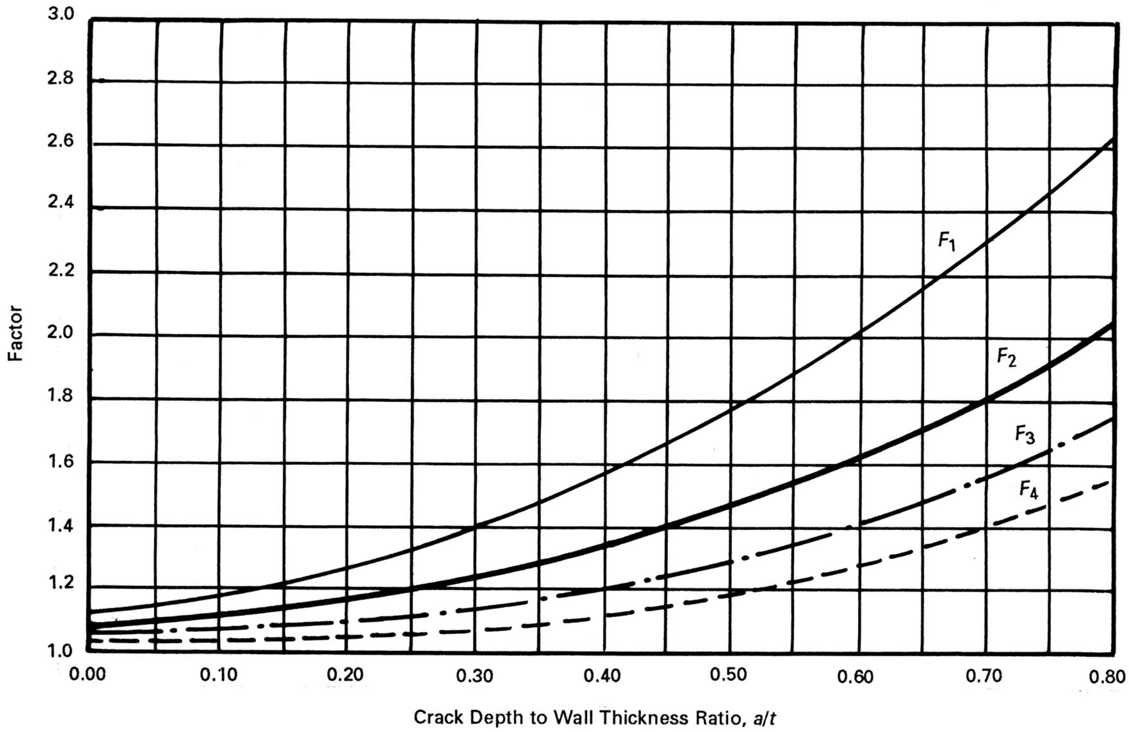


FIG. D-403.1 MAGNIFICATION FACTORS FOR CIRCUMFERENTIAL CRACK

D-403 Stress Intensity Factors for Internal Radial–Circumferential Cracks

This method applies only to crack depths within the limits of KD-412 and where pressure is not acting on the crack faces.

Type *C* fatigue cracks usually initiate at the root of the first fully loaded thread. This should be confirmed by calculation of the load distribution and by detailed stress analysis of the first and any other heavily loaded threads. To calculate the K_I for a thread root crack growing in the radial–circumferential plane, the distribution of longitudinal stress $\sigma_\ell(x)$ from the thread root through the thickness of the uncracked wall should be determined. For this analysis, the threads may be considered as annular grooves. If interrupted threads are used (see KD-631.6), it is not necessary to account for the stress concentrations at the ends of the interrupted threads, since it is assumed that all cracks of type *C* are annular.

04 *(a)* In the Buchalet–Bamford method [see D-700(d) and (e)], the distribution of direct stresses normal to the plane containing the annular crack is approximated by a third-order polynomial.

$$\sigma_\ell(x) = A_0 + A_1x + A_2x^2 + A_3x^3 \tag{1}$$

where x is the radial distance, in. (mm), from the free surface of the crack.

The stress distribution determined by a linear elastic analysis is calculated first and then the four coefficients (A_0, A_1, A_2, A_3) in Eq. (1) are chosen to give the best curve fit. After the values of A_0, A_1, A_2, and A_3 are chosen, Eqs. (2)–(6) are used to calculate the stress intensity factor K_I for various crack depths a.

$$K_I = F\sqrt{\pi a} \Big/ \sqrt{\left[1 - (F/S_y)^2/6\right]} \tag{2}$$

where

$$F = A_0F_1 + \frac{2aA_1F_2}{\pi} + \frac{a^2A_2F_3}{2} + \frac{4a^3A_3F_4}{3\pi}$$

and where $\sqrt{\left[1 - (F/S_y)^2/6\right]}$ is the plastic zone correction, which may be set equal to one for fatigue crack growth calculations. F_1, F_2, F_3, and F_4 are the magnification factors relative to the geometry considered. These magnification factors are given in Fig. D-403.1 as a function of relative crack depth or can be calculated by the following equations:

$$F_1 = 1.1259 + 0.2344(a/t) + 2.2018(a/t)^2 - 0.2083(a/t)^3 \tag{3}$$

$$F_2 = 1.0732 + 0.2677(a/t) + 0.6661(a/t)^2 + 0.6354(a/t)^3 \tag{4}$$

$$F_3 = 1.0528 + 0.1065(a/t) + 0.4429(a/t)^2 + 0.6042(a/t)^3 \tag{5}$$

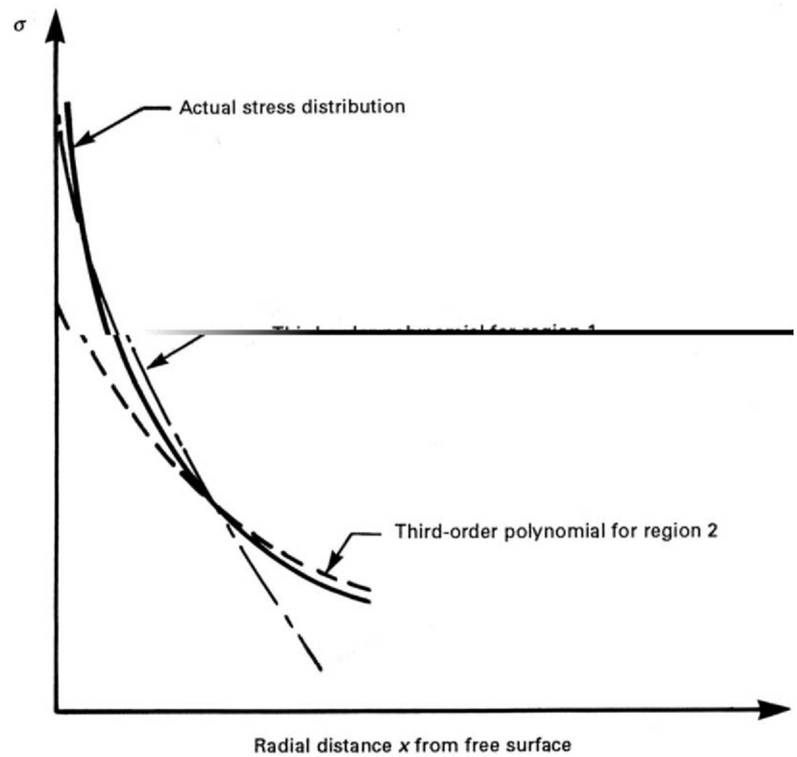


FIG. D-403.2 POLYNOMIAL REPRESENTATION OF STRESS DISTRIBUTION

$$F_4 = 1.0387 - 0.0939(a/t) + 0.6018(a/t)^2 + 0.3750(a/t)^3 \qquad (6)$$

(b) In some cases, a single third-order polynomial [Eq. (1)] will not be sufficient to fit the stress distribution in the region of interest. It is possible to split the distribution into several regions. Figure D-403.2 shows an example where the region of interest has been divided into two regions where the stress in each region is represented by a different polynomial. The values for K_I are calculated using Eq. (2) for each region with the appropriate polynomial for that region.

(c) It is important that there not be a discontinuity in the value of K_I where two regions join. For instance, since the values of A_0, A_1, A_2, and A_3 in the polynomial for region 2 are different from the values of A_0, A_1, A_2, and A_3 in the polynomial for region 1, two different values of K_I will be calculated at the point where the two regions join. To compensate for the discontinuity in the value of K_I where the two regions join, the difference at the discontinuity ΔK_I is added to the calculated values of all subsequent values of K_I. This will then produce the curve shown in Fig. D-403.3 and given by Eq. (7).

$$K_{I\text{corr}} = F\sqrt{\pi a} \Big/ \sqrt{\left[1 - (F/S_y)^2/6\right]} + \sum \Delta K_I \qquad (7)$$

where $\sum \Delta K_I$ is the sum of all ΔK's for preceding regions. The ΔK for the first region (at the free surface) is 0.

D-404 Stress Intensity Factors for Cracks of Types *D, E,* and *F*

(a) The stress intensity factors for cracks of types *D, E,* and *F* may be calculated using the method given in D-401.

(b) For cracks of types *D* and *F,* the distribution of stresses normal to the plane of the crack which would exist in the uncracked component should be determined using a stress analysis such as finite element analysis.

(c) For cracks of type *E,* the tangential stresses calculated using the Lamé equations may be used for calculating the stress intensity factor due to internal pressure.

D-405 Stress Intensity Factors Determined by Weight Function Methods

The weight function method can be used for all types of cracks.

For the annular (ring) cracks considered in D-403, the crack tip stress intensity K_I can be written as:

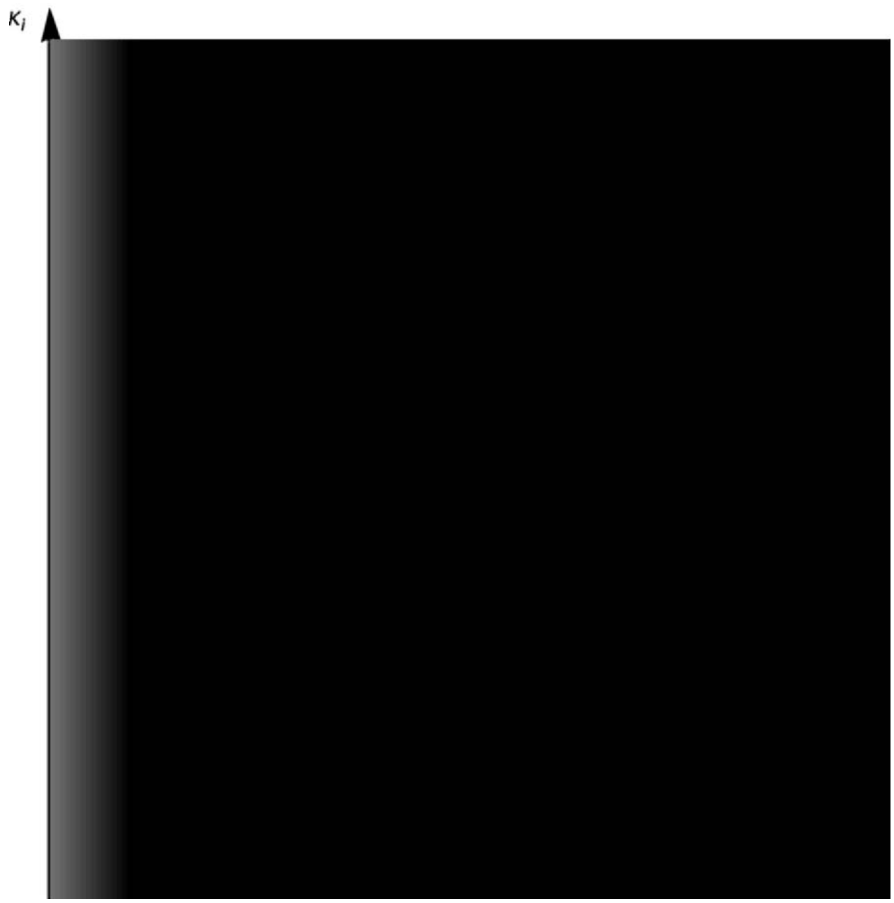


FIG. D-403.3 METHOD OF CORRECTING K_I AT DISCONTINUITIES BETWEEN REGIONS

$$K_I = \int_0^a \sigma_\ell(x)\ w(x,a)dx$$

where $\sigma_\ell(x)$ is the longitudinal stress distribution along the x-axis (see Fig. D-200) and $w(x,a)$ is the Bueckner weight function. This weight function is unique for this cracked geometry and is independent of the loading from which it is derived. Therefore, the weight function can be written as

$$w(x,a) = \frac{H}{2K_{IREF}} \left(\frac{\delta V_{REF}(x,a)}{\delta a} \right)$$

where V_{REF} is the surface opening displacement in the ℓ (longitudinal) direction and K_{IREF} is the crack tip stress intensity factor derived for this geometry and a less complex loading, e.g., uniform stress normal to the crack plane. For plane stress $H = E$ and for plane strain $H = E(1 - \nu^2)$.

Approximate methods have been developed for obtaining the crack opening displacement field V_{REF} for a ring crack in a simple cylinder. These values of V_{REF} and the associated stress intensity factors K_{REF} can be used to derive $w(x,a)$, which can then be used to derive K_I for the ring crack at the thread root.

D-500 CALCULATION OF FATIGUE CRACK GROWTH RATES

(a) In accordance with KD-430, the fatigue crack growth rate shall be calculated from

$$\frac{da}{dN} = C[f(R_K)]\ (\Delta K)^m \text{ [in./cycle (m/cycle)]}$$

(b) The function of R_K is different for positive and for negative values of R_K, and for different materials. For materials listed in Table D-500 the following functions of R_K may be used.

For $R_K \geq 0$,

$$f(R_K) = 1 + C_3 R_K$$

TABLE D-500
CRACK GROWTH RATE FACTORS

Material	C_3	C_2
High strength low alloy steels, $S_y > 90$ ksi (620 MPa)	3.53	1.5
Martensitic precipitation-hardened steels		
$R_K < 0.67$	3.48	1.5
$R_K > 0.67$	$f(R_K) = 30.53R_K - 17.0$	

For $R_K < 0$,

$$f(R_K) = [C_2/(C_2 - R_K)]^m$$

(c) The values of the constants C and m for some materials are given in Table KD-430. The values of the remaining constants given in Table D-500 should be used for the materials listed.

(d) For austenitic stainless steels, the values of C and m are given in KD-440, Table KD-430, and $f(R_K)$ should be calculated as follows: for $0 \geq R_K$, $f(R_K) = 1.0$; for $0.79 \geq R_K > 0$, $f(R_K) = 1.0 + 1.8R_K$; for $1.0 > R_K > 0.79$, $f(R_K) = -43.35 + 57.97R_K$.

(e) Other values of these constants may be used if they can be justified by standard fatigue crack propagation tests conducted at the appropriate R_K ratios.

(f) The number of cycles for fatigue crack propagation may be calculated by numerical integration of the appropriate crack growth equation by assuming that the value of K is constant over an interval of crack growth Δa which is small relative to the crack depth at that point. To ensure that the interval of crack depth is sufficiently small, the calculation should be repeated using intervals of decreasing size until no significant change in the calculated number of design operating cycles is obtained.

D-600 FRACTURE TOUGHNESS CORRELATIONS

(a) The value of the fracture toughness to be used in the calculations in Article KD-4 is the plane strain fracture toughness K_{Ic}. If values of K_{Ic} or another method for determining K_{Ic} is given in Part KM for the specific material to be used, these values should be used. Otherwise, if the MDMT is demonstrated to be on the upper shelf for the material being used, the value of K_{Ic} should be calculated from the Charpy V-notch energy (CVN) values given in Part KM using the following equation:

$$(K_{Ic}/S_y)^2 = 5.0\ (CVN/S_y - 0.05)$$

where S_y is the yield strength, ksi; CVN is the Charpy V-notch impact strength, ft-lb; and K_{Ic} is the fracture toughness, ksi$\sqrt{\text{in.}}$, or

$$(K_{Ic}/S_y)^2 = 0.64\ (CVN/S_y - 0.01)$$

where S_y is the yield strength, MPa; CVN is the charpy impact strength, J; and K_{Ic} is the fracture toughness, MPa$\sqrt{\text{m}}$.

(b) Conversions of values obtained from other toughness tests to K_{Ic} should be performed using the following equations:

(1) Equivalence of K_{Ic} and J_{Ic}

$$K_{Ic} = \sqrt{EJ_{Ic}} \quad \text{(plane stress)}$$

$$K_{Ic} = \sqrt{\frac{EJ_{Ic}}{(1 - \nu^2)}} \quad \text{(plane strain)}$$

(2) Equivalence of crack tip opening displacement ($CTOD$) and K_{Ic}

$$K_{Ic} = \sqrt{(CTOD)ES_y}$$

where

E = modulus of elasticity
S_y = yield strength
ν = Poisson's ratio

D-700 REFERENCES

(a) Cipolla, R. C. *Technical Basis for the Revised Stress Intensity Factor Equation for Surface Flaws in ASME Section XI, Appendix A.* ASME PVP-Vol. 313-1, 1995: 105–121.

(b) Kendall, D. P. *Application of the New Section XI, A-3000 Method for Stress Intensity Factor Calculation to Thick-Walled Pressure Vessels.* ASME PVP-Vol. 335, 1996: 189–194

(c) Chaaban, A. and Burns, D. J. *Design of High Pressure Vessels With Radial Crossbores.* Physica B139 and 140; 1986: 766–772

(d) Buchalet, C. B. and Bamford, W. H. *Stress Intensity Factor Solutions for Continuous Surface Flaws in Reactor Pressure Vessels, Mechanics for Crack Growth.* ASTM STP 590, 1976: 385–402

(e) Perez, E. H.; Sloan, J. G.; and Kelleher, K. J. *Application of Fatigue Crack Growth to an Isostatic Press.* ASME PVP-Vol. 125, 1987: 53–61

(f) Barsom, J. M. and Rolfe, S. T. *Correlations Between K_{Ic} and Charpy V-Notch Test Results in the Transition Temperature Range.* ASTM STP 466, 1970: 281–302

(g) Rolfe, S. T. and Novak, S. R. *Slow-Bend K_{Ic} Testing of Medium-Strength High-Toughness Steels.* ASTM STP 463, 1970: 124–159

(h) Kapp, J. A. and Underwood, J. H. *Correlation Between Fracture Toughness, Charpy V-Notch Impact Energy, and Yield Strength for ASTM A 723 Steel.* ASME PVP-Vol. 283, 1992: 219–222

NONMANDATORY APPENDIX E
CONSTRUCTION DETAILS

E-100 INTEGRAL HEADS (Blind Ends)

The thickness and proportions of blind ends of cylindrical vessels may conform to the recommendations given in this Appendix without detailed stress analysis.

E-110 THICK WALL PROPORTIONS

(a) If the D_O/D_I ratio of the vessel is 1.5 or more, the proportions of blind pressure vessel ends shall be kept within the following limits (see Fig. E-110).

(1) The minimum inside corner radius R_c shall be 25% of the design thickness of the vessel wall.

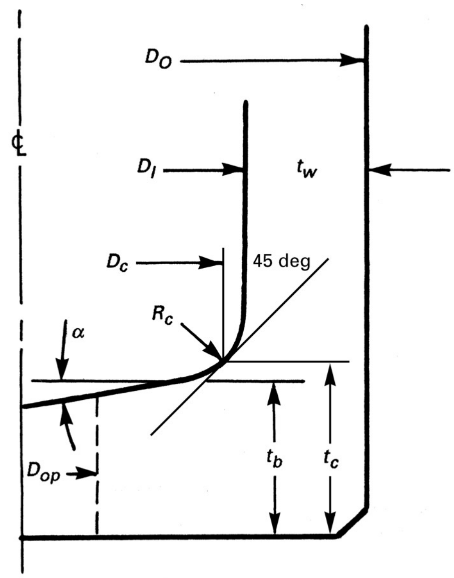
(2) The thickness of the blind end at the tangent of the inside corner (t_b in Fig. E-110) shall be no less than the design thickness of the vessel wall and no greater than twice the design thickness t_w of the vessel wall.

(3) The maximum angle α from the tangent of the inside corner to the vessel centerline shall be 10 deg from the plane perpendicular to the vessel axes (see Fig. E-110).

(4) The diameter D_{op} of any opening in the blind end shall not exceed 15% of the vessel inside diameter and shall be located on the vessel centerline.

(b) The maximum inside surface meridianal stress used to perform the fatigue evaluation in accordance with KD-141 shall be calculated by the following equation:

$$\sigma_1 = 1.045(D_c/t_c)^2\ P$$



D_c = corner diameter
D_{op} = opening diameter = $0.15D_I$ max.
R = corner radius = $0.25t_w$ min.
t_b = bottom thickness = t_w min., $2t_w$ max.
t_c = corner bottom thickness
t_w = design wall thickness
Y = D_O/D_I = 1.5 min.
α = 10 deg max.

FIG. E-110 THICK WALL BLIND END PROPORTIONS NOT REQUIRING DETAILED ANALYSIS

E-120 THIN WALL PROPORTIONS

(a) If the D_O/D_I ratio of the vessel is less than 1.5, the minimum thickness of blind ends (as shown in Fig. E-120) shall be calculated by the following equation:

$$t_b = D_I\ (1.5CP/S_y)^{0.5} \qquad (1)$$

(b) The minimum multiplier to be used with the C values below when performing fatigue and fracture mechanics evaluations using Articles KD-3 and KD-4, respectively, is 1.8. The stress intensity is:

$$S = 1.8C(D_I/t_b)^2\ P \qquad (2)$$

(c) The value of C to be used in Eqs. (1) and (2) shall be based on the following:

(1) $C = 0.22$ if the inside corner radius is at least three times the minimum required end thickness.

(2) $C = 0.44$ if the inside corner radius is less than three times the minimum required end thickness. The inside corner radius shall be greater than or equal to 25% of the design thickness of the vessel wall t_w.

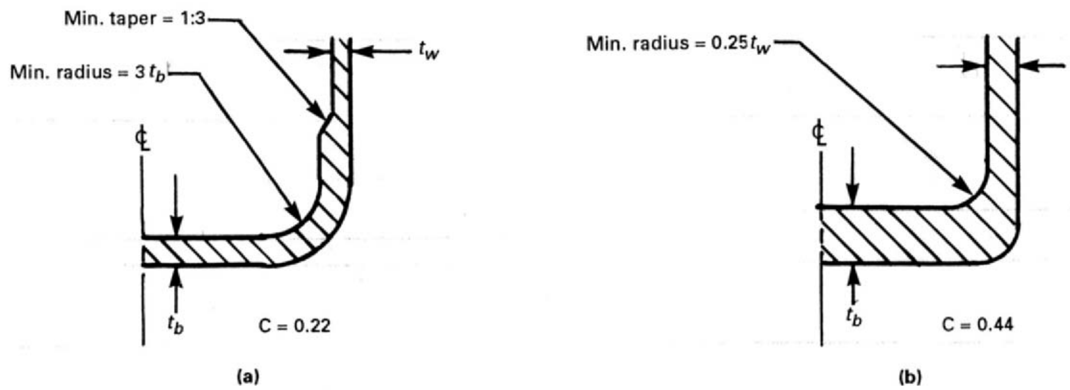


FIG. E-120 THIN WALL BLIND END PROPORTIONS NOT REQUIRING DETAILED ANALYSIS

(d) There is no special requirement with regard to cylinder lengths in the case of dissimilar cylindrical thicknesses; however, the taper between such thicknesses shall be a minimum of 3:1.

04 E-200 THREADED END CLOSURES

Specific requirements for threads and threaded closures are given in Article KD-6. In the following, *one thread* is understood to mean one 360 deg turn of a single start thread with a full cross section. The number of threads should be less than 20 but at least 4. The helix angle of the thread should not exceed 2 deg. The internal thread should have a generous undercut. The axial length of the external threaded portion should be at least one thread pitch longer than the mating internal threaded portion to ensure full engagement of all internal threads.

The threads do not carry the axial load uniformly. The internal thread closest to the undercut carries generally the largest portion of the load. The following method may be used to determine the load distribution. The threads are numbered from the undercut.

For vessels where the outside diameter is not uniform along the whole length of the body, the methods given in this Appendix for calculating thread load distribution may be nonconservative due to the effects of the vessel outer diameter on the flexibility factors calculated in E-210 for such vessels. See KD-100(b).

E-210 NOMENCLATURE (See Figs. E-210.1, E-210.2, and E-210.3)

A_B = cross-sectional area of the vessel normal to the vessel axis through the internal threads

$$= \frac{\pi}{4}(D_o^2 - D_p^2)$$

A_C = cross-sectional area of the closure normal to the vessel axis through the external threads

$$= \frac{\pi}{4} D_p^2$$

C_M = combined flexibility factor of the body and closure

$$= \left(\frac{1}{A_B} + \frac{1}{A_c}\right) P_T$$

C_T = flexibility factor of the threads

$$= \frac{2}{D_p}$$

D_O = outside diameter of the vessel
D_p = pitch diameter of the threads
F_1 = load on the first thread
F_2 = load on the second thread
F_i = load on the i^{th} thread
F_n = load on the last thread
F_T = total load on all threads
P_T = thread pitch
S = number of loaded segments in one pitch
S_i = segment load
S_M = combined flexibility factor of the body and the closure

$$= \frac{C_M}{S}$$

S_T = flexibility factor of the threads

$$= C_T 2S$$

n = total number of threads

E-220 THREAD LOAD DISTRIBUTION

E-221 Continuous Threads

The thread load distribution may be obtained by:

$$F_i = F_{i+1} + \frac{C_M}{C_T}(F_{sum})$$

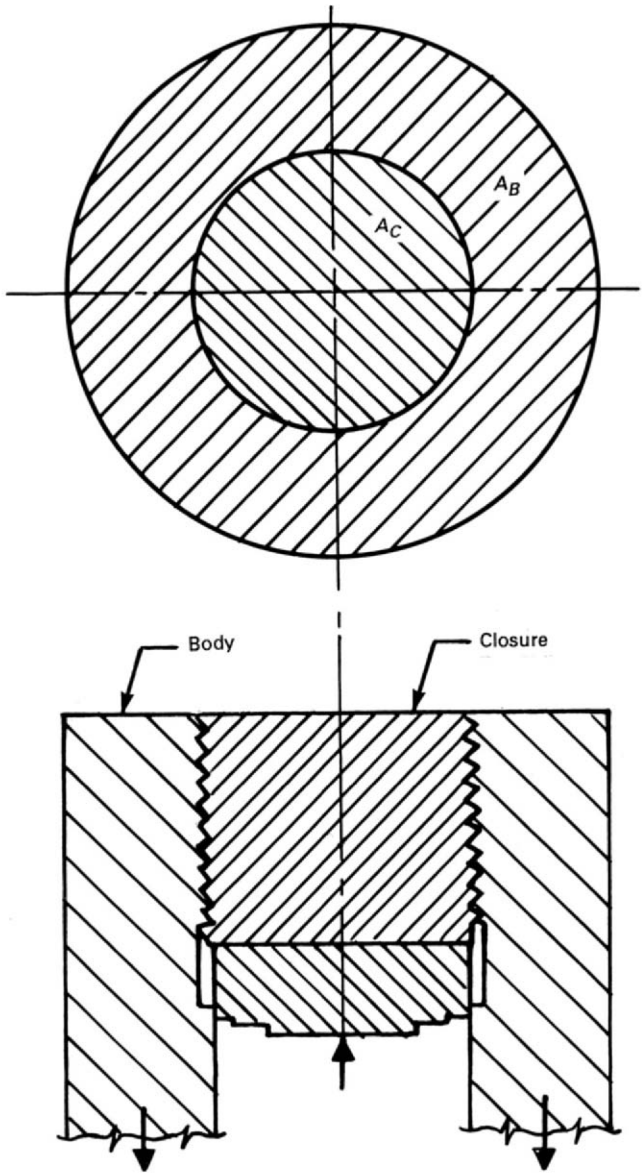


FIG. E-210.1 TYPICAL THREADED END CLOSURE

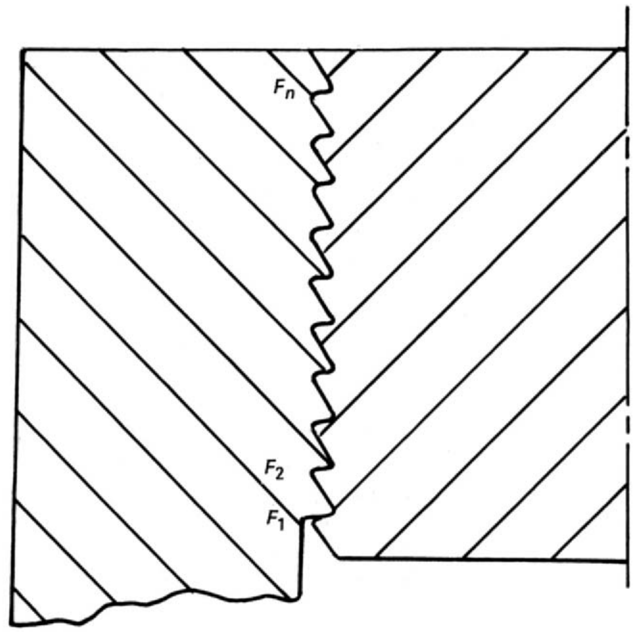


FIG. E-210.2 THREAD LOADING DISTRIBUTION

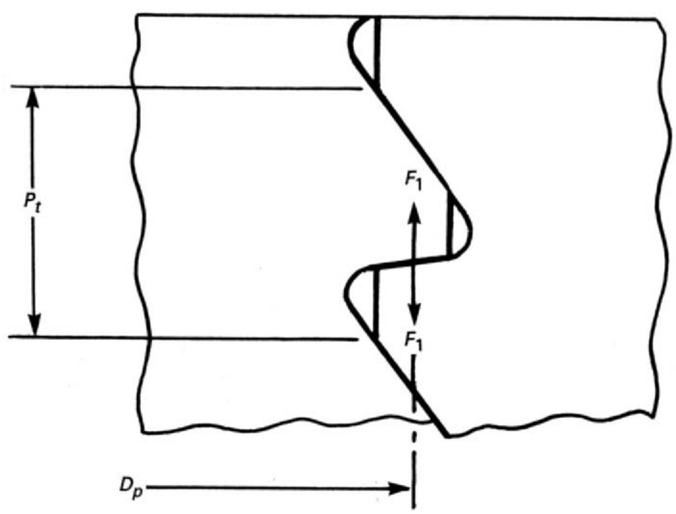


FIG. E-210.3 DETAIL OF FIRST THREAD

TABLE E-222.1
CONTINUOUS THREAD EXAMPLE

Thread	F_i [Note (1)]	F_{sum}	$C_M/C_T \times F_{sum}$	F_i, %
10	1.000	1.000	0.065	4.1
9	1.065	2.065	0.135	4.3
8	1.200	3.265	0.213	4.9
7	1.413	4.679	0.305	5.7
6	1.719	6.398	0.418	7.0
5	2.137	8.534	0.557	8.7
4	2.694	11.228	0.733	10.9
3	3.427	14.655	0.957	13.9
2	4.384	19.039	1.243	17.8
1	5.627	24.666	1.611	22.8

NOTE:
(1) $F_T = 24.666$ (obtained by adding the ten F_i values).

where

$$F_{sum} = \sum_{j=i+1}^{n} F_j$$

(See Crum, A. S. D.; High Pressure Technology, ASME PVP-Vol. 148, pp. 43–53, June 1988.) Starting with the last thread F_n, calculate the load on the previous thread F_{n-1} and the load on F_{n-2}, and so on.

E-222 Interrupted (Breech) Thread

A similar equation for segments to those for full threads is:

$$S_i = S_{i+1} + \frac{S_M}{S_T}(S_{sum})$$

(a) Example for Continuous Thread. Assuming the load on the last thread is unity, given the values below, we obtain the values in Table E-222.1.

$$D_O = 26$$
$$D_p = 13$$
$$P_T = 1$$
$$n = 10$$
$$A_B = 398.197$$
$$A_C = 132.732$$
$$C_M = 0.01$$
$$C_T = 0.154$$

(b) Example for Interrupted Thread. For $S = 4$ (one-eighth turn to open), we obtain the values in Table E-222.2.

TABLE E-222.2
INTERRUPTED THREAD EXAMPLE

Thread No.	Segment No.	S_i	S_{sum}	$S_M/S_T \times S_{sum}$	S, %	Thread, %
10	40	1.000	1.000	0.002	1.52	6.12
10	39	1.002	2.002	0.004	1.53	. . .
10	38	1.006	3.008	0.006	1.53	. . .
10	37	1.012	4.020	0.008	1.54	. . .
9	36	1.020	5.041	0.010	1.56	6.33
9	35	1.031	6.072	0.012	1.57	. . .
9	34	1.043	7.115	0.015	1.59	. . .
9	33	1.058	8.172	0.017	1.61	. . .
8	32	1.074	9.247	0.019	1.64	6.74
8	31	1.093	10.340	0.021	1.67	. . .
8	30	1.114	11.454	0.023	1.70	. . .
8	29	1.138	12.592	0.026	1.74	. . .
7	28	1.163	13.755	0.028	1.77	7.36
7	27	1.191	14.947	0.030	1.82	. . .
7	26	1.222	16.169	0.033	1.86	. . .
7	25	1.255	17.424	0.036	1.91	. . .
6	24	1.290	18.714	0.038	1.97	8.24
6	23	1.329	20.043	0.041	2.03	. . .
6	22	1.370	21.412	0.044	2.09	. . .
6	21	1.413	22.826	0.047	2.15	. . .
5	20	1.460	24.285	0.050	2.23	9.38
5	19	1.509	25.795	0.053	2.30	. . .
5	18	1.562	27.357	0.056	2.38	. . .
5	17	1.618	28.975	0.059	2.47	. . .
4	16	1.677	30.652	0.063	2.56	10.82
4	15	1.739	32.391	0.066	2.65	. . .
4	14	1.806	34.197	0.070	2.75	. . .
4	13	1.875	36.072	0.074	2.86	. . .
3	12	1.949	38.021	0.078	2.97	12.62
3	11	2.027	40.047	0.082	3.09	. . .
3	10	2.108	42.156	0.086	3.21	. . .
3	9	2.194	44.350	0.090	3.35	. . .
2	8	2.285	46.635	0.095	3.48	14.83
2	7	2.380	49.015	0.100	3.63	. . .
2	6	2.480	51.495	0.105	3.78	. . .
2	5	2.585	54.080	0.110	3.94	. . .
1	4	2.695	56.775	0.116	4.11	17.54
1	3	2.811	59.586	0.122	4.29	. . .
1	2	2.933	62.519	0.128	4.47	. . .
1	1	3.060	65.579	0.134	4.67	. . .

NONMANDATORY APPENDIX F
APPROVAL OF NEW MATERIALS UNDER THE ASME BOILER AND PRESSURE VESSEL CODE

See Section II, Part D, Appendix 5.

NONMANDATORY APPENDIX G
DESIGN RULES FOR CLAMP CONNECTIONS

G-100 SCOPE

(a) The guidelines in this Appendix are for the design of clamp connections for pressure vessels and vessel parts. They supplement the applicable requirements of Articles KD-2, KD-3, KD-4, and KD-6 of this Division. These guidelines should not be used for the determinations of thickness of supported or unsupported tubesheets integral with a hub nor for the determination of thickness of covers. These rules provide only for hydrostatic end loads, assembly, and gasket seating.

(b) The design of a clamp connection involves the selection of the gasket, bolting, hub, and clamp geometry. Bolting should be selected to satisfy the requirements of G-400. Connection dimensions should be such that the stresses in the clamp and the hub calculated in accordance with G-700 and G-800 do not exceed the allowable stresses specified in Table G-900. All calculations should be made on dimensions in the corroded condition. Calculations for assembly, gasket seating, and operating conditions are required.

(c) It is recommended that either a pressure energized and/or low seating load gasket be used. Figure G-300 shows typical pressure energized gaskets. This type of gasket is consistent with the relatively low preloading capability of this type of construction. Gasket factors m for other than pressure energized gaskets may be found in other Divisions of the Code. The designer should consider the deflection of the gasket contact faces under both assembly and operating loads when selecting or designing a gasket. Hub faces shall be designed such as to have metal-to-metal contact outside the gasket seal diameter. This may be provided by recessing the hub faces or by use of a metal spacer (see Fig. G-100.1). The contact area shall be sufficient to prevent yielding of either the hub face or spacer under both operating and assembly loads.

(d) It is recognized that there are clamp designs which utilize no wedging action during assembly since clamping surfaces are parallel to the hub faces. Such designs are acceptable and should satisfy the bolting and corresponding clamp and hub requirements of a clamp connection designed for a total included clamping angle of 10 deg.

(e) The design methods used herein to calculate stresses, loads, and moments can also be used in designing clamp connections of shapes differing from those shown in Figs. G-100.1, G-100.2, and G-100.3, and for clamps consisting of more than two circumferential segments. The design equations presented herein are based on simple straight beam theory and are conservative in that they do not account for curvature or hoop-restraint effects. Alternative techniques such as finite element analysis methods can be used to evaluate clamp designs.

(f) Clamps designed to the rules of this Appendix should be provided with two or more bolts per segment connection.

(g) The design of the hub faces and clamps should incorporate weep holes and vent passages adequately sized to vent pressure in the event of gasket leakage to prevent hub and clamp overstress.

G-200 MATERIALS

(a) Materials used in the construction of clamp connections shall comply with the requirements given in Part KM.

(b) Hubs and clamps should not be machined from plate.

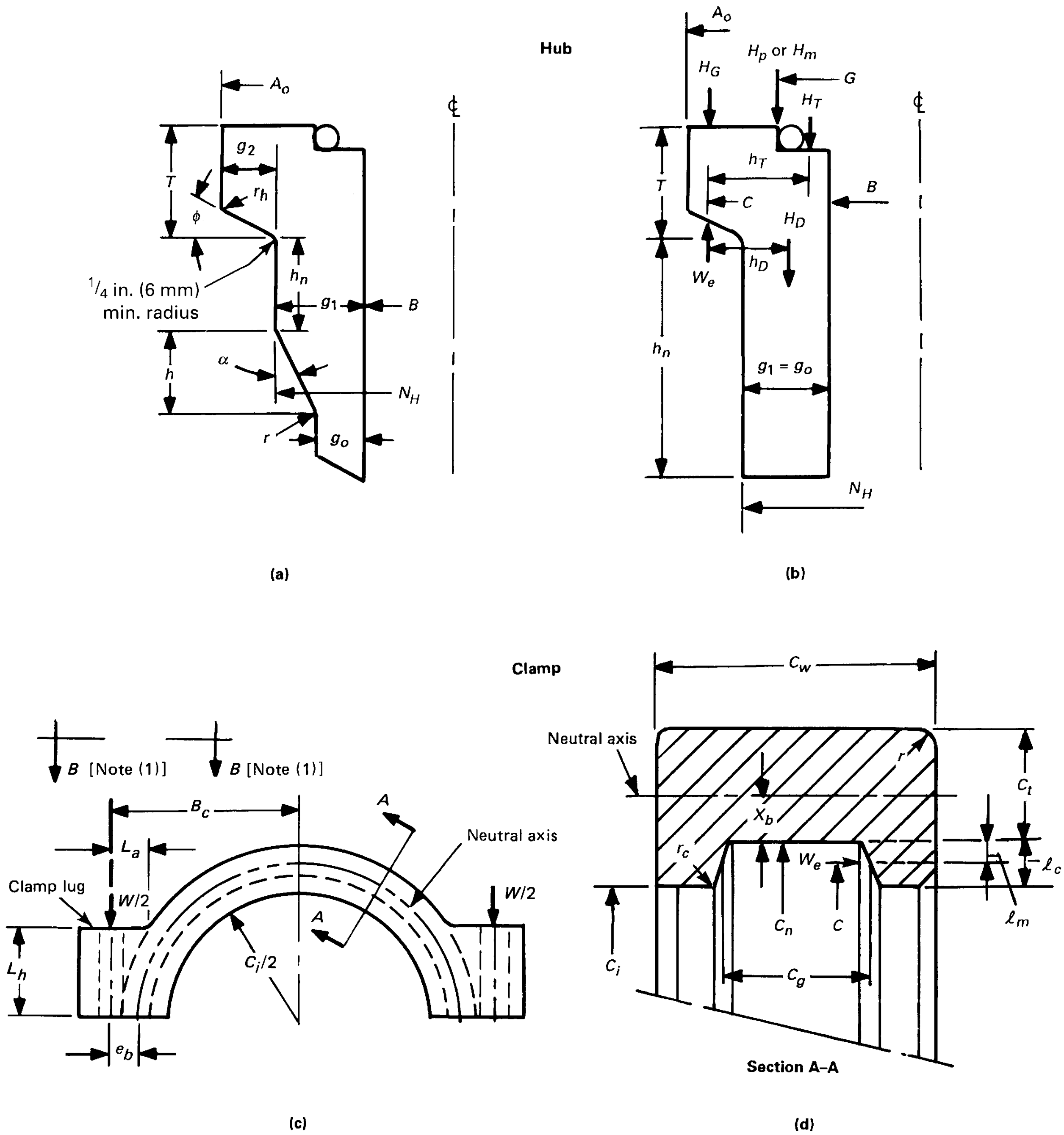
(c) Bolts, studs, nuts, and washers should comply with Article KD-6 and Part KM. Minimum diameter should be $\frac{1}{2}$ in. (13 mm).

G-300 NOMENCLATURE 04

The nomenclature below is used in the equations for the design of clamp-type connections (see also Figs. G-100.1, G-100.2, and G-100.3).

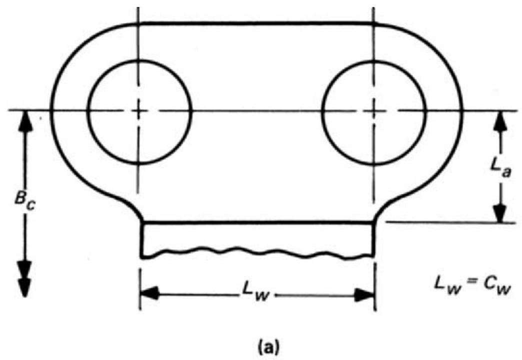
A_b = total cross-sectional area of the bolts per clamp lug using the minimum of the root diameter of the thread or least diameter of unthreaded portion, in.^{2} (mm^2)

A_c = total clamp cross-sectional area, in.^{2} (mm^2). This may be calculated as shown below or by any other consistent method based on the clamp geometry:



NOTE:
(1) See Fig. G-100.2 for view *B-B*.

04 FIG. G-100.1 CLAMP NOMENCLATURE



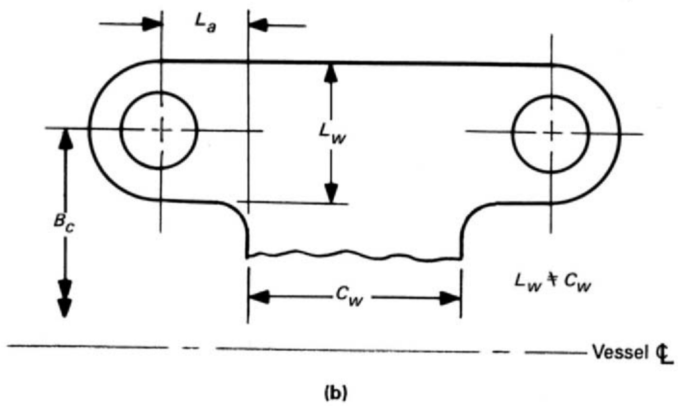


FIG. G-100.2 TYPICAL CLAMP LUG CONFIGURATIONS
[View *B-B* From Fig. G-100.1, Sketch (c)]

$= A_{c1} + A_{c2} + A_{c3}$

A_{c1} = partial clamp area, in.^{2} (mm^2)

$= (C_w - 2C_t)C_t$

A_{c2} = partial clamp area, in.^{2} (mm^2)

$= 2C_t^2 - \left(2 - \dfrac{\pi}{2}\right) r^2$

A_{c3} = partial clamp area, in.^{2} (mm^2)

$= (C_w - C_g)\ \ell_c$

A_m = total required cross-sectional area of bolts per clamp segment connection, taken as the greater of A_{m1} and A_{m2}, in.^{2} (mm^2)

A_{m1} = total cross-sectional area of bolts per clamp segment connection at root of thread or section of least diameter under stress, required for the operating conditions, in.^{2} (mm^2)

$= W_{m1}/2S_b$

A_{m2} = total cross-sectional area of bolts per clamp segment connection at root of thread or section of least diameter under stress, required for gasket seating, in.^{2} (mm^2)

$= W_{m2}/2S_a$

A_o = outside diameter of the hub, in. (mm)

A_{or} = outside bearing diameter of the hub accounting for the corner radius r_h, in. (mm)

$= A_o - 2r_h$

A_3 = hub longitudinal shear area, taken as the lesser of A_{3a} and A_{3b}, in.^{2} (mm^2)

A_{3a} = hub longitudinal shear area based on a straight shear surface in the tangential–longitudinal plane, in.^{2} (mm^2)

$= \pi C_{ir} T_h$

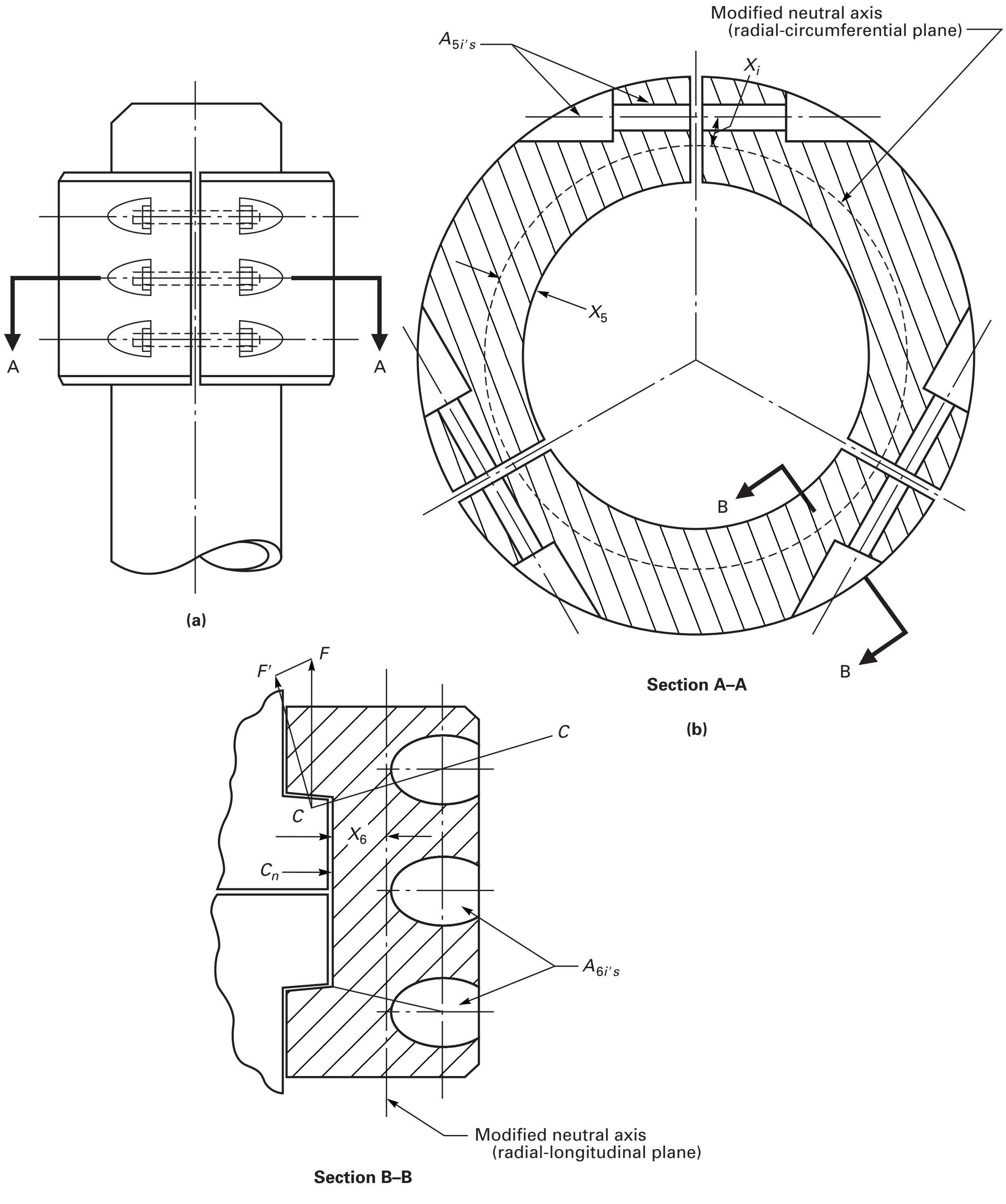
A_{3b} = hub longitudinal shear area based on a 45 deg conical shear surface, in.^{2} (mm^2). This can be calculated by any consistent method and may be limited by chamfers on the hub and thickness of the hub shoulder. A typical formulation when these effects are not limiting is shown below:

$= \dfrac{\pi\sqrt{2}}{4}\,(A_o^2 - C_{ir}^2)$

A_5 = minimum clamp cross-sectional area in the radial–tangential plane, in.^{2} (mm^2)

$= \pi(C_n + C_t)\ C_t - A_{5b}$

(The A_5 area can be further modified if only two



04 FIG. G-100.3 TYPICAL HUB DESIGN WITH THE BOLTS CONTAINED WITHIN THE BODY OF THE CLAMP

sets of bolts are used and the bolt hole cutout regions fall within a region adjacent to the clamp lip. Such a case is illustrated by Section $C–C$ in Fig. G-100.3. For this configuration, A_5 can be based on a section indicated by Section $C–C$, provided that the force acting normal to the plane is also appropriately modified.)

A_{5b} = maximum clamp bolt hole cutout area (including spot faces and undercuts) around the full circumference in any radial–tangential plane when no external lugs are used and the bolts are contained within the main body of the clamp (Fig. G-100.3), in.^{2} (mm^2)
= $\sum A_{5i}$
($A_{5b} = 0$ for external bolt lugs like those shown in Fig. G-100.2)

A_{5i} = individual clamp bolt hole cutout areas in the radial–tangential plane, in.^{2} (mm^2) (see Fig. G-100.3)

A_6 = minimum clamp cross-sectional area in the radial–longitudinal plane, in.^{2} (mm^2)
= $A_c - A_{6b}$

A_{6b} = maximum clamp bolt hole cutout area (including spot faces and undercuts) in any radial– longitudinal plane when the bolts are contained within the main body of the clamp, in.^{2} (mm^2). This corresponds to the bolt hole cutout areas indicated in Section $B–B$ of Fig. G-100.3.
= $\sum A_{6i}$
($A_{6b} = 0$ for external bolt lugs like those shown in Fig. G-100.2)

A_{6i} = individual clamp bolt hole cutout areas in the radial–longitudinal plane, in.^{2} (mm^2) (see Fig. G-100.3)

A_7 = clamp lip longitudinal shear area, taken as the lesser of A_{7a} and A_{7b}, in.^{2} (mm^2)

A_{7a} = clamp lip longitudinal shear area based on a straight shear surface in the tangential–longitudinal plane, in.^{2} (mm^2)
= $\pi A_{or} T_c$

A_{7b} = clamp lip longitudinal shear area based on a 45 deg conical shear surface, in.^{2} (mm^2). This can be calculated by any consistent method and may be limited by chamfers on the lip and the lip thickness. A typical formulation when these effects are not limiting is shown below:

$$= \frac{\pi\sqrt{2}}{4}\left(A_{or}^2 - C_i^2\right)$$

B = inside diameter of hub, in. (mm)

B_c = radial distance from connection centerline to center of bolts, in. (mm) [see Fig. G-100.1, illustration (c)]

C = diameter of effective clamp–hub reaction circle, in. (mm)
= $(A_{or} + C_{ir})/2$

C_g = effective clamp gap determined at diameter C, in. (mm)

C_i = inside bearing diameter of clamp, in. (mm)

C_{ir} = inside bearing diameter of the clamp accounting for the corner radius r_c, in. (mm)
= $C_i + 2r_c$

C_n = inside diameter of the neck of the clamp, in. (mm)

C_t = effective clamp thickness (C_t shall be equal to or greater than r), in. (mm)

C_w = clamp width, in. (mm)

C_6 = tangential bending stress moment arm, in. (mm)
= $C_t - X_6$
(if $e_b < 0$, $C_6 = X_6$)

G = diameter at location of gasket load reaction, in. (mm). As noted in Fig. G-100.1, G is defined as the diameter to the outside of the seal surface. For other than pressure energized seals, other Divisions of this Code may be consulted for appropriate gasket effective diameter. See additional illustration of G for self-energizing seals in Fig. G-300.

H = total end force required for operating or assembly conditions, as applicable, kip (N)

H_D = hydrostatic end force on bore area, kip (N)
= $\pi B^2 P/4$

H_e = total hydrostatic end force, kip (N)
= $\pi G^2 P/4$

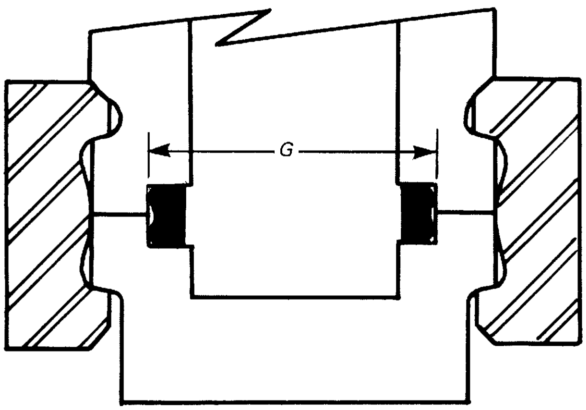
H_G = difference between total effective axial clamping preload and the sum of total hydrostatic end force and total joint-contact surface compression, kip (N)
= $[\pi W/(2\tan(\phi + \mu)] - (H + H_p)$

H_m = total axial gasket seating requirements for makeup, kip (N) (the axial seating load for self-energizing gaskets, if significant)

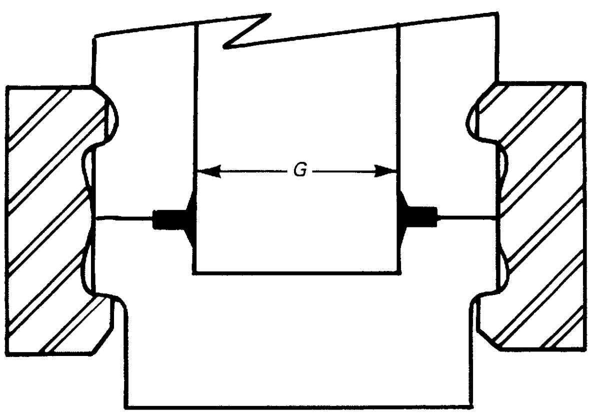
H_p = total joint-contact surface compression load, kip (N)
= $2b \times \pi GmP$
(for self-energized gaskets, use $H_p = 0$ or actual retaining load if significant)

H_T = difference between total hydrostatic end force and hydrostatic end force on bore area, kip (N)
= $H - H_D$

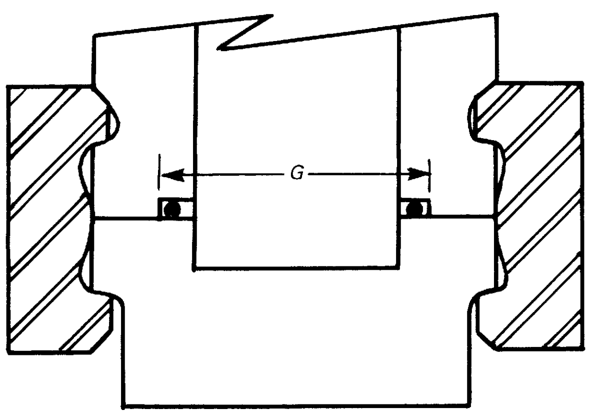
I_c = moment of inertia of clamp relative to neutral axis of the radial–longitudinal cross section, ignoring any bolt holes through the main body of the clamp, in.^{4} (mm^4). This can be calculated by any consistent method, such as that shown below based on the clamp geometry.



(a) Wave Ring Type Seal



(b) Metallic Lip Type Seal



(c) "O" Ring Type Seal

GENERAL NOTE: $m = 0$

FIG. G-300 TYPICAL SELF-ENERGIZING GASKETS USED IN THIS DIVISION, SHOWING DIAMETER AT LOCATION OF GASKET LOAD REACTION G

$= \frac{1}{3}[(A_{c1} + A_{c2})\, C_t^2 + A_{c3}\ell_c^2] - A_c X_b^2$

I_h = moment of inertia of hub shoulder relative to its neutral axis, in.^{4} (mm^4)

$= \frac{g_1 T^3}{3} + \frac{g_2 h_2^3}{3} - (g_2 h_2 + g_1 T)\overline{h}^2$

I_5 = minimum clamp moment of inertia in any radial–tangential plane, in.^{4} (mm^4)

$= [\pi(C_n + C_t)\, C_t^3/3] - I_{5b} - A_5 X_5^2$

I_{5b} = maximum reduction of the clamp moment of inertia due to bolt hole cutout areas around the full circumference in any radial–tangential plane, in.^{4} (mm^4)

$= \sum(A_{5i})(X_i)^2 + \sum$ (local moments of inertia of each area about its own centroid)[1]

($I_{5b} = 0$ when external bolt lugs are used like those shown in Fig. G-100.2)

I_6 = minimum clamp moment of inertia in any tangential–longitudinal plane, in.^{4} (mm^4)

$= I_c - I_{6b} - A_6 X_6^2 + A_c X_b^2$

I_{6b} = maximum reduction of the clamp moment of inertia due to bolt hole cutout areas in any tangential–longitudinal plane, in.^{4} (mm^4)

$= \sum(A_{6i})(X_i)^2 + \sum$ (local moments of inertia of each area about its own centroid)[1]

($I_{6b} = 0$ when external bolt lugs are used like those shown in Fig. G-100.2)

L_a = distance from centerline of the clamp bolt to the point where the clamp lug joins the clamp body, in. (mm) [see Fig. G-100.1, illustration (c)]

L_h = clamp lug height, in. (mm) [see Fig. G-100.1, illustration (c)]

L_w = clamp lug width, in. (mm) (see Fig. G-100.2)

M_D = moment due to H_D, in.-kip (N·mm)

$= H_D h_D$

M_F = offset moment, in.-kip (N·mm)

$= H_D(g_1 - g_0)/2$

M_G = moment due to H_G, in.-kip (N·mm)

$= H_G h_G$

M_H = reaction moment at hub neck, in.-kip (N·mm)

$$= \frac{M_0}{\left[1 + \frac{1.818}{\sqrt{Bg_1}} \times \left(T - \overline{h} + \frac{3.305 I_h}{g_1^2\,(B/2 + \overline{g})}\right)\right]}$$

M_o = total rotational moment on hub, in.-kip (N·mm) (see G-600)

M_p = pressure moment, in.-kip (N·mm)

$= \pi \times PBT(T/2 - \overline{h})$

M_R = radial clamp equilibrating moment, in.-kip (N·mm)

$= (\pi W/2)\,\{\overline{h} - T + [(C - N_H)\tan\phi]/2\}$

[1] In calculating I_{5b} and I_{6b}, the local moment of inertia contribution can often be ignored.

M_T = moment due to H_T, in.-kip (N·mm)
= $H_T h_T$

M_5 = clamp longitudinal stress bending moment, in.-kip (N·mm)
= $H(\ell_m + X_5) + (\pi W/2)(C_g/2)$

M_6 = clamp tangential stress bending moment, in.-kip (N·mm)
= $|e_b|\ W/2$

N_H = outside diameter of hub neck, in. (mm)

P = internal design pressure, ksi (MPa)

Q = reaction shear force at hub neck, kip (N)

$$= \frac{1.818 M_H}{\sqrt{B g_1}}$$

S_a = allowable bolt stress at room temperature (see KD-620), ksi (MPa)

S_b = allowable bolt stress at design temperature (see KD-620), ksi (MPa)

S_{YAC} = yield stress for clamp material at (assembly condition) room temperature, ksi (MPa)

S_{YAH} = yield stress for hub material at (assembly condition) room temperature, ksi (MPa)

S_{YOC} = yield stress for clamp material at (operating condition) design temperature, ksi (MPa)

S_{YOH} = yield stress for hub material at (operating condition) design temperature, ksi (MPa)

S_1 = hub longitudinal stress on outside at hub neck, ksi (MPa)

S_2 = maximum Lamé hoop stress at bore of hub, ksi (MPa)

S_3 = maximum hub shear stress at shoulder, ksi (MPa)

S_4 = maximum radial hub shear stress in neck, ksi (MPa)

S_5 = clamp longitudinal stress at clamp body inner diameter, ksi (MPa)

S_6 = clamp tangential stress at clamp body outer diameter, ksi (MPa)

S_7 = maximum shear stress in clamp lips, ksi (MPa)

S_8 = clamp lip bending stress, ksi (MPa)

S_9 = clamp lug bending stress, ksi (MPa)

S_{10} = maximum clamp lug shear stress, ksi (MPa)

S_{11} = effective bearing stress between clamp and hub, ksi (MPa)

T = thickness of hub shoulder per Fig. G-100.1, in. (mm)

T_c = clamp lip thickness below the outside edge of the hub, in. (mm)

$$= \frac{1}{2}\left[C_w - C_g + (A_{or} - C)\tan\phi\right]$$

T_h = hub shoulder thickness below the inside edge of the clamp, in. (mm)

$$= T - \left(\frac{C_{ir} - A_0}{2} + g_2\right)\tan\phi$$

W = total design bolt load required for operating or assembly condition, as applicable, kip (N)

W_c = total effective axial clamping preload on one clamp lip and hub shoulder (gasket seating or assembly), kip (N)
= $\pi W/[2\ \tan(\phi + \mu)]$

W_{m1} = minimum required total bolt load for the operating conditions, kip (N) [see G-400(b)(1)]

W_{m2} = minimum required total bolt load for gasket seating, kip (N) [see G-400(b)(2)]

X_b = basic clamp dimension to neutral axis in the longitudinal–radial plane ignoring any bolt holes through the body of the clamp, in. (mm). This may be calculated as shown below or by any consistent method.

$$= \frac{(A_{c1} + A_{c2})C_t - A_{c3}\ell_c}{2A_c}$$

X_i = average radial distance, in. (mm), from each bolt cutout area in the applicable plane to the inner edge of the neck of the clamp [i.e., to the edge whose diameter is C_n as shown in Fig. G-100.3, illustrations (b) and (c)]

X_5 = modified clamp dimension to the neutral axis in the radial–tangential plane, accounting for bolt holes in the main clamp cross section [see Fig. G-100.3, illustration (b)], in. (mm)

$$= \frac{\pi\,(C_n + C_t)(C_t^2/2) - \sum A_{5i}X_i}{A_5}$$

($X_5 = C_t/2$ for external bolt lugs like those shown in Fig. G-100.2)

X_6 = modified clamp dimension to the neutral axis in the longitudinal–radial plane, accounting for bolt holes in the main clamp cross section [see Fig. G-100.3, illustration (c)], in. (mm)

$$= \frac{X_b A_c - \sum A_{6i}X_i}{A_6}$$

[$X_6 = X_b$ (see Fig. G-100.1) for external bolt lugs like those shown in Fig. G-100.2]

Z = clamp–hub taper angle, deg (for gasket seating and preload, $Z = \phi + \mu$; for operating, $Z = \phi - \mu$) [see G-400(b)(3)]

b = effective gasket or joint-contact-surface seating width, in. (mm)

e_b = radial distance from center of the bolts to the centroid of the clamp cross section, in. (mm)
= $B_c - (C_i/2) - \ell_c - X_6$

f = hub stress correction factor from Fig. G-300.1 (this is the ratio of the stress in the small end of the hub to the stress in the large end). For values below limit of the Figure, use $f = 1.0$.

$\overline{g}$ = radial distance from the hub inside diameter B to the hub shoulder ring centroid, in. (mm)

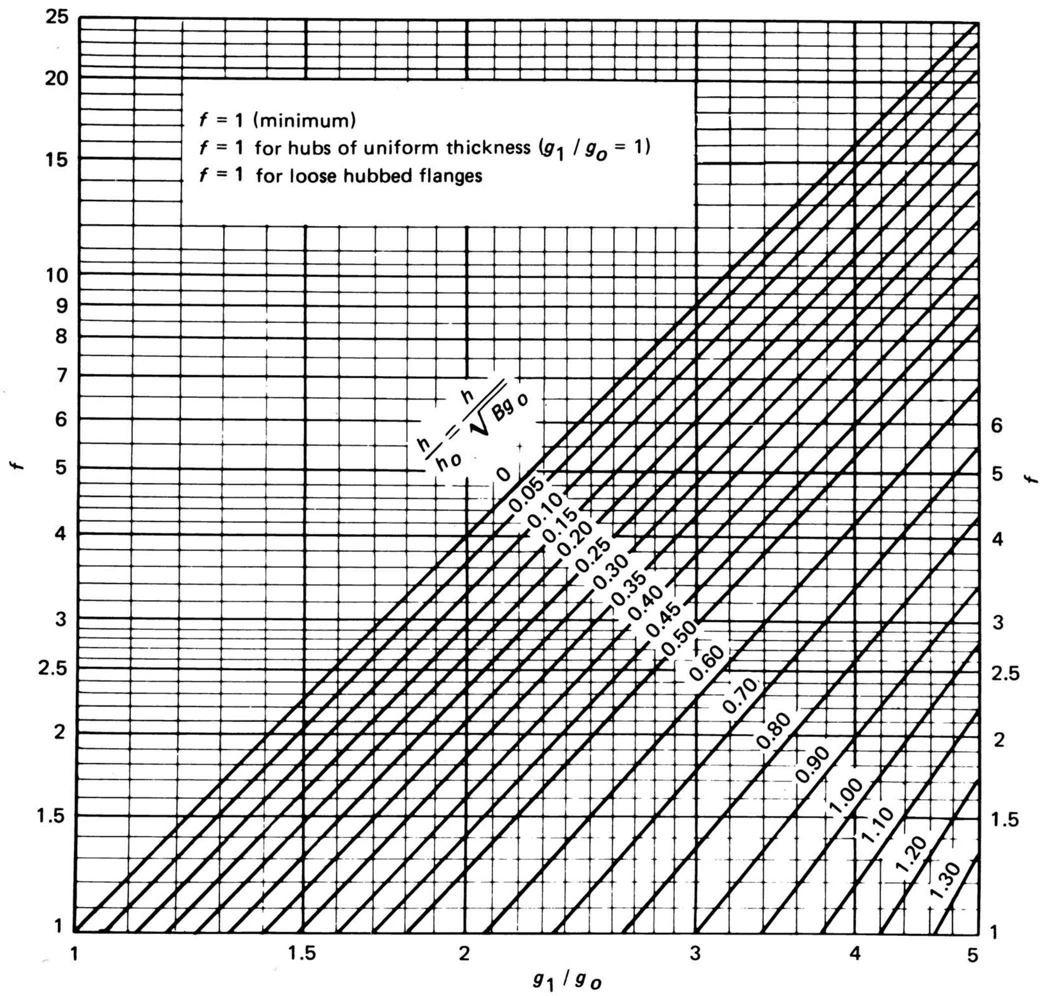


FIG. G-300.1 VALUES OF f
(Hub Stress Correction Factor)

$= \dfrac{Tg_1^2 + h_2g_2(2g_1 + g_2)}{2(Tg_1 + h_2g_2)}$

g_0 = thickness of hub neck at small end, in. (mm)

g_1 = thickness of hub neck at intersection with hub shoulder, in. (mm)

g_2 = height of hub shoulder, in. (mm) (g_2 shall not be larger than T)

h = hub taper length, in. (mm)

$\overline{h}$ = longitudinal distance from the hub face to the hub shoulder ring centroid, in. (mm)

$= \dfrac{T^2g_1 + h_2^2g_2}{2(Tg_1 + h_2g_2)}$

h_D = radial distance from effective clamp–hub reaction circle to the circle on which H_D acts, in. (mm)

$= [C - (B + g_1)]/2$

h_G = radial distance from effective clamp–hub reaction circle to the circle on which H_G acts, in. (mm) (for full-face contact geometries, $h_G = 0$)

h_n = hub neck length, in. (mm) (minimum length of h_n is $0.5g_1$ or $\frac{1}{4}$ in. (6 mm), whichever is larger)

h_T = radial distance from effective clamp–hub reaction circle to the circle on which H_T acts, in. (mm)

$= [C - (B + G)/2]/2$

$h_0 = \sqrt{Bg_0}$, in. (mm)

h_2 = average thickness of hub shoulder, in. (mm)

$= T - (g_2 \tan\phi)/2$

ℓ_c = effective clamp lip length, in. (mm)

ℓ_m = effective clamp lip moment arm, in. (mm)

$= \ell_c - \dfrac{(C - C_i)}{2}$

m = gasket factor; $m = 0$ for pressure energized gaskets. For nonpressurized gaskets, other Divisions of this Code may be consulted.

r = clamp or hub cross section corner radius, in. (mm)
= $\frac{1}{4}$ in. (6 mm) min., C_t max.
r_c = clamp inside corner radius on the surface that mates with the hub (see Fig. G-100.1), in. (mm)
r_h = hub outside corner radius on the surface that mates with the clamp (see Fig. G-100.1), in. (mm)
μ = friction angle, deg
ϕ = clamp shoulder angle, deg
= 35 deg maximum

G-400 BOLT LOADS

(a) General. During assembly of the clamp connection, the design bolt load W is resolved into an effective clamp preload W_c, which is a function of the clamp– hub taper angle ϕ and the friction angle μ. An appropriate friction angle should be established by the Manufacturer, based on test results for both assembly and operating conditions.

(b) Calculations. In the design of bolting for a clamp connection, complete calculations should be made for two separate and independent sets of conditions, which are defined as follows:

(1) The required bolt load for the operating conditions W_{m1} should be sufficient to resist the hydrostatic end force H_e exerted by the design pressure acting on the area bounded by the diameter of gasket reaction plus a gasket compressive load H_p which experience has shown to be sufficient to assure a tight joint. The minimum operating bolt load W_{m1} should be determined in accordance with Eq. (1):

$$W_{m1} = \frac{2}{\pi}(H_e + H_p)\tan(\phi - \mu) \tag{1}$$

(2) Before a tight joint can be obtained, it is necessary to seat the gasket or joint-contact surface properly by applying a minimum initial load (under atmospheric temperature conditions without the presence of internal pressure), which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt load required for gasket seating W_{m2} should be determined in accordance with Eq. (2):

$$W_{m2} = \frac{2}{\pi}H_m\tan(\phi + \mu) \tag{2}$$

(3) In Eq. (1), credit for friction is allowed based on clamp connection geometry and experience, but the bolt load should not be less than that determined using a $\phi - \mu$ value of 5 deg. Friction is also considered in determining bolt loads by Eq. (2), but the μ factor used should not be less than 5 deg.

(c) Required Bolt Area. The total cross-sectional area of bolting A_m required should be the greater of the values for operating conditions A_{m1} and gasket seating conditions A_{m2}. Bolt bending in the assembly should be considered.

(d) Clamp Connection Design Bolt Load W. The bolt load used in the design of the clamp connection should be the value obtained from Eqs. (3) and (4).

Operating conditions:

$$W = W_{m1} \tag{3}$$

Assembly conditions:

$$W = \frac{(A_m + A_b)S_a}{2} \tag{4}$$

G-500 LONGITUDINAL LOADS

The longitudinal clamp load H used in the design of the clamp connection should be the value obtained from Eqs. (5) and (6).

Operating conditions:

$$H = H_e + H_p \tag{5}$$

Assembly conditions:

$$H = \frac{\pi W}{2\tan(\phi + \mu)} \tag{6}$$

[W is calculated per Eq. (4).]

G-600 HUB MOMENTS

The moments used in determining hub stresses are the products of loads and moment arms illustrated in Fig. G-100.1 and defined in G-300. In addition, reaction moments due to hub eccentricities and bearing pressure are considered.

For the operating condition, the design moment M_o is the sum of six individual moments: M_D, M_G, M_T, M_F, M_P, and M_R. The bolt load W used is that from Eq. (3).

For assembly, the design moment M_o is based on the design bolt load of Eq. (4):

$$M_o = \frac{\pi W(C - G)}{4\tan(\phi + \mu)}$$

G-700 CALCULATION OF HUB STRESSES

The stresses in the hub should be determined for both the operating and the assembly condition.

(a) The reaction moment M_H and the reaction shear Q are defined in G-300 and should be calculated at the hub neck for rotational moment M_o.

04 *(b)* Hub stresses should be calculated from the following equations:

(1) Hub longitudinal stress

$$S_1 = f\left(\frac{PB^2}{4g_1\,(B + g_1)} + \frac{6M_H}{\pi g_1^2\,(B + g_1)}\right)$$

(2) Hub Lamé hoop stress

$$S_2 = P\left(\frac{N_H^2 + B^2}{N_H^2 - B^2}\right)$$

(3) Hub longitudinal shear stress

$$S_3 = \frac{1.5H}{A_3}$$

(4) Hub radial shear stress

$$S_4 = \frac{1.5Q}{\pi g_1(B + g_1)}$$

04 G-800 CALCULATION OF CLAMP STRESSES

The stresses in the clamp should be determined for both the operating and the assembly conditions. Clamp stresses should be calculated from the following equations:

(a) Clamp longitudinal stress at clamp body inner diameter

$$S_5 = \frac{H}{A_5} + \frac{M_5\,(C_t - X_5)}{I_5}$$

(b) Clamp tangential stress at clamp body surface

$$S_6 = \frac{W}{2A_6} + \frac{M_6 C_6}{I_6}$$

(c) Clamp lip shear stress

$$S_7 = \frac{1.5\,H}{A_7}$$

(d) Clamp lip bending stress

$$S_8 = \frac{6H\ell_m}{\pi C\,[(C_w - C_g)/2]^2}$$

(e) Clamp lug bending stress

$$S_9 = 3W\frac{L_a}{L_w L_h^2}$$

(f) Clamp lug shear stress

$$S_{10} = \frac{0.75\,W}{L_w L_h}$$

In addition, a bearing stress calculation should be made at the clamp-to-hub contact:

$$S_{11} = \frac{H}{\pi C\,(A_{or} - C_{ir})/2}$$

G-900 ALLOWABLE DESIGN STRESSES FOR CLAMP CONNECTIONS

Table G-900 gives the allowable stresses that are to be used with the equations of G-700 and G-800.

TABLE G-900
ALLOWABLE DESIGN STRESS FOR CLAMP CONNECTIONS

Stress Category	Allowable Stress
S_1	S_{YOH} or S_{YAH}
S_2	$S_{YOH}/1.5$
S_3	$0.6S_{YOH}$ or $0.6S_{YAH}$
S_4	$0.6S_{YOH}$ or $0.6S_{YAH}$
S_5	S_{YOC} or S_{YAC}
S_6	S_{YOC} or S_{YAC}
S_7	$0.6S_{YOC}$ or $0.6S_{YAC}$
S_8	$S_{YOC}/1.5$ or $S_{YAC}/1.5$
S_9	$S_{YOC}/1.5$ or $S_{YAC}/1.5$
S_{10}	$0.6S_{YOC}$ or $0.6S_{YAC}$
S_{11}	[See Note (1)]

NOTE:
(1) The lower of the yield stresses for the hub material (S_{YOH}, S_{YAH}) and clamp material (S_{YOC}, S_{YAC}).

NONMANDATORY APPENDIX H
OPENINGS AND THEIR REINFORCEMENT

H-100 SCOPE

The guidelines contained in the Appendix provide for a satisfactory design in the vicinity of openings in the pressure shell, under pressure loading only, on the basis of opening shape, area replacement, and its distribution. The requirements of Articles KD-2, KD-3, and KD-4 must also be satisfied. These guidelines do not include design requirements for piping loads that may be imposed on the nozzle and/or shell portion and that may be added to the pressure loadings.

These guidelines apply only to openings with integral reinforcement.

H-101 Dimensions and Shape of Openings

Openings may be circular, or elliptical, as results from the intersection of circular cylinders and circular vessels, provided

(a) the ratio of the diameter along the major axis to the diameter along the minor axis of the finished opening is 1.5 or less.

(b) the ratio $d/D_I \leq 0.50$, where d is the largest inside diameter of the opening and D_I is the inside diameter of the vessel.

(c) the arc distance measured between the centerlines of adjacent nozzles along the inside surface of the vessel is not less than three times the sum of their inside radii for openings in a head, or along the longitudinal axis of a vessel is not less than two times the sum of their inside radii for openings along the circumference of a cylindrical vessel. When two nozzles in a cylindrical vessel are neither in a longitudinal line nor in a circumferential arc, their centerline distance along the inside surface of the vessel should be such that $\sqrt{(\ell_c/2)^2 + (\ell_\ell/3)^2}$ is not less than the sum of their inside radii, where ℓ_c is the component of the centerline distance in the circumferential direction and ℓ_ℓ is the component of the centerline distance in the longitudinal direction.

(d) reinforcement is provided around the edge of the opening in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface as stipulated in H-120.

Some high pressure connections are shown in Fig. H-101.

H-110 CIRCULAR OPENINGS NOT REQUIRING REINFORCEMENT

Circular openings need not be provided with reinforcement if all of the following requirements are satisfied:

(a) A single opening has a diameter not exceeding D_i $(0.077y - 0.0725)$, or if there are two or more openings within any circle of diameter $0.887D_i\sqrt{y^2 - 1}$, then the sum of the diameters of such unreinforced openings should not exceed D_i $(0.09624y - 0.0906)$.

(b) No two unreinforced openings should have their centers closer to each other, measured on the inside of the vessel wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening should have its center closer than $0.887D_i\sqrt{y^2 - 1}$ to the edge of a locally stressed area in the shell, where D_i is the inside diameter and y is the cylinder diameter ratio at the location of the opening(s); locally stressed area means any area in the shell where the primary local membrane stress exceeds $0.73S_y$, but excluding those areas where such primary local membrane stress is due to an unreinforced opening.

H-120 REINFORCEMENT FOR OPENINGS IN SHELLS AND FORMED HEADS

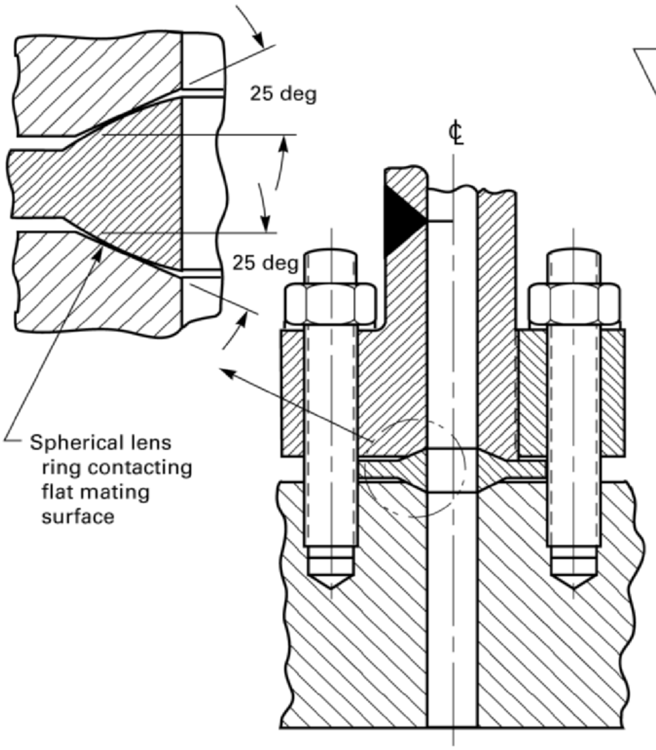
(a) Design for Internal Pressure. The total cross-sectional area of reinforcement A required in any given plane for a vessel under internal pressure should be not less than

$$A = dt_rF \tag{1}$$

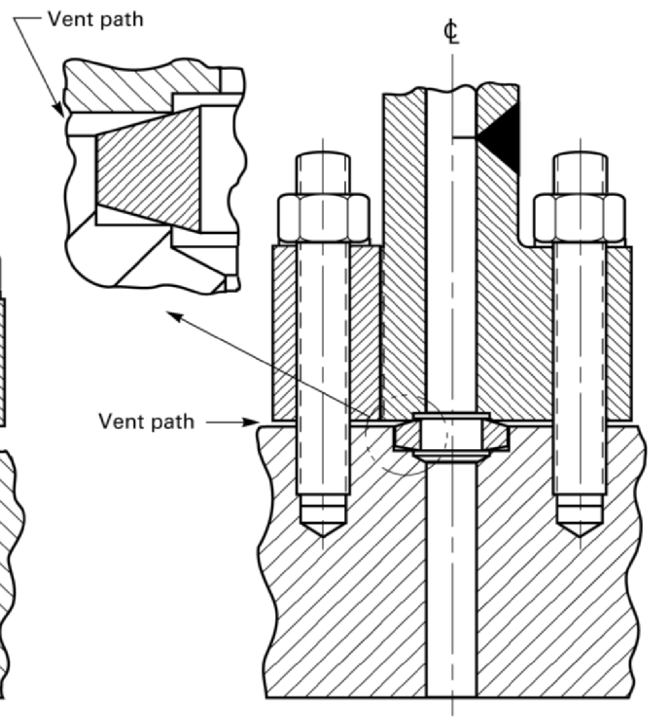
where

d = diameter in the given plane of the finished opening, in. (mm)

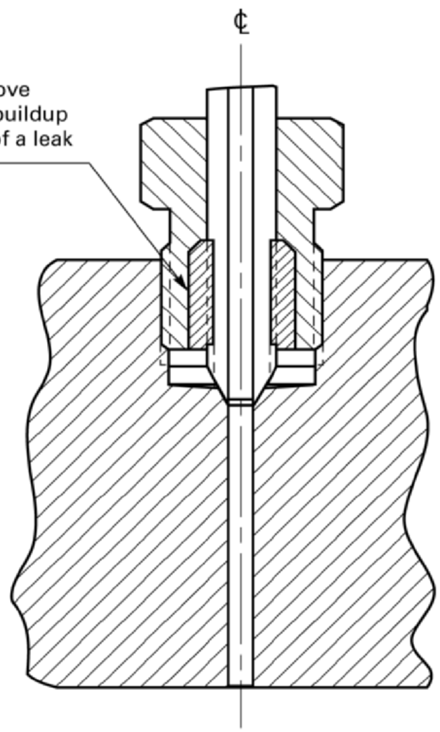
t_r = minimum thickness which meets the requirements of KD-230 in the absence of the opening, in. (mm)



(a) Lens Ring Seal



(b)



(c)

FIG. H-101 STRAIGHT DRILL CONNECTIONS FOR THICK WALLED CYLINDERS

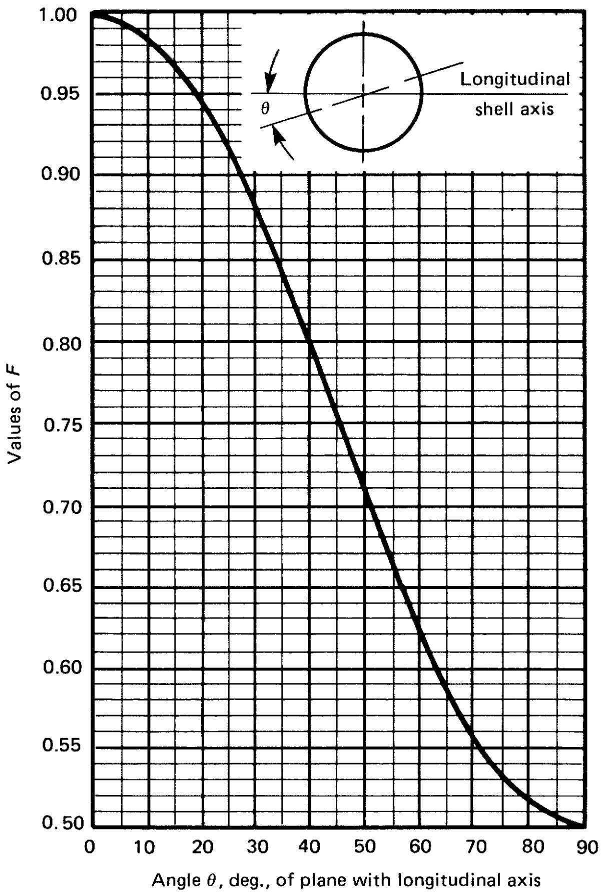


FIG. H-120.1
CHART FOR DETERMINING VALUE OF *F*

F = 1.00 when the plane under consideration is in the spherical portion of a head or when the given plane contains the longitudinal axis of a cylindrical shell. For other planes through a shell, use the value of F determined from Fig. H-120.1.

(b) Design for External Pressure. The reinforcement requirements for openings in vessels subject to external pressure need be only 50% of that required in Eq. (1) above.

H-130 REINFORCEMENT FOR OPENINGS IN FLAT HEADS

Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter should have a total cross-sectional area of reinforcement not less than that given by the equation

$$A = 0.5dt_r$$

where

d = diameter of the finished opening, in. (mm)

t_r = minimum thickness which meets the requirements of KD-640 in the absence of the opening, in. (mm)

H-140 LIMITS OF REINFORCEMENT

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening within which metal should be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are as described in H-141 and H-142.

H-141 Boundary Along Vessel Wall

Two requirements on the limits of reinforcement measured along the midsurface of the nominal wall thickness should be met as follows:

(a) 100% of the required reinforcement should be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition

(2) the radius of the finished opening in the corroded condition plus the thickness of the vessel wall plus the thickness of the nozzle wall

(b) Two-thirds of the required reinforcement should be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{R_m t}$, where R_m is the mean radius of shell or head, t is the nominal vessel wall thickness, and r is the radius of the finished opening in the corroded condition

(2) the radius of the finished opening in the corroded condition plus the thickness of the vessel wall plus the thickness of the nozzle wall

H-142 Boundary Normal to Vessel Wall

The limits of reinforcement, measured normal to the vessel wall, should conform to the contour of the surface at a distance from each surface equal to the following limits:

(a) For Fig. H-142, illustrations (a) and (b), the limit is the larger of $0.5\sqrt{r_m t_n} + K$ and $1.73x + 2.5t_p + K$, but this limit should not exceed either $2.5t$ or $L + 2.5t_p$, where

K = $0.73r_2$ when a transition radius r_2 is used and the smaller of the two legs when a fillet weld transition is used, in. (mm)

L = length along nozzle with thickness of t_n plus transition length, in. (mm)

r = inside radius of nozzle, in. (mm)

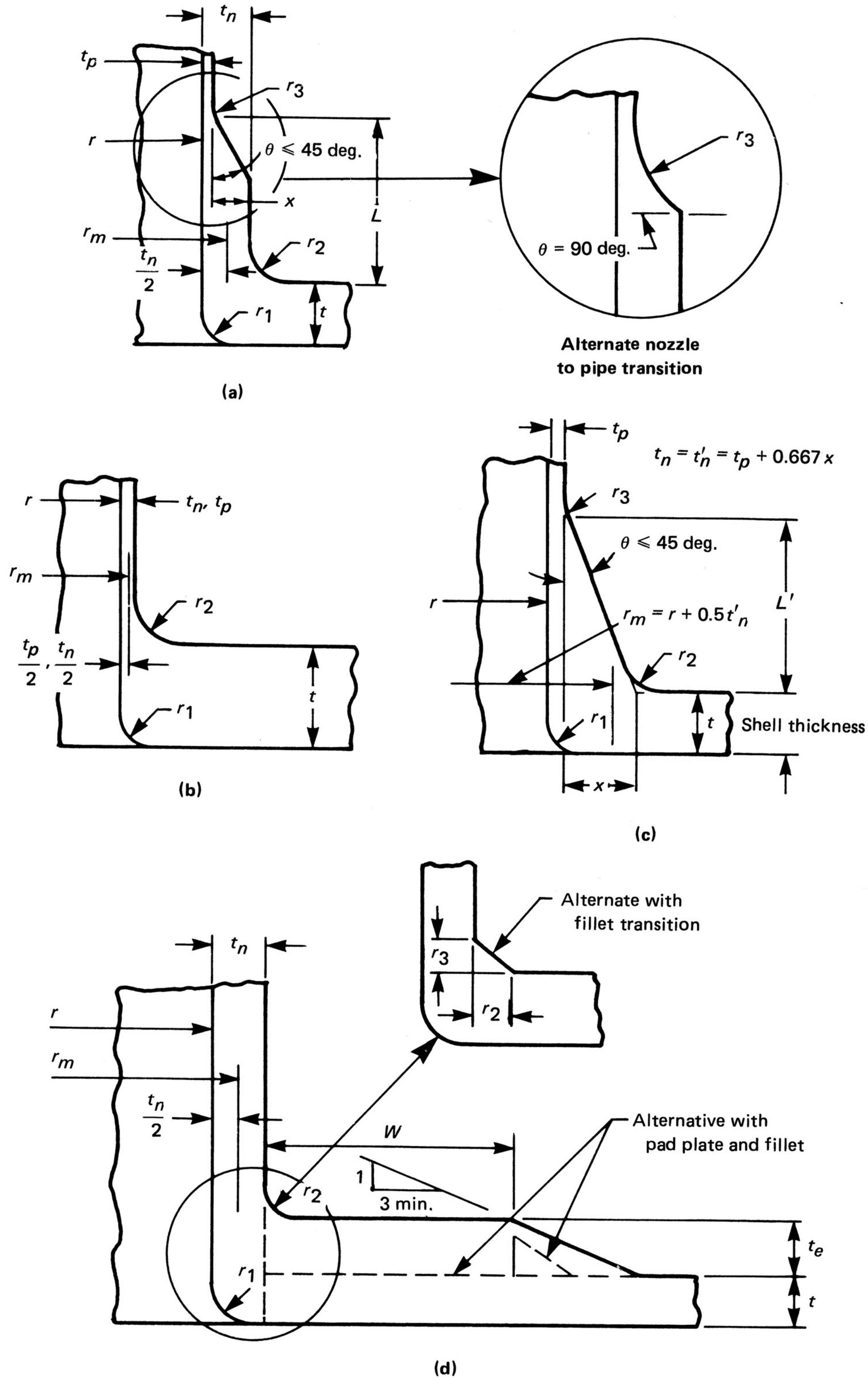


FIG. H-142 NOZZLE NOMENCLATURE AND DIMENSIONS
(Depicts Configuration Only. See Article KD-11 for Details of Construction.)

r_m = mean radius of nozzle, in. (mm)
= $r + 0.5t_n$
r_2 = transition radius between nozzle and vessel wall, in. (mm)
t = nominal vessel thickness, in. (mm)
t_n = nominal nozzle thickness, in. (mm)
t_p = nominal thickness of connecting pipe, in. (mm)
x = slope offset distance, in. (mm)
= $t_n - t_p$

(b) For Fig. H-142, illustration (c):

(1) When 45 deg $\geq \theta \geq$ 30 deg, the limit is the larger of $0.5\sqrt{r_m t_n'}$ and $L' + 2.5t_p \leq t$.

(2) When $\theta <$ 30 deg, the limit is the larger of $0.5\sqrt{r_m t_n'}$ and $1.73x + 2.5t_p \leq 2.5t$, where

L' = length of tapered section along nozzle, in. (mm)
r = inside radius of nozzle, in. (mm)
r_m = $r + 0.5t_n'$
t_n' = $t_p + 0.667x$
θ = angle between vertical and slope (45 deg or less), deg

Other terms are given in H-142(a).

(c) For Fig. H-142, illustration (d), the limit is the larger of $0.5\sqrt{r_m t_n} + t_e$ and $2.5t_n + t_e \leq 2.5t$. In no case can the thickness t_e used to establish the limit exceed $1.5t$ or $1.73W$, where

W = width of added reinforcing element, in. (mm)
t_e = thickness of added reinforcing element, in. (mm)

Other terms are given in H-142(a).

H-150 METAL AVAILABLE FOR REINFORCEMENT

Metal may be counted as contributing to the area of reinforcement called for in H-120 and H-130 provided it lies within the area of reinforcement specified in H-140, and should be limited to material which meets the following requirements:

(a) metal forming a part of the vessel wall which is in excess of that required by the static design requirements of Article KD-2, and is exclusive of corrosion allowance

(b) similar metal in the nozzle wall, provided the nozzle is integral with the vessel wall or is joined to it by a full-penetration weld

(c) all reinforcement metal should be fully continuous with the shell, nozzle, or combination thereof

(d) the metal to be included as reinforcement under H-150(b) and (c) should meet the following limit:

$$|(\alpha_r - \alpha_v)\Delta T| \leq 0.0008$$

where

α_r = mean coefficient of the thermal expansion of reinforcing metal at design temperature, in./in. °F (mm/mm °C)
α_v = mean coefficient of thermal expansion of vessel metal at design temperature, in./in. °F (mm/mm °C)
ΔT = operating temperature range from 70°F (21°C) to the operating temperature, or the difference from the lowest operating temperature to the highest operating temperature, if greater

For designs exceeding this limit, no credit should be taken for reinforcing potentially available in the nozzle neck within the limits of reinforcement.

NOTE: It is likely that designs exceeding the limit in H-150(d) will not meet the desired results of the required fatigue analysis.

(e) metal available for reinforcement should not be considered as applying to more than one opening.

H-151 Strength of Reinforcement Material

In no case should the yield strength of the nozzle material be less than 80% of the yield strength of the vessel wall at the design temperature.

If material with a lower yield strength is used, the area provided by such material should be increased in proportion to the inverse ratio of the yield strength of the nozzle and the vessel wall material. No reduction in the reinforcement requirement may be made if the nozzle material or weld metal has a yield strength higher than that of the material of the vessel wall. The strength of the material at the point under consideration should be used in fatigue analyses.

04

NONMANDATORY APPENDIX I
GUIDANCE FOR THE USE OF U.S. CUSTOMARY AND SI UNITS IN THE ASME BOILER AND PRESSURE VESSEL CODE

I-100 USE OF UNITS IN EQUATIONS

The equations in this Nonmandatory Appendix are suitable for use only with either the U.S. Customary or the SI units provided in Mandatory Appendix 7, or with the units provided in the nomenclature associated with that equation. It is the responsibility of the individual and organization performing the calculations to ensure that appropriate units are used. Either U.S. Customary or SI units may be used as a consistent set. When SI units are selected, U.S. Customary values in referenced specifications may be converted to SI values to at least three significant figures for use in calculations and other aspects of construction.

I-200 GUIDELINES USED TO DEVELOP SI EQUIVALENTS

The following guidelines were used to develop SI equivalents:

(a) SI units are placed in parentheses after the U.S. Customary units in the text.

(b) In general, separate SI tables are provided if interpolation is expected. The table designation (e.g., table number) is the same for both the U.S. Customary and SI tables, with the addition of suffix "M" to the designator for the SI table, if a separate table is provided. In the text, references to a table use only the primary table number (i.e., without the "M"). For some small tables, where interpolation is not required, SI units are placed in parentheses after the U.S. Customary unit.

(c) Separate SI versions of graphical information (charts) are provided, except that if both axes are dimensionless, a single figure (chart) is used.

(d) In most cases, conversions of units in the text were done using hard SI conversion practices, with some soft conversions on a case-by-case basis, as appropriate. This was implemented by rounding the SI values to the number of significant figures of implied precision in the existing U.S. Customary units. For example, 3,000 psi has an implied precision of one significant figure. Therefore, the conversion to SI units would typically be to 20 000 kPa. This is a difference of about 3% from the "exact" or soft conversion of 20 684.27 kPa. However, the precision of the conversion was determined by the Committee on a case-by-case basis. More significant digits were included in the SI equivalent if there was any question. The values of allowable stress in Section II, Part D generally include three significant figures.

(e) Minimum thickness and radius values that are expressed in fractions of an inch were generally converted according to the following table:

Fraction, in.	Proposed SI Conversion, mm	Difference, %
1/32	0.8	−0.8
3/64	1.2	−0.8
1/16	1.5	5.5
3/32	2.5	−5.0
1/8	3	5.5
5/32	4	−0.8
3/16	5	−5.0
7/32	5.5	1.0
1/4	6	5.5
5/16	8	−0.8
3/8	10	−5.0
7/16	11	1.0
1/2	13	−2.4
9/16	14	2.0
5/8	16	−0.8
11/16	17	2.6
3/4	19	0.3
7/8	22	1.0
1	25	1.6

(f) For nominal sizes that are in even increments of inches, even multiples of 25 mm were generally used. Intermediate values were interpolated rather than converting and rounding to the nearest mm. See examples in the following table. [Note that this table does not apply

to nominal pipe sizes (NPS), which are covered below.]

Size, in.	Size, mm
1	25
1⅛	29
1¼	32
1½	38
2	50
2¼	57
2½	64
3	75
3½	89
4	100
4½	114
5	125
6	150
8	200
12	300
18	450
20	500
24	600
36	900
40	1 000
54	1 350
60	1 500
72	1 800

Size or Length, ft	Size or Length, m
3	1
5	1.5
200	60

(g) For nominal pipe sizes, the following relationships were used:

U.S. Customary Practice	SI Practice	U.S. Customary Practice	SI Practice
NPS ⅛	DN 6	NPS 20	DN 500
NPS ¼	DN 8	NPS 22	DN 550
NPS ⅜	DN 10	NPS 24	DN 600
NPS ½	DN 15	NPS 26	DN 650
NPS ¾	DN 20	NPS 28	DN 700
NPS 1	DN 25	NPS 30	DN 750
NPS 1¼	DN 32	NPS 32	DN 800
NPS 1½	DN 40	NPS 34	DN 850
NPS 2	DN 50	NPS 36	DN 900
NPS 2½	DN 65	NPS 38	DN 950
NPS 3	DN 80	NPS 40	DN 1000
NPS 3½	DN 90	NPS 42	DN 1050
NPS 4	DN 100	NPS 44	DN 1100
NPS 5	DN 125	NPS 46	DN 1150
NPS 6	DN 150	NPS 48	DN 1200
NPS 8	DN 200	NPS 50	DN 1250
NPS 10	DN 250	NPS 52	DN 1300
NPS 12	DN 300	NPS 54	DN 1350
NPS 14	DN 350	NPS 56	DN 1400
NPS 16	DN 400	NPS 58	DN 1450
NPS 18	DN 450	NPS 60	DN 1500

(h) Areas in square inches (in.^{2}) were converted to square mm (mm^2) and areas in square feet (ft^2) were converted to square meters (m^2). See examples in the following table:

Area (U.S. Customary)	Area (SI)
1 in.^{2}	650 mm^2
6 in.^{2}	4 000 mm^2
10 in.^{2}	6 500 mm^2
5 ft^2	0.5 m^2

(i) Volumes in cubic inches (in.^{3}) were converted to cubic mm (mm^3) and volumes in cubic feet (ft^3) were converted to cubic meters (m^3). See examples in the following table:

Volume (U.S. Customary)	Volume (SI)
1 in.^{3}	16 000 mm^3
6 in.^{3}	100 000 mm^3
10 in.^{3}	160 000 mm^3
5 ft^3	0.14 m^3

(j) Although the pressure should always be in MPa for calculations, there are cases where other units are used in the text. For example, kPa is used for small pressures. Also, rounding was to one significant figure (two at the most) in most cases. See examples in the following table. (Note that 14.7 psi converts to 101 kPa, while 15 psi converts to 100 kPa. While this may seem at first glance to be an anomaly, it is consistent with the rounding philosophy.)

Pressure (U.S. Customary)	Pressure (SI)
0.5 psi	3 kPa
2 psi	15 kPa
3 psi	20 kPa
10 psi	70 kPa
14.7 psi	101 kPa
15 psi	100 kPa
30 psi	200 kPa
50 psi	350 kPa
100 psi	700 kPa
150 psi	1 MPa
200 psi	1.5 MPa
250 psi	1.7 MPa
300 psi	2 MPa
350 psi	2.5 MPa
400 psi	3 MPa
500 psi	3.5 MPa
600 psi	4 MPa
1,200 psi	8 MPa
1,500 psi	10 MPa

(k) Material properties that are expressed in psi or ksi (e.g., allowable stress, yield and tensile strength, elastic modulus) were generally converted to MPa to three significant figures. See example in the following table:

Strength (U.S. Customary)	Strength (SI)
95,000 psi	655 MPa

(l) In most cases, temperatures (e.g., for PWHT) were

rounded to the nearest 5°C. Depending on the implied precision of the temperature, some were rounded to the nearest 1°C or 10°C or even 25°C. Temperatures colder than 0°F (negative values) were generally rounded to the nearest 1°C. The examples in the table below were created by rounding to the nearest 5°C, with one exception:

Temperature, °F	Temperature, °C
70	20
100	38
120	50
150	65
200	95
250	120
300	150
350	175
400	205
450	230
500	260
550	290
600	315
650	345
700	370
750	400
800	425
850	455
900	480
925	495
950	510
1,000	540
1,050	565
1,100	595
1,150	620
1,200	650
1,250	675
1,800	980
1,900	1 040
2,000	1 095
2,050	1 120

I-300 CHECKING EQUATIONS

When a single equation is provided, it has been checked using dimensional analysis to verify that the results obtained by using either the U.S. Customary or SI units provided are equivalent. When constants used in these equations are not dimensionless, different constants are provided for each system of units. Otherwise, a U.S. Customary and an SI version of the equation are provided. However, in all cases, the Code user should check the equation for dimensional consistency.

I-400 EXAMPLES OF DIMENSIONAL ANALYSIS

(a) This example illustrates the concept of dimensional analysis.

(1) Equation and Nomenclature

$$S = \frac{Pr}{t}$$

where

S = stress, psi (MPa)
P = pressure, psi (MPa)
r = radius, inches (mm)
t = thickness, inches (mm)

(2) Dimensional Analysis

$$S\left[\frac{\text{pounds}}{(\text{inches})(\text{inches})}\right] = \frac{P\left[\frac{\text{pounds}}{(\text{inches})(\text{inches})}\right] r(\text{inches})}{t(\text{inches})}$$

(b) Note that in the above equation, it is necessary that the dimensions of the radius, r, and the thickness, t, be the same, since they must cancel out. The dimensions of the pressure, P, and the stress, S, must also be the same. For this particular equation, r and t could be in U.S. Customary units and P and S in SI units, and the result would still be acceptable. Further, any consistent units could be used for the radius and the thickness (e.g., feet, miles, meters, light years) and the result would be the same. Similarly, the units of pressure and stress can be any legitimate pressure or stress unit (e.g., psi, ksi, kPa, MPa), as long as they are the same.

(c) When the equation is converted to SI units,

$$S(\text{MPa}) = \frac{P(\text{MPa})\, r(\text{mm})}{t(\text{mm})}$$

(d) However, more complex equations present special challenges, e.g., it is necessary to add the stress from an axial load acting on a cylinder to the stress that results from pressure.

(1) Equation and Nomenclature

$$S_t = \frac{Pr}{2t} + \frac{L}{2\pi rt}$$

where

S_t = total stress, psi (MPa)
P = pressure, psi (MPa)
L = load, pounds (N)
r = radius, inches (mm)
t = thickness, inches (mm)

(2) Dimensional Analysis

$$S_t\left[\frac{\text{pounds}}{(\text{inches})(\text{inches})}\right] = \frac{P\left[\frac{\text{pounds}}{(\text{inches})(\text{inches})}\right] r(\text{inches})}{2t(\text{inches})} + \frac{L(\text{pounds})}{2\pi r(\text{inches})\, t(\text{inches})}$$

(e) Note that in the above equation, it is necessary that the pressure, load, and length dimensions be consistent, because quantities cannot be added unless they have the same units. Although the first part of the equation is similar to the first example, where the length and pressure units could be in different systems, the second example requires that if the pressure and stress units are in pounds per square inch, the load must be in pounds and the radius and thickness must be in inches. Note that the load could be in kips and the pressure in ksi. This is why we should permit any consistent system of units to be used. However, the equations should be checked only for the "standard" units.

(f) When the equation is converted to SI units,

$$S_t(\text{MPa}) = \frac{P(\text{MPa})r(\text{mm})}{2t(\text{mm})} + \frac{L(\text{N})}{2\pi r(\text{mm})t(\text{mm})}$$

Note that 1 MPa = 1 N/mm^2, so

$$S_t\left[\frac{\text{N}}{(\text{mm})(\text{mm})}\right] = \frac{P\left[\frac{\text{N}}{(\text{mm})(\text{mm})}\right]r(\text{mm})}{2t(\text{mm})} + \frac{L(\text{N})}{2\pi r(\text{mm})t(\text{mm})}$$

which reduces to

$$S_t\left[\frac{\text{N}}{(\text{mm})(\text{mm})}\right] = \frac{P(\text{N})r(\text{mm})}{(\text{mm})(\text{mm})2t(\text{mm})} + \frac{L(\text{N})}{2\pi r(\text{mm})t(\text{mm})}$$

(g) Therefore, the units in the above equation are consistent. However, this is not always the case. For example, the bolted joint design rules define an effective gasket seating width as a function of the actual width using an equation of the form below.

(1) Equation and Nomenclature

$$b_e = \sqrt{b_a}$$

where

b_e = effective gasket seating width
b_a = actual gasket seating width

(2) Dimensional Analysis

$$b_e(\text{inches}) = \sqrt{b_a(\text{inches})}$$

(h) Obviously, the equation above is not dimensionally consistent; therefore, a constant is needed if it is to be used with SI units. The constant can be calculated by converting the SI unit (mm) to the U.S. Customary unit (in.) for the calculation, then converting back to get the result in mm as follows:

$$b_e(\text{mm}) = 25.4(\text{mm/inch})\sqrt{\frac{b_a(\text{mm})}{25.4(\text{mm/inch})}}$$

which can be reduced to

$$b_e(\text{mm}) = 5.04\sqrt{b_a(\text{mm})}$$

I-500 SOFT CONVERSION FACTORS

The following table of "soft" conversion factors is provided for convenience. Multiply the U.S. Customary value by the factor given to obtain the SI value. Similarly, divide the SI value by the factor given to obtain the U.S. Customary value. In most cases it is appropriate to round the answer to three significant figures.

U.S. Customary	SI	Factor	Notes
in.	mm	25.4	. . .
ft	m	0.3048	. . .
in.^{2}	mm^2	645.16	. . .
ft^2	m^2	0.09290304	. . .
in.^{3}	mm^3	16,387.064	. . .
ft^3	m^3	0.02831685	. . .
U.S. gal	m^3	0.003785412	. . .
U.S. gal	liters	3.785412	. . .
psi	MPa	0.0068948	Used exclusively in equations
psi	kPa	6.894757	Used only in text and for nameplate
ft-lb	J	1.355818	. . .
°F	°C	$\frac{5}{9}$ × (°F − 32)	Not for temperature difference
°F	°C	$\frac{5}{9}$ × °F	For temperature differences only
R	K	$\frac{5}{9}$	Absolute temperature
lbm	kg	0.4535924	. . .
lbf	N	4.448222	. . .
in.-lb	N·mm	112.98484	Use exclusively in equations
ft-lb	N·m	1.3558181	Use only in text
ksi$\sqrt{\text{in.}}$	MPa$\sqrt{\text{m}}$	1.0988434	. . .
Btu/hr	W	0.2928104	Use for boiler rating and heat transfer
lb/ft^3	kg/m^3	16.018463	. . .

I-600 SPECIAL REQUIREMENTS FOR POSTWELD HEAT TREAT TIMES

In general, PWHT times in hours per inch of thickness were converted to minutes per millimeter of thickness as follows:

(a) 1 hr/in. = 2 min/mm. Although this results in heat treatment for only 51 min for a 25.4 mm thick section, this is considered to be within the range of intended precision of the U.S. Customary requirement.

(b) 15 min/in. = 0.5 min/mm. Although converting and rounding would give 0.6 min/mm, it was necessary to use 0.5 to be consistent with the rounding for 1 hr/in.

I-700 NOTES ON CONVERSIONS IN SECTION II, PARTS A, B, AND C

The conversions provided by ASTM and AWS were used for consistency with those documents.

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