ASME PCC-1–2022
(Revision of ASME PCC-1–2019)

Pressure Boundary Bolted Flange Joint Assembly

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

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This Standard will be revised when the Society approves the issuance of a new edition.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this Standard. Interpretations are published on the Committee web page and under http://go.asme.org/InterpsDatabase. Periodically certain actions of the ASME PCC Committee may be published as Cases. Cases are published on the ASME website under the PCC Committee Page at http://go.asme.org/PCCcommittee as they are issued.

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The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

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FOREWORD

ASME formed an Ad Hoc Task Group on Post Construction in 1993 in response to an increased need for recognized and generally accepted engineering standards for the inspection and maintenance of pressure equipment after it has been placed in service. At the recommendation of this task group, the Board on Pressure Technology Codes and Standards (BPTCS) formed the Post Construction Committee (PCC) in 1995. The scope of this committee was to develop and maintain standards addressing common issues and technologies related to post-construction activities and to work with other consensus committees in the development of separate, product-specific codes and standards addressing issues encountered after initial construction for equipment and piping covered by Pressure Technology Codes and Standards. The BPTCS covers nonnuclear boilers, pressure vessels (including heat exchangers), piping and piping components, pipelines, and storage tanks.

The PCC selects standards to be developed based on identified needs and the availability of volunteers. The PCC formed the Subcommittee on Inspection Planning and the Subcommittee on Flaw Evaluation in 1995. In 1998, a task group under the PCC began preparation of Guidelines for Pressure Boundary Bolted Flange Joint Assembly, and in 1999 the Subcommittee on Repair and Testing was formed. Other topics are under consideration and may be developed into future guideline documents.

The subcommittees were charged with preparing standards dealing with several aspects of the in-service inspection and maintenance of pressure equipment and piping. ASME PCC-1, Pressure Boundary Bolted Flange Joint Assembly, is the standard for bolted flange joint assemblies. ASME PCC-3, Inspection Planning Using Risk-Based Methods, provides guidance on the preparation of a risk-based inspection plan. Imperfections found at any stage of assembly, installation, inspection, operation, or maintenance are then evaluated, when appropriate, using the procedures provided in API 579-1/ASME FFS-1, Fitness-for-Service. Guidance on repair procedures is provided in the appropriate portion of ASME PCC-2, Repair of Pressure Equipment and Piping. To provide all stakeholders involved in pressure equipment with a guide to identify publications related to pressure equipment integrity, ASME PTB-2, Guide to Life Cycle Management of Pressure Equipment Integrity, has been prepared.

None of these documents are Codes. They provide recognized and generally accepted good practices that may be used in conjunction with post-construction codes, such as API 510, API 570, and NBBI NB-23, and with jurisdictional requirements.

This Standard uses the words "shall," "should," and "may" as follows:

(a) "Shall" is used to denote a requirement.

(b) "Should" is used to denote a recommendation.

(c) "May" is used to denote permission, which is neither a requirement nor a recommendation.

The first edition of ASME PCC-1 was approved for publication in 2000. The 2010 edition was approved by the American National Standards Institute (ANSI) as an American National Standard on January 14, 2010. The 2013 edition included many updates and a major new Appendix A titled "Training and Qualification of Bolted Joint Assembly Personnel" and was approved by ANSI as an American National Standard on August 12, 2013. The 2019 edition contained a number of updates. The most notable of these updates were the removal of the reference torque tables (Tables 1M and 1) for similar tables in Appendix O introducing the Target Torque Index and the insertion of a new Appendix Q titled "Considerations for the Use of Powered Equipment." ASME PCC-1–2019 was approved by ANSI as an American National Standard on January 17, 2019.

This 2022 edition is a major revision of ASME PCC-1. Requirements and recommendations have replaced the guidelines of previous editions. "Guidelines for" has been deleted from the title. The main text and many of the appendices have been revised in their entirety. ASME PCC-1–2022 was approved by ANSI as an American National Standard on August 18, 2022.

ASME PRESSURE TECHNOLOGY POST-CONSTRUCTION COMMITTEE

(The following is the roster of the Committee at the time of approval of this Standard.)

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General. ASME Standards are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Standard may interact with the Committee by requesting interpretations, proposing revisions or a case, and attending Committee meetings. Correspondence should be addressed to:

Secretary, PCC Standards Committee
The American Society of Mechanical Engineers
Two Park Avenue
New York, NY 10016-5990
http://go.asme.org/Inquiry

Proposing Revisions. Revisions are made periodically to the Standard to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Standard. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Proposing a Case. Cases may be issued to provide alternative rules when justified, to permit early implementation of an approved revision when the need is urgent, or to provide rules not covered by existing provisions. Cases are effective immediately upon ASME approval and shall be posted on the ASME Committee web page.

Requests for Cases shall provide a Statement of Need and Background Information. The request should identify the Standard and the paragraph, figure, or table number(s), and be written as a Question and Reply in the same format as existing Cases. Requests for Cases should also indicate the applicable edition(s) of the Standard to which the proposed Case applies.

Interpretations. Upon request, the PCC Standards Committee will render an interpretation of any requirement of the Standard. Interpretations can only be rendered in response to a written request sent to the Secretary of the PCC Standards Committee.

Requests for interpretation should preferably be submitted through the online Interpretation Submittal Form. The form is accessible at http://go.asme.org/InterpretationRequest. Upon submittal of the form, the Inquirer will receive an automatic e-mail confirming receipt.

If the Inquirer is unable to use the online form, he/she may mail the request to the Secretary of the PCC Standards Committee at the above address. The request for an interpretation should be clear and unambiguous. It is further recommended that the Inquirer submit his/her request in the following format:

Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry in one or two words.
Edition:	Cite the applicable edition of the Standard for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. Please provide a condensed and precise question, composed in such a way that a "yes" or "no" reply is acceptable.
Proposed Reply(ies):	Provide a proposed reply(ies) in the form of "Yes" or "No," with explanation as needed. If entering replies to more than one question, please number the questions and replies.
Background Information:	Provide the Committee with any background information that will assist the Committee in understanding the inquiry. The Inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in the format described above may be rewritten in the appropriate format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

Moreover, ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Standard requirements. If, based on the inquiry information submitted, it is the opinion of the Committee that the Inquirer should seek assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

Attending Committee Meetings. The PCC Standards Committee regularly holds meetings and/or telephone conferences that are open to the public. Persons wishing to attend any meeting and/or telephone conference should contact the Secretary of the PCC Standards Committee.

ASME PCC-1–2022
SUMMARY OF CHANGES

Following approval by the ASME PCC Committee and ASME, and after public review, ASME PCC-1–2022 was approved by the American National Standards Institute on August 18, 2022.

In ASME PCC-1–2022, "Guidelines for" has been deleted from the title. The main text has been revised in its entirety. Appendices A through Q have been redesignated as "Nonmandatory." All figures, tables, and forms have been redesignated based on their parent paragraph. Cross-references have been updated. In addition, ASME PCC-1–2022 includes the following changes, identified by a margin note, **(22)**.

Page	*Location*	*Change*
10	Mandatory Appendix I	Added
15	Nonmandatory Appendix A	Revised in its entirety
24	Nonmandatory Appendix B	Definitions moved to Mandatory Appendix I
25	Nonmandatory Appendix C	(1) "Contact surface" revised to "seating surface" throughout (2) In Table C-1, "Gasket Seating Surface Finish" column editorially revised
26	Nonmandatory Appendix D	(1) Title revised (2) Sections D-1 through D-3 revised
31	Nonmandatory Appendix E	Revised in its entirety
34	Nonmandatory Appendix F	Revised in its entirety
48	Nonmandatory Appendix G	Revised in its entirety
49	Table H-1M	Note (2) revised
51	Nonmandatory Appendix I	Deleted
52	Nonmandatory Appendix J	Revised in its entirety
56	Nonmandatory Appendix K	Revised in its entirety
59	M-1.1	Last paragraph revised
61	M-2.10	Added and former para. M-2.10 redesignated as M-2.11
64	N-1	Revised
65	N-4	Added
66	O-1.1	Revised
66	O-1.3	Definitions of $G_{I.D.}$ and $G_{O.D.}$ revised
67	O-2	Subparagraphs (b) through (d) revised
67	O-3.1	First sentence revised
67	O-3.2	Second and third paragraphs and eq. (O-3) revised
68	O-4.1	Revised
68	O-4.2	First paragraph and footnotes revised
69	O-4.3	Revised
69	O-5.1	Revised
71	Table O-3.2-1M	In General Note (b), cross-reference revised
72	Table O-3.2-1	In General Note (b), cross-reference revised
82	Nonmandatory Appendix P	Revised in its entirety

Page	*Location*	*Change*
96	Q-5	Added and former section Q-5 redesignated as Q-6
99	Nonmandatory Appendix R	Added

PRESSURE BOUNDARY BOLTED FLANGE JOINT ASSEMBLY

1 SCOPE

This Standard covering bolted flange joint assemblies (BFJAs) applies to pressure-boundary flange joints with ring-type gaskets that are entirely within the circle enclosed by the bolt holes and with no contact outside this circle.[1] The principles of this Standard may be selectively applied to other joint geometries. By selecting those features suitable to the specific service or need, this Standard may be used to develop effective joint assembly procedures for the broad range of sizes and service conditions normally encountered in industry.

Users [see para. 2(b)] of this Standard are cautioned that the content contained in ASME PCC-1 has been developed generically and may not necessarily be suitable for all applications. Precautionary considerations are provided in some cases but should not be considered as all-inclusive. Sound engineering judgment and practices should be used to determine the applicability of a specific method or part of a method to a specific application. Each joint assembly procedure should be subject to an appropriate review by qualified personnel. While this Standard covers joint assembly within the scope of ASME Pressure Technology Codes and Standards, it may be used on equipment constructed in accordance with other codes and standards.

Guidance on troubleshooting BFJAs not providing leak-tight performance is also provided in this Standard (see Nonmandatory Appendix P).

2 INTRODUCTION

(a) Intent. A BFJA is a complex mechanical device; therefore, BFJAs that provide leak-free service result from many selections and activities having been made and performed within a relatively narrow band of acceptable limits. One of the activities essential to leak-free performance is the joint assembly process. The content outlined in this Standard covers the assembly elements essential for a high level of leak-tightness integrity of otherwise properly designed and constructed BFJAs. Users should develop written assembly procedures based on the owner's requirements, incorporating the features contained herein that are deemed suitable to the specific application under consideration. Alternative features and methods for specific applications may be used subject to endorsement by the owner.

(b) User. The user is defined as any entity that applies the provisions of this Standard. The user could be the owner, owner's representative, manufacturer, fabricator, erector, or other contract personnel. The specific assignment of responsibilities among these entities is outside the scope of this Standard. As a result, this Standard is silent when assigning specific provisions to a single entity.

(c) Owner and Representative. Within the context of this Standard, "owner" and "representative" are defined as follows:

owner: the person, partnership, organization, or business responsible for the leak tightness of BFJAs on their pressure equipment.

representative: a person, partnership, organization, or business designated by the owner to carry out selected responsibilities on the owner's behalf.

(d) Responsibilities

(1) Owner. The owner is responsible for establishing the requirements for assembly, examination, inspection, and testing of BFJAs on their pressure equipment. The owner may designate a representative to carry out selected responsibilities in establishing such requirements; however, the owner retains ultimate responsibility for the actions of the representative.

NOTE: Within the context of this Standard, the term "owner" includes the owner and the owner's representative, as recorded in either the contract documents or the written assembly procedures [see para. 13(a)].

(2) Assembler. The assembler (see Mandatory Appendix I) of piping, pipelines, or equipment containing BFJAs is responsible for providing workmanship in conformance to the requirements of the assembly procedure.

(e) Organization of This Standard. The main body of this Standard covers the following topic areas associated with the BFJA assembly process:

(1) scope and introduction

(2) training and qualification of bolted joint assembly personnel

(3) cleaning of gasket seating surfaces of flanges

[1] Rules for the design of bolted flanges with ring-type gaskets are covered in ASME Boiler and Pressure Vessel Code (ASME BPVC), Section VIII, Division 1, Mandatory Appendix 2. See also ASME BPVC, Section VIII, Division 1, Nonmandatory Appendix S for supplementary considerations for bolted flanges that are helpful to the designer of Mandatory Appendix 2 flanges.

(4) examination of flange and fastener seating surfaces (including flange surface finish and flatness, fastener contact surfaces, and the washers' bearing surfaces)

(5) alignment of flange joints

(6) installation of gasket

(7) lubrication

(8) installation of bolts

(9) tightening procedure

(10) optional practices

(11) joint pressure and tightness testing

(12) records

(13) joint disassembly

(f) Use of "Approved Disposition." When used in this Standard, the phrase "approved disposition" refers to a decision on actions to address a nonconforming condition, specified by the person having authority (typically the owner or the owner's representative).

(g) Use of "Approved." The term "approved" refers to a selection made by the owner or the owner's representative as being suitable for the application under consideration.

Where the phrases in (f) and (g) are used, they will generally be accompanied by the relevant references from which additional guidance may be obtained.

3 TRAINING AND QUALIFICATION OF BOLTED JOINT ASSEMBLY PERSONNEL

Employers of bolted joint assembly personnel have the responsibility to provide, or arrange to have provided, an appropriate training and qualification program in accordance with Nonmandatory Appendix A. If alternative solutions that meet the intent of this Standard are used, they shall be properly justified and documented in the employer's training and qualification program.

The technical classifications and topic of understanding for each classification are included in Nonmandatory Appendix A. These classifications and topics are intended to identify and give names to the skill sets normally associated with the various levels of work required by assemblers.

Assigning titles to these industry-wide skill sets standardizes expectations of competency for users, contractors, labor suppliers, unions, assembly personnel, and third parties. These titles also represent specific training objectives.

4 CLEANING OF GASKET SEATING SURFACES OF FLANGES

The following instructions should be included in the assembly procedure:

(a) Remove all debris and residual material from the previous gasket installation from the gasket seating surfaces.

NOTE: If the replacement gasket is a flexible graphite-clad gasket or a spiral-wound gasket with flexible graphite filler, residual flexible graphite from the previous gasket may remain in the surface-finish grooves.

(b) Avoid surface contamination and damage to the existing surface finish.

(1) Use approved solvents and soft wire brushes.

(2) Do not use carbon steel brushes on stainless steel flanges.

5 EXAMINATION OF FLANGE AND FASTENER CONTACT SURFACES

5.1 Examination of Gasket Seating Surfaces for Surface Finish

(a) Site assembly guidance should specify

(1) acceptable gasket contact surface finish based on the gasket type (see Nonmandatory Appendix C)

(2) acceptable limits on gasket seating surface imperfections and their locations (see Nonmandatory Appendix D, sections D-3 and D-4)

NOTE: If machining or weld repair of imperfections is required [see (a)(2)], see ASME PCC-2, Article 305 for repair considerations.

(b) The following instructions should be included in the assembly procedure:

(1) Examine the gasket seating surfaces of both mating flanges for conformance to the acceptable surface-finish criteria and damage such as scratches, nicks, gouges, and burrs.

(2) Report any nonconforming imperfections for approved disposition.

NOTES:
(1) Indications running radially across the facing are of particular concern.
(2) It is recommended that surface finish comparator gauges be available to joint assembly personnel.

5.2 Examination of Gasket Seating Surfaces for Flatness

(a) Site assembly guidance should specify

(1) whether measurement of flange gasket seating surfaces for flatness is required

NOTE: A flatness check is typically specified when working with large-diameter, problematic, or critical service flanges with a history of leakage or suspect fabrication.

(2) the acceptable flatness limits for the flange gasket seating surface, if a flatness check is specified (see Nonmandatory Appendix D, section D-2)

(3) acceptable methods of flatness check, if required

NOTES:
(1) Methods of flatness checks include the use of a machinist's straight edge and feeler gauges, a securely mounted flatness ("run-out") gauge, and laser or field machining equipment capable of providing accurate total indicator readings.
(2) If machining or weld repair of imperfections is required, see ASME PCC-2, Article 305 for repair considerations.

(b) If the measurement of the gasket seating surfaces for flatness is required [see (a)(1)], the following instructions should be included in the assembly procedure:

(1) Check gasket seating surfaces of both joint flanges for flatness, both radially and circumferentially, using an approved method.

(2) Report any nonconforming flatness measurements for approved disposition.

5.3 Examination of Fastener Contact Surfaces and Washers

(a) Site assembly guidance should specify the criteria for replacement or repair of bolts and washers (see Nonmandatory Appendix N).

NOTES:
(1) Nonmandatory Appendix M provides a through-hardened washer specification guideline.
(2) If tapped holes require repair, an approved method shall be used; see ASME PCC-2, Article 303.

(b) The following instructions should be included in the assembly procedure:

(1) Examine bolt and nut threads and washer faces of nuts for damage such as rust, corrosion, and burrs.

(2) Verify that each nut turns freely by hand past the location on the bolt where it will come to rest after tightening.

(3) If the bolted joint assembly includes tapped hole threads, verify that the bolts thread by hand to the full depth of the tapped holes.

(4) Replace or correct any damaged or nonconforming components.

5.4 Examination of Flange Nut or Washer Bearing Surfaces

(a) Site assembly guidance should specify

(1) whether through-hardened, flat washers are required to provide a smooth and square nut bearing surface

(2) any critical joints (see Mandatory Appendix I) for which removal of coating from flange nut or washer bearing surfaces is required [see (b)(3)]

(b) The following instructions should be included in the assembly procedure:

(1) Examine nut or washer bearing surfaces of flanges for excessive coating, scores, burrs, visual evidence of out-of-squareness (indicated by uneven wear), etc.

NOTE: Excessive coating is defined as thickness on the flange nut or washer bearing surface thicker than 0.13 mm (0.005 in.) or 130 μm (5 mils).

(2) Remove roughness, gouges, and protrusions.

(3) Report severely damaged flanges or excessive coating for approved disposition.

6 ALIGNMENT OF FLANGE JOINTS

(a) Site assembly guidance should specify

(1) the sequence of the alignment procedure and any checks, measurements, or verifications to be done during the alignment process (see Nonmandatory Appendix E, section E-1)

(2) the verification methods, limits to corrective loads, and tolerances (see Nonmandatory Appendix E, section E-2)

(3) the acceptable methods and tools to achieve alignment (see Nonmandatory Appendix E, section E-3)

(4) the criteria for defining when an engineering evaluation is necessary (see Nonmandatory Appendix E, section E-4)

(5) whether there is a requirement to measure and record initial joint alignment

(6) whether there is a requirement to measure and record final joint alignment (see Nonmandatory Appendix J, section J-2)

NOTE: Correct alignment of all joint components is a critical and essential element of flange joint assembly. It results in maximum sealing surface contact and maximum opportunity for uniform and optimum gasket loading, and it reduces frictional variation of fasteners.

(b) The following instructions should be included in the assembly procedure:

(1) Assess the flange alignment during initial assembly.

(2) Assess the flange alignment during final assembly, if required.

(3) Report misalignment of joints that cannot be rectified using acceptable levels of load for approved disposition.

7 INSTALLATION OF GASKET

(a) Site assembly guidance should specify the approved methods of ensuring the gasket remains in place during assembly and the acceptable adhesive, if used, for securing the gasket in place during the assembly process.

NOTE: A very light dusting of an approved spray adhesive may be used for this purpose. When selecting an adhesive, avoid adhesive chemistry that is incompatible with the process fluid or that could result in stress corrosion cracking or pitting of the flange surfaces.

(b) The following instructions should be included in the assembly procedure:

(1) Examine the new gasket for damage or defects.

(2) Verify the gasket conforms to dimensional [outside diameter (O.D), inside diameter (I.D.), thickness] and material specifications.

(3) Position the gasket to be concentric with the flange I.D. such that the gasket is supported during the positioning process.

(4) Verify that no portion of the gasket sealing face projects into the flow path.

(5) For gaskets designed to fit inside a recessed flange face, verify that the gasket fits completely within the recess, i.e., the gasket does not project beyond the O.D. of the recess.

(6) Secure the gasket in place using an approved method.

(7) Ensure the gasket will remain in place during the joint assembly process.

(8) Do not apply adhesive tape or other materials across the gasket sealing face.

(9) Do not apply grease or sealing paste on the gasket or flange.

8 LUBRICATION

(a) Site assembly guidance should specify an approved lubricant that is chemically compatible with the process fluid and the fastener system materials (nut, stud, washer).

NOTE: Improper lubrication selection could contribute to undesirable outcomes such as stress corrosion cracking, galvanic corrosion, or autoignition in oxygen service.

(b) The following instructions should be included in the assembly procedure:

(1) Apply lubricant irrespective of the tightening method used.

(2) Apply lubricant to working surfaces (see Mandatory Appendix I) of the fastener system (nut, stud, washer).

NOTE: Application of lubricant after stud insertion minimizes the likelihood of contamination with foreign particles such as rust, paint scale, sand, coke fines, or similar abrasive particles that could negatively affect the overall nut factor.

(3) Apply lubricant liberally by completely filling the threads from root to crest on both ends of the studs. Figure 8-1 illustrates the proper application of lubrication.

NOTES:
(1) The liberal application of lubrication will result in the formation of a bead of excess lubricant visible on the nut contact face as the nut runs down the stud. This bead of lubricant is visible evidence of an adequate amount of lubricant application.
(2) A consistent amount and extent of application for each bolt in a flange promotes a consistent nut factor and helps achieve a consistent bolt load.

(4) Apply the lubricant from the end of the stud to extend past the location where the nut face will rest after tightening.

(5) Do not apply lubricant on the gasket or gasket seating surfaces.

9 INSTALLATION OF BOLTS

(a) To support the assembly procedure, determine the minimum adequate length of bolts.

(1) Bolt length should accommodate washers, nut height, and the required thread protrusion.

(2) For assemblies involving bolt tensioning, the bolt length should provide for the threaded portion of the bolt to extend at least one bolt diameter beyond the outside nut face on the tensioner side of the joint.

CAUTION: Avoid excessively long bolts. Excessive thread protrusion can complicate joint disassembly due to corrosion, paint, or damage on the exposed thread.

(b) The following instructions should be included in the assembly procedure:

(1) Verify that the bolts, nuts, and washers conform to required specifications [material grade, nominal diameter, thread pitch, and nut thickness (heavy hex versus regular hex)].

(2) Verify that the bolts are the specified length.

(3) Install the bolts such that the marked ends are on the same side of the joint. Install nuts with the identification marking facing outward. This practice facilitates inspection.

(4) Install the nut on one end of the stud with minimal thread protrusion such that any excess thread length is located on the opposite end of the stud. This practice facilitates joint disassembly (see section 14).

(5) Hand tighten the nuts. Then snug up the bolts to 15 N·m to 30 N·m (10 ft-lb to 20 ft-lb) but not to exceed 10% of the total target assembly bolt load (see Nonmandatory Appendix O).

(6) Examine the bolts for adequate thread protrusion. The criterion in the new construction codes[2] is thread engagement for the full depth of the nut. However, it has been shown that the full strength in a threaded fastener can be developed with less than complete thread engagement, a consideration in certain post-construction situations (e.g., see para. 15.13 and para. 15.15, refs. [4]–[6]).

10 TIGHTENING PROCEDURE

(a) The site assembly guidance should include the following:

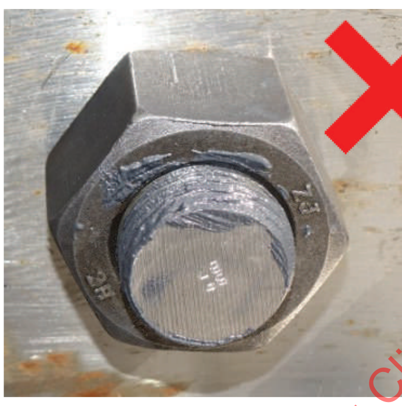
(1) acceptable tightening method and load-control techniques, e.g., hand wrenches, hand-operated or powered tools with torque measurement, tensioning

[2] ASME BPVC, Section VIII, Division 1, Part UG, UG-13 details thread engagement criteria.

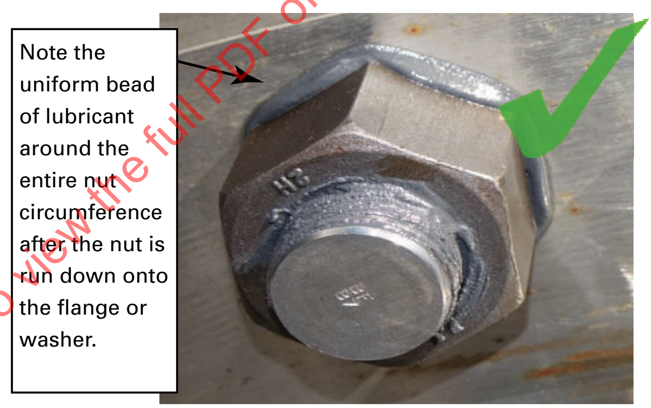
Figure 8-1
Examples of Lubrication Application

(a) Insufficient Lubrication: Lack of Fill Between Root and Crest of Threads

(b) Correct Application of Lubrication: Complete Fill Plus Some Excess



(c) Insufficient Application: Incomplete Extrusion of Lubricant Bead



(d) Correct Application: Complete Extrusion of Lubricant Bead

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tools with force measurement, or any tightening method used with bolt elongation or load-control measurement

(2) acceptable tightening patterns (see Nonmandatory Appendix F), including

(-a) single- or multitool usage

(-b) tightening sequence, including consideration of bolt grouping for flanges containing 48 or more bolts (see Nonmandatory Appendix J, section J-5)

(-c) guidance on the number of passes and the load increments for each pass

(-d) whether gap measurements are required between passes (see Nonmandatory Appendix J, section J-2)

(-e) whether an additional pass is required based on the use of a soft (versus hard) gasket

(3) the assembly bolt stress or assembly target torque or bolt load, as applicable to the tightening method (see Nonmandatory Appendix O)

(b) The selections from (a) should be included as the instructions in the assembly procedure.

11 OPTIONAL PRACTICES

Nonmandatory Appendix J provides the following optional practices that may be included in the assembly procedure:

(a) measurement of gaps (see section J-2)

(b) bolt elongation (bolt stretch) measurement (see section J-3)

(c) start-up retorque (see section J-4)

(d) grouped bolting for large flanges (see section J-5)

(e) alternative legacy cross-pattern tightening sequence and bolt-numbering system (see section J-6 and Table J-6-1)

(f) controlled disassembly (see section J-7)

12 JOINT PRESSURE AND TIGHTNESS TESTING

Specification of the requirements for joint pressure and tightness testing is often influenced by an applicable code or standard or by jurisdictional requirements. This testing is typically performed according to site maintenance and operating procedures, rather than being included in the scope of the flange assembly procedure.

NOTE: Refer to ASME PCC-2, Article 501 for general practices for pressure and tightness testing of pressure equipment.

Site assembly guidance should specify the gasket to be used for the test.

(a) The test gasket should be suitable for the test and the service conditions.

(b) If a substitute or temporary gasket is selected that does not meet the service conditions, then

(1) Specify a gasket that is suitable for the test conditions.

(2) Upon completion of the test and before the bolted flange joint is put into service, verify that the temporary gasket has been replaced with a gasket that is suitable for the service conditions.

WARNING: Use of substitute or temporary gaskets during testing instead of those designed as the final seal has occasionally resulted in gasket blowout during testing, and/or in-service leaks due to the failure to replace the substitute or temporary gasket with the appropriate final seal gasket. Gasket blowout may include a portion of the gasket becoming a projectile.

13 RECORDS

(a) The owner should record in either the contract or the assembly procedure the authorization of any representatives. See section 2 for additional information on representatives.

(b) The user should decide the details required in the joint assembly records, based on the relative probability and consequences of joint leakage (see Nonmandatory Appendix R, para. R-2.2). Joint assembly records may include the following information:

(1) joint location or identification

(2) joint class and size

(3) specifications and conditions of flanges, fasteners, washers (including nut or washer bearing surfaces), and gaskets

(4) date of the activity (assembly, disassembly, pressure test, etc.)

(5) names of assemblers and workers

(6) name of the inspector or person responsible for the quality assurance or quality control of the joint

(7) disassembly method

(8) leak history

(9) bolts, nuts, and washers used

(10) flatness measurements, when made (see Nonmandatory Appendix D)

(11) assembly procedure and tightening method used, including applicable target prestress values in accordance with the indicated tightening method

(12) unanticipated problems and their solutions during assembly or disassembly (tool access or safety issues, presence of nut seizing or thread galling, unanticipated pipe cold spring, etc.)

(13) tool data such as type, model, pressure setting, and calibration identification

(14) recommendations for future assembly procedures and joint maintenance and repairs

See Nonmandatory Appendix R for examples of joint assembly records. See Nonmandatory Appendix P, Form P-3-1 for an example of a joint leakage record.

14 JOINT DISASSEMBLY

(a) Before disassembling any joint, determine whether a controlled disassembly procedure should be specified. A controlled disassembly procedure may be specified for bolted flange connections meeting any of the following:

(1) those meeting all the criteria of (-a) through (-c)

(-a) flanges larger than DN 600 (NPS 24)

(-b) flange thicknesses greater than 125 mm (5 in.)

(-c) bolt diameters M45 ($1^3/_4$ in.) and larger

(2) where galling has occurred, or disassembly has been problematic

(3) where high local strains could be detrimental (e.g., glass-lined equipment, lens ring joints)

(4) where the gasket is to be retained for inspection or failure analysis

See Nonmandatory Appendix J, section J-7 for an example of a controlled disassembly procedure.

(b) The joint disassembly procedure should include the following instructions, regardless of whether a controlled disassembly procedure is used:

(1) Leave a sufficient number of loosened nuts in place until all tension has been relieved from the bolted flange connection to prevent significant movement of the flanges and guard against unanticipated movement such as pipe spring and falling components.

(2) Select the first bolts to be loosened at locations to direct any pressure release or residual contents away from the assembler.

NOTE: Generally, for joints in the vertical plane, this is at the top, followed by the bottom to drain the liquid.

15 REFERENCES

Paragraphs 15.1 through 15.15 list publications referenced in this Standard. Unless otherwise specified, the latest edition shall apply.

15.1 API Publications

API Standard 660, Shell-and-Tube Heat Exchangers
API Recommended Practice 686, Recommended Practice for Machinery Installation and Installation Design
Publisher: American Petroleum Institute (API), 200 Massachusetts Avenue NW, Suite 1100, Washington, DC 20001–5571 (www.api.org)

15.2 ASME Boiler and Pressure Vessel Code (BPVC)

ASME BPVC, Section II, Materials: Part A — Ferrous Material Specifications
SA-105/SA-105M, Specification for Carbon Steel Forgings, for Piping Applications
SA-182/SA-182M, Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service
SA-193/SA-193M, Specification for Alloy-Steel and Stainless Steel Bolting for High-Temperature or High Pressure Service and Other Special Purpose Applications
SA-194/SA-194M, Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both
SA-453/SA-453M, Specification for High-Temperature Bolting, With Expansion Coefficients Comparable to Austenitic Stainless Steels
SA-540/SA-540M, Specification for Alloy-Steel Bolting Materials for Special Applications

ASME BPVC, Section II, Materials: Part B — Nonferrous Material Specifications
SB-637, Specification for Precipitation-Hardening and Cold Worked Nickel Alloy Bars, Forgings, and Forging Stock for Moderate or High-Temperature Service

NOTE: ASME SA and SB material specifications are used in ASME PCC-1. ASTM material specifications may also be used or taken to apply, as allowed by the applicable code of construction, for the joint being considered.

ASME BPVC, Section VIII, Rules for Construction of Pressure Vessels: Division 1
Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990 (www.asme.org)

15.3 ASME Standards

ASME B1.1, Unified Inch Screw Threads (UN, UNR, and UNJ Thread Forms)
ASME B1.13M, Metric Screw Threads: M Profile
ASME B16.5, Pipe Flanges and Flanged Fittings: NPS ½ Through NPS 24 Metric/Inch Standard
ASME B16.20, Metallic Gaskets for Pipe Flanges
ASME B16.47, Large Diameter Steel Flanges: NPS 26 Through NPS 60 Metric/Inch Standard
ASME B31.3, Process Piping
ASME B46.1, Surface Texture (Surface Roughness, Waviness, and Lay)
ASME PCC-2, Repair of Pressure Equipment and Piping
Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990 (www.asme.org)

15.4 ASTM Publications

ASTM A240/A240M, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications
ASTM A693/A693M, Standard for Precipitation-Hardening Stainless and Heat-Resisting Steel Plate, Sheet, and Strip
ASTM A829/A829M, Standard Specification for Alloy Structural Steel Plates
ASTM F436/F436M, Standard Specification for Hardened Steel Washers Inch and Metric Dimensions
ASTM F606/F606M, Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets
Publisher: American Society for Testing and Materials (ASTM International), 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959 (www.astm.org)

15.5 European Committee for Standardization Publication

EN 1591-1, Flanges and their joints — Design rules for gasketed circular flange connections — Part 1: Calculation
Publisher: European Committee for Standardization (CEN), Avenue Marnix 17, B-1000 Brussels, Belgium (www.cen.eu)

15.6 ISO Publications

ISO 6789–2, Assembly tools for screws and nuts — Hand torque tools — Part 2: Requirements for calibration and determination of measurement uncertainty

ISO 7005-1, Pipe flanges — Part 1: Steel flanges for industrial and general service piping systems
ISO 27509, Petroleum and natural gas industries — Compact flanged connections with IX seal ring
Publisher: International Organization for Standardization (ISO), Central Secretariat, Chemin de Blandonnet 8, Case Postale 401, 1214 Vernier, Geneva, Switzerland (www.iso.org)

15.7 Japanese Standards Association Publication

JSA JIS B 2251, Bolt Tightening Procedure for Pressure Boundary Flanged Joint Assembly
Publisher: Japanese Standards Association (JSA), Mita MT Building, 3-13-12 Mita, Minato-ku, Tokyo 108-0073, Japan (www.jsa.or.jp)

15.8 MSS Publication

MSS SP-9, Spot Facing for Bronze, Iron and Steel Flanges
Publisher: Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. (MSS), 127 Park Street, NE, Vienna, VA 22180 (www.msshq.org)

15.9 PIP Publication

PIP VESV1002, Design and Fabrication Specification for Vessels: ASME Code Section VIII, Divisions 1 and 2
Publisher: Process Industry Practices (PIP), Construction Industry Institute, The University of Texas at Austin, 3925 West Braker Lane (R4500), Austin, TX 78759 (www.pip.org)

15.10 SAE Publication

SAE J419, Methods of Measuring Decarburization
Publisher: SAE International, 400 Commonwealth Drive, Warrendale, PA 15096 (www.sae.org)

15.11 TEMA Publication

Standards of the Tubular Exchanger Manufacturers Association
Publisher: Tubular Exchanger Manufacturers Association, Inc. (TEMA), 25 North Broadway, Tarrytown, NY 10591 (www.tema.org)

15.12 U.S. Department of Labor, Occupational Safety and Health Administration Publication

29 CFR 1910.119, Process Safety Management of Highly Hazardous Chemicals
Publisher: Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, 200 Constitution Avenue, Washington, DC 20210 (www.osha.gov)

15.13 VDI Publication

VDI 2230, Systematic calculation of high duty bolted joints — Joints with one cylindrical bolt
Publisher: Verein Deutscher Ingenieure (VDI), P.O. Box 10 11 39, 40002 Dusseldorf, Germany (www.vdi.de)

15.14 WRC Publications

WRC Bulletin 449, Guidelines for the Design and Installation of Pump Piping Systems
WRC Bulletin 538, Determination of Pressure Boundary Joint Assembly Bolt Loads
Publisher: Welding Research Council (WRC), P.O. Box 201547, Shaker Heights, OH 44120

15.15 Other Publications

[1] Bickford, J. H., *An Introduction to the Design and Behavior of Bolted Joints*, CRC Press, United Kingdom (1995)
[2] Bickford, J. H., and Nassar, S., eds., *Handbook of Bolts and Bolted Joints*, Marcel Dekker, Inc., New York (1998)
[3] Brown, W., "Hydraulic Tensioner Assembly: Load Loss Factors and Target Stress Limits," ASME 2014 Pressure Vessels and Piping Conference, PVP2014-28685, Anaheim, CA, July 20–24, 2014, DOI: 10.1115/PVP2014-28685
[4] Brown, W., and Long, S., "Acceptable Levels of Corrosion for Pressure Boundary Bolted Joints," ASME 2017 Pressure Vessels and Piping Conference, PVP2017-65507, Waikoloa, HI, July 16–20, 2017, DOI: 10.1115/PVP2017-65507
[5] Kikuchi, T., Omiya, Y., and Sawa, T., "Effects of Nut Thinning Due to Corrosion on the Strength Characteristics and the Sealing Performance of Bolted Flange Joints Under Internal Pressure," ASME 2011 Pressure Vessels and Piping Conference, Volume 2: Computer Technology and Bolted Joints, PVP2011-57445, pp. 35–41, Baltimore, MD, July 17–21, 2011, DOI: 10.1115/PVP2011-57445
[6] Kikuchi, T., and Sawa, T., "Effects of Nut Thinning on the Bolt Load Reduction in Bolted Flange Joints Under Internal Pressure and Bending Moments," ASME 2013 Pressure Vessels and Piping Conference, PVP2013-97191, Paris, France, July 14–18, 2013, DOI: 10.1115/PVP2013-97191

[7] Koves, W. J., "Design for Leakage in Flange Joints Under External Loads," ASME 2005 Pressure Vessels and Piping Conference, Vol. 2: Computer Technology, PVP2005-71254, pp. 53–58, Denver, CO, July 17–21, 2005, DOI: 10.1115/PVP2005-71254

[8] Payne, J. R., and Schneider, R. S., "On the Operating Tightness of B16.5 Flanged Joints," ASME 2008 Pressure Vessels and Piping Conference, Vol. 2: Computer Applications/Technology and Bolted Joints, PVP2008-61561, pp. 115–124, Chicago, IL, DOI: 10.1115/PVP2008-61561

MANDATORY APPENDIX I
DEFINITIONS

(22)

50% stud removal: see *half-bolting*.

applied tensioner load: the load applied to the bolt by the tensioner (i.e., prior to load loss).

assembler: see *bolting assembler*.

assembly bolt stress: the target final bolt stress selected for a joint assembly to obtain a desired target gasket stress (see Nonmandatory Appendix O).

assistant bolting assembler: an individual who can perform the pretightening activities as applicable to their job function, including but not limited to identifying and differentiating among the major components of a bolted flange joint (i.e., gasket types, flange types, lubricants, and stud and nut material markings), and preparing a joint to be tightened. See Nonmandatory Appendix A, para. A-1.3.1.

backup wrench: the tool used to secure the nut or bolt head opposite to the one being turned or torqued.

bolt load loss factor (BLLF): when using hydraulic tensioners and less than 100% tensioner coverage (i.e., other than having a tensioner fitted to each bolt), when the second set of bolts is tensioned, the residual tensioner load on the first set of bolts is reduced. This loss of bolt load (expressed as a fraction of the originally applied tensioner load) is termed the BLLF. The BLLF occurs when more than one tensioning pass is applied; it can be eliminated by performing 100% tensioner coverage. Also called *flange load loss factor (FLLF)*.

bolt with integral head: a threaded fastener with a fixed or forged head on one end and employing a nut or a drilled and tapped hole on the other end.

bolt without integral head: a fully threaded fastener employing two nuts or one nut and a drilled and tapped hole.

bolting assembler: an individual who assembles and disassembles bolted flange joints. See Nonmandatory Appendix A, para. A-1.3.2.

NOTE: In the context of this Standard, *assembler* and *bolting assembler* are used interchangeably.

bolting inspector: an individual who performs pretightening, in-process, and post-assembly inspection for quality assurance. See Nonmandatory Appendix A, para. A-1.3.3.

bolting subject matter expert (bolting SME): an individual considered knowledgeable in the field of bolted joint assembly. See Nonmandatory Appendix A, para. A-1.3.6.

bolting supervisor: an individual trained to skill level 3 in the topics listed in Nonmandatory Appendix A, section A-2, and any supplemental topics required for bolted flange joint assemblies conducted under the individual's leadership. See *skill level 3*.

bolting trainer: an individual trained to skill level 3 in the topics listed in Nonmandatory Appendix A, section A-2, and any supplemental topics required for bolted flange joint assemblies conducted by the user. See *skill level 3*.

centerline high/low: the alignment of piping or vessel flanges so that the seating surfaces, the inside diameter of the bore, or the outside diameter of the flanges matches or meets with the greatest amount of contact surface (see Nonmandatory Appendix E, Figure E-2-1).

certification: written testimony of qualification.

check pass: the tightening of all bolts in circular order at 100% of target torque until there is no further nut rotation.

circular pass: see *check pass*.

common grades: materials common to the facility or industry in satisfactory quantity and price as to be considered the normal materials to use. For example, common grades of threaded fasteners in the petroleum refining and chemical processing industries are SA-193 B7 bolts and SA-194 2H nuts or SA-193 B16 bolts and SA-194 4 or 7 nuts.

controlled reuse: the first and subsequent uses thereafter that have been conducted and documented under specific thread engagement, locations, torque, tension, lubrication, inspection, nut replacement, handling, cleaning, and installation guidelines.

critical issue: any issue that directly contributes to or results from the proper or improper assembly of a joint.

critical joints: those joints in service applications designated by the owner as being of a probability or consequence to justify more rigorous requirements such as assembly details, quality control checks, and/or record keeping. Considerations in designating joints as critical include governing design conditions (pressure, temperature, etc.), mechanical criteria (bolt diameter, flange diameter, gasket type, etc.), joint leakage history, and fluid service category. Examples of critical service include service requirements as defined by local jurisdictional requirements [e.g., in the United States, CFR 1910.119 (OSHA PSM rule)]; lethal substance service as defined in ASME BPVC, Section VIII, Division 1; or Category M Fluid Service as defined in ASME B31.3.

eight-bolting: the removal of every bolt except eight evenly spaced opposing bolts in preparation for breaking the joint (typically for blinding or valve removal) during a shutdown. The unit is offline to do this, as in the requirements for half-bolting outlined in ASME PCC-2. However, as the joint is not broken, the line may still contain process fluid, and there is a small likelihood of leakage with this procedure. Eight-bolting is performed to speed up blinding or valve removal during a shutdown. A risk assessment of the eight-bolting operation should be carried out to establish that the operation can be performed safely. See also *four-bolting*.

excessive gap: a condition in which two flanges are separated by a distance greater than twice the thickness of the gasket when the flanges are at rest and the flanges will not come together using reasonable force (see Nonmandatory Appendix E, Figure E-2-2). Also called *excessive spacing*.

experience: work activities accomplished in a specific bolted joint assembly method under the direction of qualified supervision, including the performance of the bolted joint assembly method and related activities but not including time spent in organized training programs.

flange load loss factor (FLLF): see *bolt load loss factor (BLLF)*.

four-bolting: the removal of every bolt except four evenly spaced opposing bolts in preparation for breaking the joint (typically for blinding or valve removal) during a shutdown. The unit is offline to do this, as in the requirements for half-bolting outlined in ASME PCC-2. However, as the joint is not broken, the line may still contain process fluid, and there is a small likelihood of leakage with this procedure. Four-bolting is performed to speed up blinding or valve removal during a shutdown. A risk assessment of the four-bolting operation should be carried out to establish that the operation can be performed safely. See also *eight-bolting*.

gasket contact surface: see *gasket seating surface*.

gasket sealing surface: see *gasket seating surface*.

gasket seating surface:

(a) the contact area of the gasket that performs the sealing function during operation (nominally the part of the gasket that is seated against the flange to affect a seal). The gasket seating surface is measured in the undeformed state. For spiral-wound gaskets, this is defined as the region between the inner diameter (I.D.) of the outer ring and the outer diameter (O.D.) of the inner ring; for grooved-metal and fiber-sheet gaskets, it is defined by the gasket I.D. and O.D. (unless the raised-face O.D. is smaller than the gasket O.D.). When determining the seating surface for gaskets that may not sit central during installation or that are designed to move on the flange face during installation, a larger seating surface may be necessary to account for the possibility of seating surface offset. For example, see Nonmandatory Appendix D for the definition of the seating surface for a ring-type joint gasket.

(b) the area on a flange where the gasket seats both initially and finally after assembly.

half-bolting: the removal of every other bolt (so the flange is left with half the number of bolts) during plant depressurization, usually when the system is close to atmospheric pressure. Half-bolting generally consists of removing every second bolt, relubricating them, reinstalling them, and retightening to a specified torque. The remaining bolts are then removed, relubricated, reinstalled, and retightened to a specified torque such that all bolts have been reinstalled. There is a small likelihood of leakage with this procedure, particularly if the system is accidentally repressurized. A risk assessment of the half-bolting operation should be carried out to establish that the operation can be performed safely. Refer to ASME PCC-2 for further information on joint-tightening activities once the unit is fully operational. Also called *50% stud removal*.

hard gaskets: gaskets such as grooved-metal gaskets, corrugated metal gaskets, and flat solid-metal gaskets. Hard gaskets are typically defined as gaskets that have less than 1.0 mm (0.04 in.) compression during assembly. Generally speaking, it is not appropriate to classify gaskets as hard or soft based solely on the physical hardness or softness of the gasket material itself. For example, 1.5-mm ($^1/_{16}$-in.) thick polytetrafluoroethylene, flexible-graphite, or fiber gaskets are classified as hard gaskets. See also *hard-faced gaskets*.

NOTE: Ring-type joint gaskets and lens gaskets are a special case and are addressed separately in Nonmandatory Appendix D, section D-4; and Nonmandatory Appendix F, section F-8.

hard-faced gaskets: gaskets constructed entirely from metal that do not have a soft filler material on the faces that contact the flange seating surfaces or that have insufficient filler material to fill imperfections on the flange faces. It may not be acceptable to categorize by gasket type as extremely thin gaskets or gaskets without sufficient filler will not fill imperfections and therefore are categorized as hard-faced gaskets. Metal-faced gaskets, such as flat metal, ring-type joints, or double-jacketed gaskets, are categorized as hard-faced gaskets. See also *hard gaskets*.

heat exchanger joints: gasketed bolted joints that comprise the pressure-boundary closure between the tubesheet and the mating shell and tubeside girth flanges and that require special assembly considerations (see Nonmandatory Appendix A, para. A-2.4). The gaskets for these joints are generally located entirely within the circle enclosed by the bolt holes, with no contact outside this circle; however, this is not intended to exclude other configurations, such as flat-faced flanges, from Nonmandatory Appendix A.

hot torque: see *start-up retorque*.

live tightening: tightening all bolts on a joint while the unit is operational or has been in operation for a period of time. The technique used for tightening may be manual torque, hydraulic torque, or hydraulic tension. However, torque can typically no longer be considered accurate after more than a few days of operation. Therefore, other techniques, such as turn-of-nut or tensioning, are preferred. Single-stud replacement is also an option, but there is a higher associated likelihood of leak with that activity due to the reduction in gasket stress if the tightening is performed while the joint is pressurized. Live tightening should not be considered the same as start-up retorque, which is performed as part of the assembly operation; live tightening is an operational activity that may be performed periodically to recover relaxation (typically on high-temperature joints that have a history of leakage) or as a reaction to joint leakage. A risk assessment of the live-tightening operation should be carried out to establish that the operation can be performed safely. Refer to ASME PCC-2 for further information on joint tightening activities once the unit is fully operational.

local gasket stress: for purposes of single-stud replacement, the average gasket stress along a radial line at a given circumferential location.

lubricant: a generic term that may include antiseize products.

manual tightening: the use of an uncalibrated torquing device such as an impact wrench.

manual torque wrench tightening: the use of a manual torque wrench (typically a "clicker" type) to achieve the desired torque.

nut load loss factor (NLLF): when using hydraulic tensioners, the load is transferred from the tensioner to the nut as the tensioner pressure is released. As part of this process, the thread and nut deflect, which releases some of the load originally established by the tensioner. This loss of load (expressed as a fraction of the originally applied tensioner load) is termed the NLLF. The NLLF occurs at all times when using hydraulic tensioners (i.e., it cannot be reduced without redesign of the joint). Also called *tool load loss factor (TLLF)*.

odd-bolting: see *half-bolting*.

online tightening: see *live tightening*.

owner: the person, partnership, organization, or business responsible for the leak tightness of bolted flange joint assemblies on their pressure equipment.

parallelism: a measure of alignment, representing the uniformity of distance between the sealing surfaces of two flange faces (see Nonmandatory Appendix E, Figure E-2-3).

pass: the incremental tightening steps taken to achieve the target bolt stress.

pattern: the combination of passes applied in a sequence leading to the assembly bolt stress.

piping joints: similar to pressure vessel joints; however, considerations relating to alignment and external loadings on the joints are more likely to govern design and assembly requirements. The gaskets for piping joints are generally located entirely within the circle enclosed by the bolt holes, with no contact outside this circle; however, this is not intended to exclude other configurations, such as flat-faced flanges, from Nonmandatory Appendix A.

powered equipment: hydraulic, pneumatic, or battery-powered joint assembly equipment, such as a hydraulic torque wrench, pneumatic torque wrench, battery-powered torque wrench, or hydraulic bolt tensioning equipment.

pre-pass torque: the torque that is applied to the existing studs to confirm tightness prior to performing single-stud replacement.

pressure vessel joints: gasketed bolted joints that comprise the pressure-boundary closure between two flanges. The gaskets for pressure vessel joints are generally located entirely within the circle enclosed by the bolt holes, with no contact outside this circle; however, this is not intended to exclude other configurations, such as flat-faced flanges, from Nonmandatory Appendix A.

program manual: user's documentation of the program in accordance with Nonmandatory Appendix A, para. A-1.3.

qualification: the demonstration of knowledge, skills, and abilities, along with documented training and experience required for personnel to properly perform the duties of a specific job or task. Alternative solutions to those outlined in Nonmandatory Appendix A may be used as long as they meet the intent of this Standard and are properly justified and documented.

remaining gasket stress factor (RGSF): for purposes of single-stud replacement, the ratio of the minimum local gasket stress when a single stud is removed to the gasket stress when all studs are installed.

representative: a person, partnership, organization, or business designated by the owner to carry out selected responsibilities on the owner's behalf.

residual tensioner load: the load remaining on the bolt after the release of the tensioner pressure (i.e., after load loss).

retighten: to tighten again in a subsequent assembly. This does not include tightening the fastener again to turn the nut to a tighter position from a static position.

reuse: to use more than once.

ring-type joints (RTJ): flanges fitted with metal ring-type joint gaskets (as detailed in ASME B16.20).

ringer pass: see *check pass*.

risk assessment: an engineering and risk analysis conducted when an activity or decision may require extra consideration, outside of normal assembly and operational practices, due to additional risks or modes of failure that may not be inherently apparent. The lack of use of this term in sections of this Standard should not be taken to diminish the requirements for normal risk assessment activities in those sections.

rotational-two hole: the alignment of piping or vessel flanges so that the bolt holes align with each other, allowing the fasteners to pass through perpendicular to the flanges.

safety data sheet (SDS): a data sheet for chemicals that defines important information such as the levels of toxicity, flammability, and first-aid actions required.

sequence: the numbering protocol used to indicate the order in which bolts are tightened.

sequential circular pass: associated with single-stud replacement, the action of starting with one stud and proceeding to the adjacent stud in a clockwise or counterclockwise direction.

single-stud replacement: an operation used to replace corroded or defective bolts, to proactively increase the gasket stress to prevent leakage (typically in high-temperature or cyclic services), or to reseal a small stable leak. Also called *hot bolting*.

NOTE: Single-stud replacement while the unit is online to increase gasket stress or seal a small stable leak is not recommended or required if turn-of-nut tightening can be used. A risk assessment of the single-stud replacement operation should be carried out to establish that the operation can be performed safely. See ASME PCC-2 for further information on joint-tightening activities once the unit is fully operational.

skill: the ability to perform mental and physical activities acquired or developed through training or experience.

skill level 1: a depth of knowledge characterized by recalling and reproducing the desired learning objectives.

skill level 2: a depth of knowledge that includes recall of facts and providing the basic application of the desired learning objectives. An individual at this skill level can proficiently perform steps defined in a procedure.

skill level 3: a depth of knowledge that allows an individual to justify resolutions for situations that do not meet the scope of what would be considered normal. An individual at this skill level can explain why tasks should be performed a certain way.

skill level 4: a depth of knowledge that allows application of an individual's expertise in an original way or as a response to an original situation.

soft gaskets: gaskets in which the movement between the flange faces during assembly is relatively large, e.g., polytetrafluoroethylene (PTFE), spiral-wound, and compressed-fiber or flexible-graphite-sheet gaskets. Soft gaskets are typically defined as gaskets that have more than 1.0 mm (0.04 in.) compression during assembly. It is not appropriate to classify gaskets as hard or soft based solely on the physical hardness or softness of the gasket material itself. For example, 1.5-mm ($^{1}/_{16}$-in.) thick PTFE, flexible graphite, or fiber gaskets do not have sufficient compression to be classified as soft gaskets. See also *soft-faced gaskets*.

NOTE: Ring-type joint gaskets and lens gaskets are a special case and are addressed separately in Nonmandatory Appendix D, section D-4; and Nonmandatory Appendix F, section F-8.

soft-faced gaskets: gaskets that are constructed from or have a soft filler material on the faces that come into contact with the flange seating surfaces. Soft-faced gaskets have sufficient soft filler (such as graphite, rubber, or polytetrafluoroethylene) that both the gasket substrate and the flange seating surface finish will be filled and additional filler exists on the gasket such that any small imperfections will also be filled as the gasket is compressed between the flanges. It may not be acceptable to categorize by gasket type as extremely thin sheet gaskets or gaskets without sufficient filler or facing will not fill imperfections and therefore are categorized as hard-faced gaskets. See also *soft gaskets*.

special joint: any process-specific flanged connection requiring different or additional instruction or considerations for assembly (such as clamped connectors, valve bonnets, and valve body joints).

start-up retorque: while the unit is coming up to operating temperature, the procedure of tightening all bolts on a joint in a circular pass until the nuts no longer turn. Start-up retorque (formerly called hot torque) is performed to increase the residual operational stress on the gasket (to recover initial gasket relaxation) to minimize the likelihood of leakage. It is typically performed while the unit is online but may be performed prior to operation using heating pads to bring the flange up to temperature. Since start-up retorque will increase the load on only the gasket, the likelihood of leakage is significantly lower than for other activities (such as hot bolting).

stud loading: the act of increasing the tensile stress state within the stud.

stud-loading method: the method of operator control used to increase or decrease the stress state within a stud.

stud unloading: the act of decreasing the tensile stress state within the stud.

tensioner coverage: the percentage of the number of tensioners compared to the number of bolts on the joint. For example, 100% tensioner coverage requires a tensioner to be fitted to every bolt (i.e., all bolts tensioned simultaneously), 50% tensioner coverage requires one tensioner to be fitted to every second bolt, and 25% coverage requires one tensioner to be fitted to every fourth bolt.

tensioning: a stud-loading method of increasing or decreasing the load on a stud by controlling a direct axial force on the stud.

tighten: to apply load to the threaded fastener system through some means of turning of the nut or direct tension.

tool load loss factor (TLLF): see *nut load loss factor (NLLF)*.

torquing: a stud-loading method of increasing or decreasing the load on a stud by controlling a torque-force acting on helical threads.

training: an organized program developed to impart the knowledge and skills necessary for qualification.

training organization: a user or organization that undertakes the training, demonstration of knowledge, and practical examination outlined in Nonmandatory Appendix A.

turn-of-nut:

(a) a stud-loading method of increasing or decreasing the load on a stud by controlling the rotation of the nut on helical threads.

(b) a stud-loading method of increasing or decreasing the load on a stud by controlling the rotation of the nut on helical threads. Turn-of-nut involves tightening the joint by turning one nut on each bolt by a specific amount. Turn-of-nut does not require knowledge of the nut factor and therefore can be applied at any stage during the life of the joint. Turn-of-nut is used either to proactively increase the gasket stress to prevent leakage (in high-temperature or cyclic services) or to reseal a small stable leak. If turn-of-nut is performed while the unit is online, there is a small likelihood of additional leakage. However, since the load on the gasket will only increase, the likelihood of leakage is significantly less than for other activities such as hot bolting. Bolted joints with fiber-sheet-type gaskets tend to degrade in service and are more likely to blow out if retightened while operating; thus, turn-of-nut for joints with such gasket types should be limited to low-pressure nonhazardous services.

use: the process whereby a threaded fastener or group of such fasteners is installed in a joint and tightened for the purpose of obtaining and maintaining a seal between the flanges.

user: any entity that applies the provisions of this Standard. Because of the broad variation of possible contract scenarios for which this Standard might be applied, the user could be the owner, owner's representative, manufacturer, fabricator, erector, or other contract personnel.

working surfaces: those interfaces in the fastener system that slide against each other when a bolted flange joint is being tightened.

NONMANDATORY APPENDIX A TRAINING AND QUALIFICATION OF BOLTED JOINT ASSEMBLY PERSONNEL

(22)

A-1 INTRODUCTION

A-1.1 Scope

This Appendix outlines requirements for training and qualification of bolted joint assemblers using procedures in accordance with the Standard. The Appendix uses titles for different assembler skill levels. Assigning titles to skill levels standardizes expectations of competency for users, contractors, labor suppliers, unions, and assembly personnel. These titles also represent specific training objectives. Owners may refer to and require these skill levels when contracting personnel from third parties.

The employer of the assembly personnel shall document the requirements of their training and qualification program, which should include demonstration of knowledge and skills, along with documented training and experience required for personnel to properly perform the duties of a specific job or task. Alternative solutions to those outlined in this Appendix may be used as long as they meet the intent of this Standard and are properly justified and documented.

The training and qualification program should

(a) evaluate the individual assembler's technical knowledge based on the types of flanges the assembler is going to assemble

(b) assess assemblers by having them demonstrate their skills

(c) document the content of the training and the results of the evaluation

(d) provide a certificate stating that the trainee has demonstrated the knowledge and skills corresponding to the applicable skill level

When choosing provisions of this Appendix, the employer should specify the skill level required of an individual to meet the user's needs.

Skill levels should be evaluated periodically as defined by the employer.

A-1.2 Definitions

See Mandatory Appendix I.

A-1.3 Framework

Paragraphs A-1.3.1 through A-1.3.6 offer a framework for skill levels and responsibilities for individuals involved in the assembly and disassembly of bolted joints.

A-1.3.1 Assistant Bolting Assembler. An assistant bolting assembler is an individual who is able to identify and differentiate between the major components of a bolted flange joint, i.e., gasket types, flange types, lubricants, and stud and nut material markings. These individuals should be trained to skill level 1 (see Mandatory Appendix I and Table A-1.4-1), which is appropriate for anyone in any discipline to gain awareness of the assembly of bolted flange joints. Skill level 1 is required for any individual who will be assisting bolting assemblers and for development into a future bolting assembler role.

A-1.3.2 Bolting Assembler. A bolting assembler is an individual who assembles and disassembles bolted flange joints. Bolting assemblers should be able to

(a) perform disassembly and assembly procedures

(b) assess pre-assembly condition

(c) inspect assembled joints

(d) complete documentation

(e) notify supervisors when tightening equipment, flange conditions, or fasteners and gaskets are unsatisfactory

Bolting assemblers shall be trained to skill level 2 (see Mandatory Appendix I and Table A-1.4-1) in the topics listed in para. A-2.1 and any supplemental topics required for their job function.

A-1.3.3 Bolting Inspector. A bolting inspector is an individual who performs pretightening, in-process, and post-assembly inspections for quality assurance. Bolting inspectors will have achieved skill level 2 (see Mandatory Appendix I and Table A-1.4-1) for the topics listed in para. A-2.1 and all supplemental endorsements that apply to the user's scope of work. Additionally, bolting inspectors should be knowledgeable of

(a) subject matter relevant to the inspection function

(b) ASME PCC-1

(c) the user's bolting procedures, requirements, and quality assurance and quality control processes

Table A-1.4-1
Training Matrix

Skill Level	Training of Fundamentals (Para. A-2.1)	Piping Endorsement (Para. A-2.2)	Powered Equipment Endorsement (Para. A-2.3)	Heat Exchanger Endorsement (Para. A-2.4)	Special Joint Endorsement (Para. A-2.5)	Training Method: Training Knowledge	Training Method: Practical Demonstration	Assessment Method: Technical Knowledge	Assessment Method: Practical Skills
1	C-1	...	...	...	...	CBT or ILT	NA	CBT or ILT	NA
2	C-2	C-2	A	A	A	CBT or ILT	ILT	CBT or ILT	ILT
3	C-3	C-3	A	A	A	CBT or ILT	ILT	CBT or ILT	ILT
4	C-4	C-4	C-2	A	A	ILT	ILT	ILT	ILT

Legend:
A = when applicable; refers to information the trainee is required to learn only if it is part of the trainee's job function. Otherwise, the information is optional.
C = core information needed to perform the role; as the skill level increases, it is expected that the topics listed in Table A-2.1-1 are taught in greater depth.
C-1 = an understanding of how to perform the role and what is needed to perform the role.
C-2 = an understanding of why bolted joint assembly activities needed to perform the role are important.
C-3 = an understanding of how to troubleshoot general bolted joint assembly issues for the roles under their supervision.
C-4 = maintaining and directing the general bolted joint assembly procedures and training materials.
CBT = computer-based training; this method is used for teaching academic and practical concepts and for testing academic knowledge.
ILT = instructor-led training; this method may be used for the entire training process but shall be used for practical demonstration and assessment of practical skills.
NA = not applicable.
O = optional information, i.e., information the trainee is not required to learn to attain the skill level.

A-1.3.4 Bolting Supervisor. A bolting supervisor is an individual who is trained to skill level 3 (see Mandatory Appendix I and Table A-1.4-1) in the topics listed in para. A-2.1 and any supplemental topics required for bolted flange joint assemblies conducted under their leadership. Bolting supervisors provide clarification to bolting assemblers as needed.

A-1.3.5 Bolting Trainer. A bolting trainer is an individual who is trained to skill level 3 (see Mandatory Appendix I and Table A-1.4-1) in the topics listed in para. A-2.1 and any supplemental topics required for bolted flange joint assemblies conducted by the user. Bolting trainers should also receive additional instructor-led training (ILT) on how to deliver effective training sessions in accordance with para. A-2.1.

A-1.3.6 Bolting Subject Matter Expert (Bolting SME). A bolting SME is an individual who is trained to skill level 4 (see Mandatory Appendix I and Table A-1.4-1) in the topics listed in section A-2 and all supplemental endorsements that apply to the user's scope of work. A bolting SME is responsible for reviewing, maintaining, and approving procedures and training materials.

A-1.4 Training Program Objectives

This Appendix includes items pertaining to individuals who participate in the assembly of bolted flange joint assemblies and individuals trained to skill levels 1 through 4.

Table A-1.4-1 specifies the different levels of training and the expectations for the training and examination process.

Additional, supplemental endorsements may be obtained on the basic endorsements to extend the individual's duties and responsibilities to include

(a) piping-specific (hand torque) joints
(b) powered equipment (hydraulic torque/hydraulic tension)
(c) heat exchanger pressure-boundary bolted joints
(d) special pressure-boundary bolted joints

A-1.5 Exempt Assembly Activities

This Appendix does not cover personnel engaged in the assembly of structural-type bolted joints or pressure-boundary body joints on rotating equipment.

A-2 ACADEMIC TRAINING PROGRAM

A-2.1 Training of Fundamentals — Training

Training for all skill levels shall include the fundamentals of the assembly, operation, and quality assurance of bolted joints. Practical and academic examinations shall be given to establish to the satisfaction of the employer that the trainee meets the expectations of this Appendix. As a minimum, the employer shall address the following topics when evaluating trainees for skill level 1 (see also Table A-2.1-1):

(a) general health and safety precautions. While some areas of health and safety are outside the scope of ASME PCC-1, the following topics are included for the purpose of awareness and for completeness in describing typical competencies:

(1) awareness of common health issues and safety precautions per the requirements of applicable government health and safety regulatory bodies and plant-specific regulations

(2) awareness in areas such as hazardous chemicals and gases, personal protective equipment (PPE), hazard communication, procedures for opening process equipment or piping, hearing protection, confined-space entry, scaffold safety, personal fall protection, stairways and ladders, rigging, respiratory protection, asbestos considerations, and walking and working surfaces

(3) job safety analysis

(b) principles of bolt elongation, bolt load, and gasket stress

(c) functionality of gasket and seal

(d) gasket types and their limitations

(e) bolt types and their limitations

(f) identification of correct joint components

(g) manual torque joint tightening

(h) importance of using the specified lubricant (see section 8)

(i) techniques used for load control

(j) calibration and maintenance of bolt-tightening equipment

(k) inspection and reporting of defects or faults

(l) procedure for preparing a joint for closure

(m) gasket handling, preparation, and installation

(n) sources of information on joint assembly

(o) safe joint disassembly and assembly

(p) joint assembly procedures

(q) correct use of additional joint components

(r) importance of joint quality-assurance procedures, certification, and records

(s) joint disassembly

A-2.2 Piping Endorsement — Training

The piping endorsement curriculum for skill levels 2, 3, and 4 is detailed in Table A-2.2-1.

The practical examination requires the trainee to satisfactorily assemble by means of hand-torque tightening a number of flange joint types, including

(a) raised-face or full-face flange

(b) ring-type joint (RTJ)

A-2.3 Powered-Equipment Endorsement — Training

For all powered-equipment training, the curriculum shall ensure trainees have a thorough understanding of joint disassembly, assembly, and tightening using the equipment that is suited for their job requirements. See Table A-2.3-1.

A-2.4 Heat Exchanger Endorsement — Training

The heat exchanger endorsement curriculum shall ensure trainees have a thorough understanding of how to disassemble, assemble, and tighten exchanger joints. See Table A-2.4-1.

A-2.5 Special Joint Endorsement — Training

Special joint endorsement training should cover joints or components that have a proprietary design, including, but not limited to

(a) expansion joints

(b) isolated joints

(c) compact flanges

(d) hub or clamp connectors

(e) rupture disks or spectacle disks

The training curriculum shall ensure trainees have a thorough understanding of all significant aspects of joint disassembly, assembly, and tightening for special joints.

A comprehensive list of the requirements is outside the scope of this Standard. However, the general approach used in the previous sections for piping and exchangers should be followed in formulating the expectations for special joints. As a minimum, the training curriculum should cover the items listed in para. A-3.7.

Table A-2.1-1
Training of Fundamentals Curriculum

Topics	Concepts Addressed
(a) General health and safety precautions	(1) Common procedures for the work permit and ensuring system isolation (2) Finger pinch points with assembly and alignment equipment (3) Injury from tightening tools (4) Cleaning (material and process-medium compatibility) and a light dusting of gasket adhesive for vertical flanges [see para. 7(b)(6)] (5) Basic joint alignment equipment (pry-bar, drift pins; see Nonmandatory Appendix E) (6) Site or corporate guidelines
(b) Principles of bolt elongation, bolt load, and gasket stress	(1) Relationship between bolt stress and bolt elongation (see section 11) (2) Relationship between bolt stress and gasket stress during assembly and operation (pressure and temperature effects) (3) Influence of bolt length on bolt-load loss due to gasket creep relaxation and surface embedment loss (4) Relationship between applied torque and achieved bolt stress or load (5) Bolting terminology, including common terms found in the field and their relationship to each other (e.g., kips, psig, psi, lb, ft-lb, N·m, ksi, tpi)
(c) Functionality of gasket and seal	(1) Purpose of a gasket (2) Effect of gasket stress on leak rate (3) Effect of bolt-load loss (creep or relaxation and operating conditions) on joint leakage and overall joint reliability
(d) Gasket types and their limitations	(1) Summary of common gasket types and materials (2) Sensitivity of different gasket types to assembly procedures (3) Maximum allowable gasket stress (4) Minimum required gasket stress (5) Awareness of the need for chemical compatibility (6) Awareness of temperature limits
(e) Bolt types and their limitations	(1) Brief detail of common bolting specifications, including yield strength (2) Nut–bolt combinations, nut strength versus bolt strength (3) Generic material temperature limits (4) Materials for stress-corrosion-cracking environments (5) Corrosion resistance (6) Coatings for assembly and disassembly
(f) Identification of correct joint components	(1) Bolt and nut identification marks (2) Installation of bolts and studs such that marked ends are all on the same side of the joint, with nut identification marks facing out, to facilitate inspection (3) Flange identification marks (4) Gasket identification marks and spiral-wound gasket color codes and types (5) Use of piping-arrangement drawing or system diagram to identify and verify correct materials for gasket and fasteners
(g) Manual torque joint tightening	(1) Working parts of a manual torque wrench (2) Setting required torque values on common types of wrenches (3) Bolting procedures (number of cross-pattern passes) required to achieve desired bolt torque (see section 10) (4) Accuracy of bolt torque tightening versus that of manual tightening (5) Variables affecting the accuracy and consistency of torque
(h) Importance of proper application and use of specified lubricant (see section 8)	(1) Purpose of lubricant (2) Effect of type of lubricant (3) Where to use lubricant (under nut and on bolt threads) (4) Limitations of lubricants, including oxygen ignition, oxidation, temperature, shelf life, catalyst poisoning, and stress corrosion cracking (compatibility with process fluid and materials of construction) (5) Proper application and amount of lubricant to use (6) Contamination of lubricants during assembly (7) Interpreting the label and material Safety Data Sheet (SDS) information
(i) Techniques used for load control	(1) Techniques used for load control by torque measurement (2) Techniques used for load control by hydraulic tension (3) Techniques used for load control by length or strain measurement [see paras. 10(a) and 10(b)] (4) Accuracy of each method and relationship to service or joint criticality (see Table F-4-1)

Table A-2.1-1
Training of Fundamentals Curriculum (Cont'd)

Topics	Concepts Addressed
(j) Calibration and maintenance of bolt-tightening equipment	(1) Requirements for maintenance of common field equipment (2) Inspection of common field equipment (especially torque wrenches) (3) Familiarization with methods for performing calibration and verification of common field equipment (4) Importance and frequency of calibration and tool verification
(k) Inspection and reporting defects or faults	(1) Flange-face gasket contact surface inspection (see section 4 and Nonmandatory Appendix D) (2) Acceptable levels of surface flatness and imperfections corresponding to different gasket types (3) Bolt inspection (thread form, corrosion, and free running nut for triggering replacement; see section 4 and Nonmandatory Appendix N) (4) Inspection of flange and nut contact surfaces (for galling, paint, or corrosion; see section 4) (5) Joint gap measurement (see section 12) (6) Joint tolerances and alignment (see Nonmandatory Appendix E) (7) Joint-tightness leak check (see section 14)
(l) Procedure for preparing a joint for closure	(1) General workflow for inspecting and preparing a joint for closure (2) Methods for holding the gasket in place (including the detrimental effects of excessive adhesive and use of unapproved methods such as heavy grease, lubricant, or tape; see section 7) (3) System cleanliness requirements
(m) Gasket handling, preparation, inspection, and installation	(1) Use of a single new (not used or damaged) gasket for final installation (see section 7) (2) Final inspection of gasket seal surface and gasket (dimensions, type, and damage) (3) Ensuring gasket can be inserted into joint without damage (4) Ensuring gasket is correctly located (use of flange bolts or a light dusting of approved adhesive sprays)
(n) Sources of information on joint assembly	(1) ASME PCC-1 (2) Corporate and site standards and specifications for gaskets, bolting, and piping (3) Corporate and site standards for joint assembly (4) Corporate and site standards and specifications for bolt loads and assembly techniques
(o) Safe joint disassembly and assembly	(1) Ensuring pressure isolation, valve-tagging systems, and safe work practices (see section 14) (2) Verification of pressure isolation, gas detection, and safe entry into the system (3) Temporary support and/or rigging considerations for joint components (4) Working on internal joints and high-level or below-grade joints (scaffold and confined-space entry)
(p) Joint assembly procedures	(1) Identification of correct assembly target bolt load (2) Reason for needing a pattern (sequence and passes) in procedure (3) Reason for needing multiple passes in the procedure (see Nonmandatory Appendix F) (4) Measurement of joint gaps during assembly [see para. 10(a)] (5) Hydraulic or pneumatic testing of joint after assembly (see section 14) (6) Measurement of joint gaps after assembly [see para. 10(a)] (7) Use of proprietary backup wrenches and alignment tools, which may improve safety and speed of assembly
(q) Ensuring correct use of additional joint components	(1) Use of through-hardened washers (see Nonmandatory Appendix M). (2) Use of conical disk (Belleville) spring washers. (3) Use of spacers or bolt collars for the purpose of additional effective length and elongation. (4) Use of prevailing torque nuts, instrumented studs, reaction washers, tensioning nuts, direct tension-indicating washers, and other special-purpose accessories. (5) Use of proprietary nuts, washers, etc. There are innovative proprietary nuts, washers, and other mechanical and hydraulic devices that assist the assembly process. Detailed training on the application of these devices is available from the supplier and/or manufacturer. (6) Use and misuse of locking devices and locking compounds.
(r) Importance of joint quality assurance, procedures, certification, and records	(1) Joint assembly procedures and typical forms (2) Joint assembly records (see section 13) (3) Certification systems for tracking equipment calibration (4) The importance of a joint traveler sheet or assembly tag

Table A-2.1-1
Training of Fundamentals Curriculum (Cont'd)

Topics	Concepts Addressed
(s) Joint disassembly	(1) Reasons for requiring a disassembly procedure (see section 14) (2) Disassembly procedures and critical issues (3) Use of nut splitters

Table A-2.2-1
Piping Endorsement Curriculum

Topics	Concepts Addressed
(a) Assembly technique and gasket recognition in relation to flange-face type	(1) Flat face versus raised face versus RTJ and their appropriate gaskets (2) Understanding of ASME B16.5 and ASME B16.47 nominal pipe size and pressure class (3) Common flange types, including slip-on, weld neck, socket weld, threaded, and lap joint/stub end (4) Installation and operational characteristics (rotation, stiffness, flange sealing area, etc.) of common flange types (5) The importance of multipoint tightening or additional passes for RTJ and lens ring joints (6) The potential consequences of mating flat-faced flanges to raised-face flanges (7) Failure potential of brittle cast flanges on valves, pumps, and similar equipment
(b) Tightening piping joints connecting to rotating equipment	(1) The need to ensure equipment alignment (shaft alignment) is not affected by external loads caused by the assembly of piping connected to the rotating equipment (2) Equipment-allowable nozzle loads and moments (3) Purpose of piping expansion joints
(c) Tightening piping joints on pressure relief devices	(1) Potential for inspection work-hold point to ensure that there is no blockage in the relief path (2) Correct installation, gaskets, handling, and orientation of rupture disks and discharge lines (3) Confirmation of piping status by a certified inspector (if required)
(d) Tightening piping joints on and around piping expansion joints and cold-set spring hangers	(1) Methods of safely restraining bellows and cold-set spring hangers (2) Ensuring restraints are removed prior to operation (3) How to recognize and report if too much force is required to bring the flanges together (see Nonmandatory Appendix E)
(e) Importance of alignment and gap uniformity	(1) Nonmandatory Appendix E flange alignment tolerances (2) Tighter limits are required for shorter or stiff spans (3) Importance of the bolts passing freely through the bolt holes so that the nuts rest parallel to the flange
(f) Selecting the target bolt-assembly load	(1) Parameters that determine appropriate bolt load (flange size, gasket type, flange class, flange type, flange material, bolt material, piping service) (2) Determination of correct load from gasket specifications and bolt size or flange class charts for torque and hydraulic tensioning (see section 13) (3) Discussion of the advantages and disadvantages of the tightening methods
(g) Selecting appropriate bolt-tightening tooling	(1) Acceptable methods in relation to bolt size (2) Naturally occurring clearance problems related to general styles of tooling such as hand-torque wrenches, torque multipliers, and impact wrenches (3) Where to look for guidance (user specifications, company guidelines, tool manufacturer websites)

Table A-2.3-1
Powered-Equipment Endorsement Curriculum

Topics	Concepts Addressed
(a) General health and safety precautions	(1) Safety and securing of high-pressure fluids, fittings, and hoses during operation (2) Placement and removal of backup wrench under high loads (3) Pinch points relative to hydraulic, electric or battery, or pneumatic torque equipment and backup wrenches (4) Dangers associated with socket failure under load from using the incorrect or a low-quality socket
(b) Selecting appropriate bolt-tightening tooling	(1) Acceptable methods in relation to bolt size (2) Naturally occurring clearance problems related to general styles of tooling such as hydraulic inline ratchets, hydraulic square-drive ratchets, fixed-size tensioners, variable-size tensioners, hydraulic nuts, and mechanical jack nuts (3) Bolt-load limitation of hydraulic tensioners as related to pressure, ram size, bolt size, and bolt length (4) Use of comparative angle of nut rotation method when standard hydraulic tooling will not work (insufficient space for hydraulic equipment for one or two bolts)
(c) Powered equipment torque	(1) Working parts of hydraulic, electric or battery, and pneumatic torque equipment (2) Working parts of a hydraulic pump and hydraulic or pneumatic regulator (3) Troubleshooting hydraulic wrench, hose, hose connections, and pump failures (4) Method of setting target torque (5) Method of using a hydraulic torque wrench (6) Single-point tightening versus simultaneous multiple-point tightening, and the tightening procedure's influence on the assembly procedure
(d) Powered equipment tension	(1) Working parts of a hydraulic bolt tensioner (2) Working parts of a hydraulic pump and hydraulic regulator (3) Method of setting correct bolt load (formulas for calculating the target bolt load) for the number of tools in relation to the number of bolts in the joint (4) Method of using a hydraulic bolt tensioner (5) Troubleshooting of tensioner, hose, hose connections, and pump failures (6) Use of a single tensioner versus simultaneous use of multiple tensioners and the influence of each on the assembly procedure (see Nonmandatory Appendix O) (7) Effect of load losses (BLLF and NLLF) and elastic recovery (indicated tensioner in relation to final bolt load, need for overtension, and the effect of bolt grip-length to bolt diameter ratio; see section 9 and Nonmandatory Appendix Q, para. Q-4.1)
(e) Calibration and maintenance of powered equipment	(1) Requirements for maintenance of common hydraulic field equipment (2) Inspection of hydraulic hoses and cylinders (3) Familiarization with methods for calibrating common hydraulic field equipment (4) Importance and frequency of calibration

Table A-2.4-1
Heat Exchanger Endorsement Curriculum

Topics	Concepts Addressed
(a) Types of exchangers [Tubular Exchanger Manufacturers Association (TEMA) designations] and their joints	(1) Joint configurations, terminology, and locations (2) Gasket configurations for the different types of joints (3) Confined gaskets versus unconfined gaskets (4) Measurement of final joint gaps as a measure of success
(b) Bundle pushing and considerations for assembly	(1) Bundle and channel orientation to align piping and one or more pass-partition grooves (2) Risks during pushing (damage to the flange face or shell gasket)
(c) Tubesheet joint considerations, shell-side gasket damage, and recompression of shell-side gaskets on tube-sheet joints	(1) Second gasket compression (more assembly passes may be required) (2) Risks if the shell-side gasket seal is broken when the channel is removed (if the bundle is not being pulled) (3) Inspection of pass-partition surfaces (pass-partition flush with flange facing) (4) Consideration of tightening shoulder-type bolts from both sides (5) Gasket pass-partition alignment

A-3 EXAMINATION PROGRAM

A-3.1 Academic Examination

Trainees at and above skill level 2 shall demonstrate their academic understanding and knowledge of health, safety, quality, and technical procedures relevant to the assembly of bolted joints by completion of a written or online assessment. A separate set of examination questions will be required for each supplemental endorsement and should cover the topics detailed in paras. A-2.1 through A-2.5.

A-3.2 Practical Examination

Trainees at and above skill level 2 shall demonstrate their understanding of practical skills in the assembly of bolted joints by completing at least one bolted joint practical demonstration and witnessing the others (see paras. A-3.3.1 through A-3.3.3). The training of fundamentals demonstrations are designed to highlight significant aspects of the training curriculum and shall be performed in the presence of and to the satisfaction of the user and be administered and witnessed by a bolting trainer as defined in para. A-1.3.5.

The training of fundamentals demonstrations detailed in paras. A-3.3.1 through A-3.3.3 highlight several critical points of the joint assembly. The user may modify the demonstrations or substitute alternative demonstrations for specific joint types or gaskets, provided the bolting SME (see para. A-1.3.6) determines the desired learning points are still achieved.

A-3.3 Examples for Training of Fundamentals — Examination

A-3.3.1 Importance of Correct Pretightening Basic Skills. Perform the following on a flange test rig:

(a) Select the correct gasket, bolt and nut material, and lubricant.

(b) Install gasket, bolt and nut, and lubricant correctly.

A-3.3.2 Reaction of Different Types of Gaskets to Standard Tightening Procedure. Perform the following on a flange test rig having four or more bolts:

(a) Assemble a four-bolt flange with a polytetrafluoroethylene (PTFE) sheet gasket, small-diameter flange with a spiral-wound gasket without inner and outer rings using a tightening pattern and ensure the gasket is centrally located on the raised face. Monitor the bolt load, stress, or elongation during the tightening to see when it stabilizes (number of passes).

(b) Repeat (a) with a spiral-wound gasket with inner and outer rings.

(c) Repeat (a) with a corrugated or grooved-metal gasket that has graphite facing.

A-3.3.3 Demonstration of the Effect of Lubricants. Perform the following:

(a) Tighten a bolt using manual torque control with an instrumented bolt to measure the achieved bolt load.

(b) Assemble a bolt without lubricant to a torque value.

(c) Assemble the same bolt as in (b) with lubricant to the same torque value.

(d) Compare the different achieved bolt loads.

A-3.4 Piping Endorsement — Examination

The practical examination for a piping endorsement requires the trainee to use a manual torque wrench to satisfactorily assemble one or more of the following types of flange joint:

(a) raised-face flange

(b) RTJ

(c) flat-faced flange

A-3.5 Powered-Equipment Endorsement — Examination

A-3.5.1 Torque. The practical examination for a powered-equipment torque endorsement requires the trainee to use hydraulic, pneumatic, or electric-powered torque equipment to satisfactorily assemble flange joint types, including

(a) raised-face flange

(b) RTJ

A-3.5.2 Tension. The practical examination for a powered-equipment tension endorsement requires the trainee to use hydraulic bolt tensioning to satisfactorily assemble flange joint types, including

(a) raised-face flange

(b) RTJ

A-3.6 Heat Exchanger Endorsement — Examination

The practical examination for a heat exchanger endorsement requires the trainee to satisfactorily assemble either a simulated heat exchanger or a heat exchanger in the field under supervision. The exchanger joint configurations shall include

(a) tubesheet to shell

(b) bonnet or cover to tubesheet

(c) collar bolt

A-3.7 Special Joint Endorsement — Examination

The practical examination for a special joint endorsement should cover joints or components that have a proprietary design, including, but not limited to, expansion joints, isolated joints, compact flanges, hub or clamp connectors, and rupture disks or spectacle disks.

The practical examination requires the trainee to satisfactorily assemble the specific special joint.

Key learning objectives should include

(a) seal surface preparation

(b) the importance of alignment and gap uniformity

(c) gasket handling, preparation, and installation

(d) specific assembly steps, tooling, or procedures pertaining to the joint consideration

A-3.8 Skill-Level Evaluation

As recommended in para. A-1.1, skill-level evaluation should occur on a regular basis. Users who prefer to implement a periodic evaluation process should use both the academic and the practical parts of the examination process relevant to the individual's role, skill level, and any supplemental endorsements.

Individuals with legacy Appendix A training or qualification certificates should use the academic and practical examinations detailed within this Appendix to complete or update their certification.

A-4 QUALITY ASSURANCE

A-4.1 Program Manual

The employer should have a program manual that outlines how the program is administered and includes a reference to the training course syllabus, lesson plans, and examination documents. The program manual should form the basis for demonstration of compliance with this Appendix and with the training organization.

A-4.2 Program Records

The employer should maintain records of all training and assessments conducted in compliance with this Appendix for traceability purposes. These records should include copies of certification and examinations and a feedback process for review and monitoring of program effectiveness.

NONMANDATORY APPENDIX B
(22) DESCRIPTION OF COMMON TERMS

The definitions formerly in this Appendix have been moved to Mandatory Appendix I.

NONMANDATORY APPENDIX C
RECOMMENDED GASKET SEATING SURFACE FINISH FOR VARIOUS GASKET TYPES

(22)

See Table C-1.

Table C-1
Recommended Gasket Seating Surface Finish for Various Gasket Types

Gasket Description	Gasket Seating Surface Finish, μm (μin.) [Note (1)]
Spiral-wound	3.2–6.4 (125–250)
Soft-faced metal core with facing layers such as flexible graphite, PTFE, or other conformable materials	3.2–6.4 (125–250)
Flexible graphite reinforced with a metal interlayer insert	3.2–6.4 (125–250)
Grooved metal	1.6 max. (63 max.)
Flat solid metal	1.6 max. (63 max.)
Flat metal jacketed	2.5 max. (100 max.)
Soft cut sheet, thickness ≤1.5 mm (≤$^1/_{16}$ in.)	3.2–6.4 (125–250)
Soft cut sheet, thickness >1.5 mm (>$^1/_{16}$ in.)	3.2–13 (125–500)

NOTE: (1) Finishes listed are average surface roughness values and apply to either the serrated concentric or serrated spiral finish on the gasket seating surface of the flange.

NONMANDATORY APPENDIX D GUIDELINES FOR ALLOWABLE GASKET SEATING SURFACE FLATNESS AND DEFECT DEPTH

(22)

D-1 INTRODUCTION

The imperfections and flange flatness limits listed in this Appendix are intended as inspection guidance. If the limits are exceeded, then engineering judgment should be used to determine whether the particular defect is acceptable. Such determinations should consider factors such as the actual gasket construction, flange flexibility, bolt spacing, joint leakage history, and the risk associated with leakage.

D-2 FLANGE FACE FLATNESS TOLERANCES

A flatness check of the flange gasket seating surface is usually considered for large-diameter flanges, those with a history of leakage, or when it is desired to establish that the surface meets a particular flatness criterion.

The tolerances in Table D-2-1M/Table D-2-1 are dependent on the type of gasket employed and are categorized based on the expected axial deflection of the gasket at a typical target assembly stress.

Soft gaskets (see Mandatory Appendix I) are more tolerant of flange flatness imperfections but are typically more difficult to assemble. Hard gaskets (see Mandatory Appendix I) have less compression than soft gaskets and, while this can help with improved assembly due to less bolt interaction (cross-talk), it generally means that hard gaskets are more sensitive to flange flatness out-of-tolerance. It is suggested that load-compression test results for the gasket being used be obtained from the gasket manufacturer to determine which of the listed flatness tolerance limits should be employed. Some types of gaskets, such as expanded or microcellular PTFE, elastomers, and flexible graphite, with sufficient initial thickness and applied load, may provide suitable sealing performance to justify the use of larger tolerances (ref. [1]).

The highest and lowest measurements around the entire circumference of the gasket seating surface may be recorded and the differences between the two compared to the sum of the radial and circumferential limits stated in Table D-2-1M/Table D-2-1. Mating flanges that have only one possible alignment configuration may also be gauged to determine that any waviness of the flange faces is complimentary, such that the seating surfaces follow the same pattern. This is found in multipass exchanger joints and is often caused by thermal distortion. In this case, it is conservative to calculate the overall gaps between the flanges at points around the circumference and use the single-flange tolerances as shown in Table D-2-1M/Table D-2-1 to determine the acceptability of the gap.

D-3 FLANGE FACE IMPERFECTION TOLERANCES

The tolerances shown in Table D-3-1M/Table D-3-1 are separated into two categories, depending on whether a hard or a soft gasket is being used in the joint (see Mandatory Appendix I). Care should be taken to ensure the correct tolerances are employed for the gasket being installed. It is important to note that the tolerances apply to the gasket seating surface.

D-4 RTJ GASKETS

Flanges for RTJ gaskets are typically inspected for flange flatness and seating surface imperfections in a different manner than that for raised-face flanges. The flange flatness and groove dimensions are examined prior to joint disassembly by inspection of the gap between the outer edges of the raised faces. If the gap at any location around the joint circumference is less than 1.5 mm (0.062 in.), then consideration should be given to repair or remachining of the groove at the next opportunity. This eliminates the possibility of the flange faces touching during assembly, which can lead to joint leakage. Once the joint is disassembled, the gasket seating surface (see Figure D-4-1) should be inspected for damage in accordance with the requirements listed for hard gaskets in Table D-3-1M/Table D-3-1. In addition, the gasket groove may be inspected for cracking using a suitable inspection technology. Refer to ASME PCC-2, Article 305 for repair considerations.

D-5 REFERENCE

[1] Brown, W., "Background on the New ASME PCC-1 2010 Appendices D & O 'Guidelines for Allowable Gasket Contact Surface Flatness and Defect Depth' and 'Assembly Bolt Load Selection,' " ASME 2010 Pressure Vessels and Piping Conference, PVP2010-25766, Bellevue, WA, July 18-22, 2010, DOI: 10.1115/PVP2010-25766

Table D-2-1M
Flange Seating Face Flatness Tolerances (Metric)

Measurement	Hard Gaskets	Soft Gaskets
Acceptable variation in circumferential flange seating surface flatness	$T1 < 0.15$ mm	$T1 < 0.25$ mm
Acceptable variation in radial (across the surface) flange seating surface flatness	$T2 < 0.15$ mm	$T2 < 0.25$ mm
Maximum acceptable pass-partition surface height vs. flange face	-0.25 mm $< P < 0.0$ mm	-0.50 mm $< P < 0.0$ mm

GENERAL NOTE: See Figures D-2-1 and D-2-2 for the description of *T*1 and *T*2 measurement methods.

Table D-2-1
Flange Seating Face Flatness Tolerances (U.S. Customary)

Measurement	Hard Gaskets	Soft Gaskets
Acceptable variation in circumferential flange seating surface flatness	$T1 < 0.006$ in.	$T1 < 0.01$ in.
Acceptable variation in radial (across the surface) flange seating surface flatness	$T2 < 0.006$ in.	$T2 < 0.01$ in.
Maximum acceptable pass-partition surface height vs. flange face	-0.010 in. $< P < 0.0$ in.	-0.020 in. $< P < 0.0$ in.

GENERAL NOTE: See Figures D-2-1 and D-2-2 for the description of *T*1 and *T*2 measurement methods.

Figure D-2-1
Flange Circumferential Variation Tolerance, *T*1

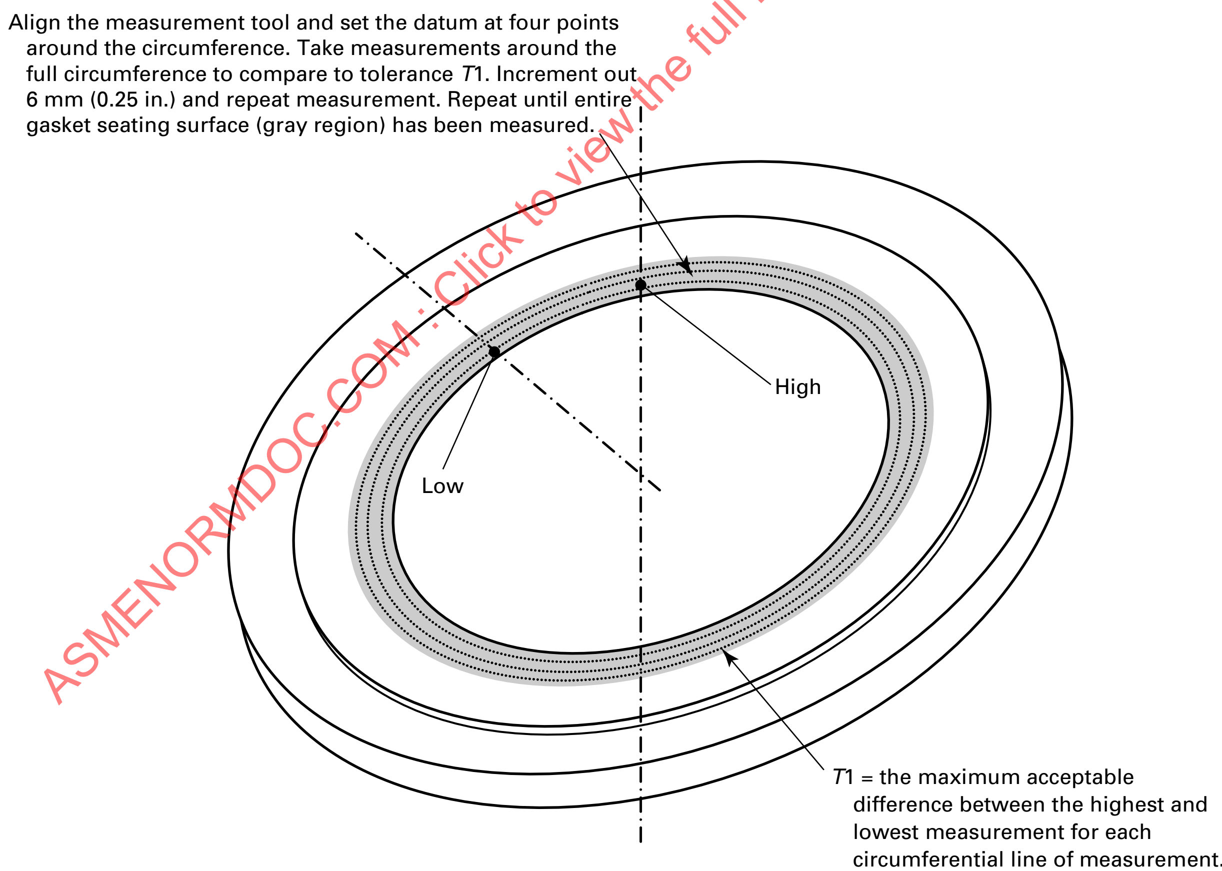


Figure D-2-2
Flange Radial Variation Tolerance, *T*2

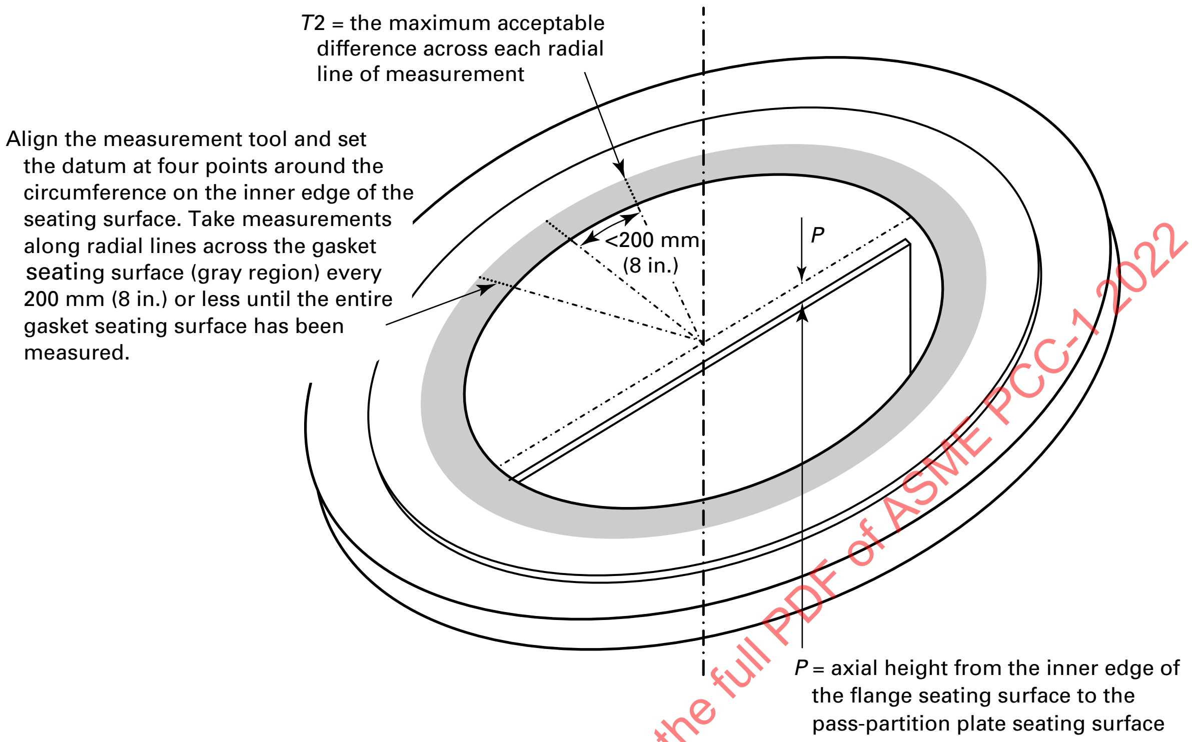


Table D-3-1M
Allowable Defect Depth vs. Width Across Face (Metric)

Measurement	Hard-Faced Gaskets	Soft-Faced Gaskets
$r_d < w/4$	<0.76 mm	<1.27 mm
$w/4 < r_d < w/2$	<0.25 mm	<0.76 mm
$w/2 < r_d < 3w/4$	Not allowed	<0.13 mm
$r_d > 3w/4$	Not allowed	Not allowed

GENERAL NOTES:
(a) See Figures D-3-1 and D-3-2 for the description of defect measurement and for the definition of *w*.
(b) Defect depth is measured from the peak of the surface finish to the bottom of the defect.

Table D-3-1
Allowable Defect Depth vs. Width Across Face (U.S. Customary)

Measurement	Hard-Faced Gaskets	Soft-Faced Gaskets
$r_d < w/4$	<0.030 in.	<0.050 in.
$w/4 < r_d < w/2$	<0.010 in.	<0.030 in.
$w/2 < r_d < 3w/4$	Not allowed	<0.005 in.
$r_d > 3w/4$	Not allowed	Not allowed

GENERAL NOTES:
(a) See Figures D-3-1 and D-3-2 for the description of defect measurement and for the definition of *w*.
(b) Defect depth is measured from the peak of the surface finish to the bottom of the defect.

Figure D-3-1
Flange Surface Damage Assessment: Pits and Dents

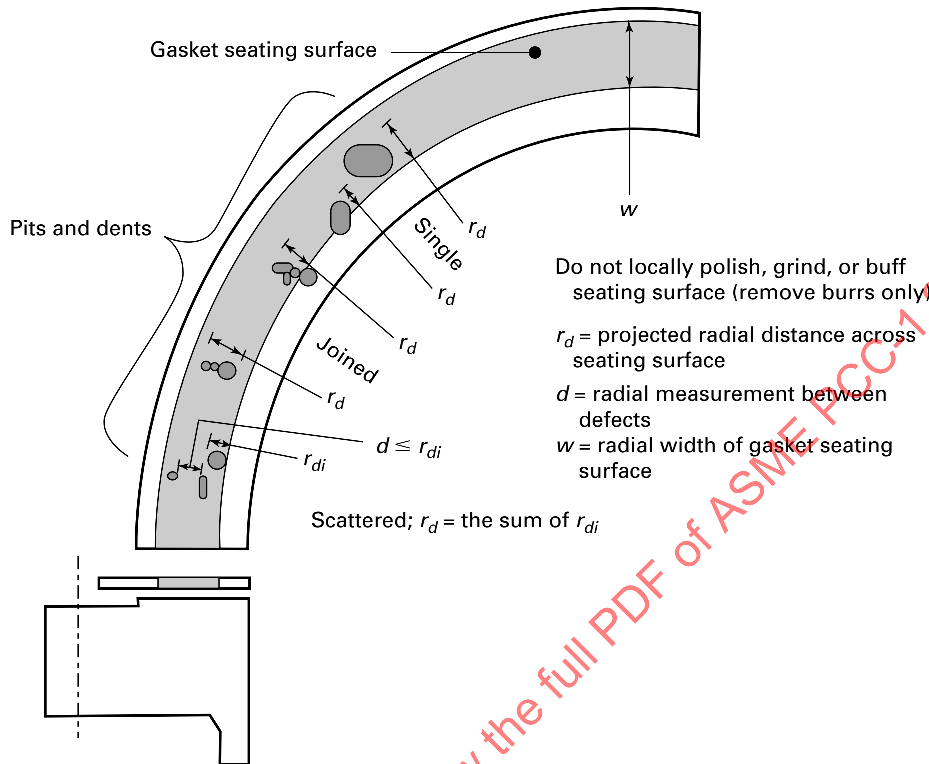


Figure D-3-2
Flange Surface Damage Assessment: Scratches and Gouges

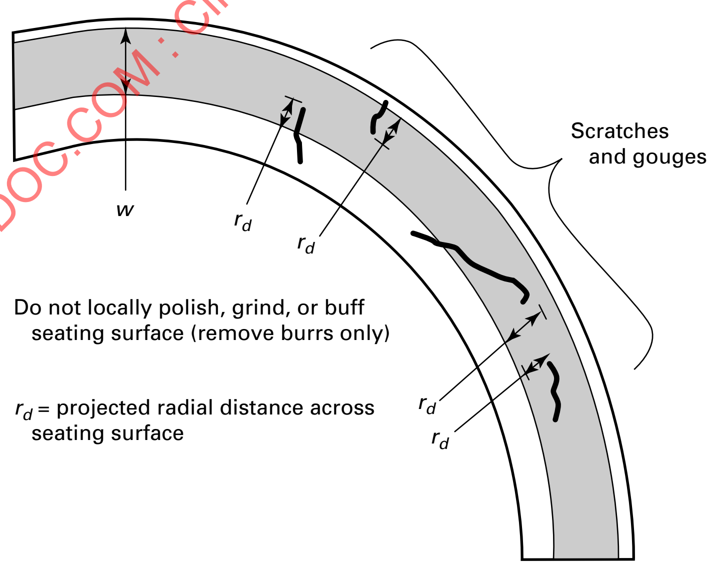
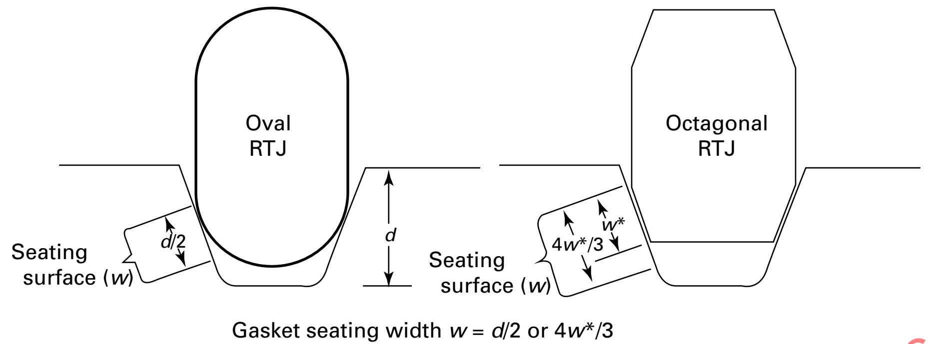


Figure D-4-1
RTJ Gasket Seating Surface Assessment



NONMANDATORY APPENDIX E FLANGE JOINT ALIGNMENT GUIDELINES

(22)

E-1 CHECKS, MEASUREMENTS, OR VERIFICATIONS

(a) Specify the necessary sequence of the alignment procedure and any checks, measurements, or verifications during the alignment process.

(b) See Nonmandatory Appendix J, section J-2 for the final joint alignment assessment.

E-2 VERIFICATION METHODS AND TOLERANCES

(a) For machinery, refer to API Recommended Practice (RP) 686, Chapter 6, Sections 4.6 through 4.9 and Figure B-4 for acceptable alignment tolerances.

(b) WRC Bulletin 449, para. 1.2.2 covers stringent alignment tolerances that apply to critically stiff (as described in WRC Bulletin 449) piping systems, such as rotating equipment nozzles.

(c) Centerline (CL) tolerance should be measured at four locations, each approximately 90 deg apart on the flange. Hold a straight edge parallel to the axis of one flange and flush with the outside diameter (O.D.). Extend the straight edge to the adjoining flange and measure the distance from the straight edge surface to the same surface on the adjoining flange (see Figure E-2-1).

(d) Gap (GP) tolerance is a measurement of the spacing between the seating surfaces (see Figure E-2-2).

(e) Parallelism (PRL) tolerance is a measurement defining the uniformity of distance between the sealing surfaces of two flange faces. PRL tolerance is calculated as the difference between the largest and smallest distance between the two sealing surfaces at the sealing surface O.D. (see Figure E-2-3).

(f) Rotational two-hole (RTH) ensures the flange holes are rotationally aligned to one another such that fasteners can be installed perpendicular to both flanges. Measure RTH by confirming the hole centers are aligned (see Figure E-2-4).

(g) For common alignment tolerances, see Table E-2-1.

E-3 ALIGNMENT METHODS AND TOOLS

(a) Specify acceptable tools and methods for correcting misaligned flanges.

(b) Flanges that cannot be aligned with accepted alignment methods and tools should be evaluated and replaced if necessary. For misalignments on piping systems larger than DN 450 (NPS 18), consider the special guidelines of WRC Bulletin 449, para. 1.2.3 concerning the modification or rebuilding of a portion of the system.

(c) Flanges such as blind flanges and tube bundles not attached to external piping or components can be aligned with sufficient support or force.

(d) When external alignment devices are used, flanges should be brought into uniform contact with the uncompressed gasket face using a maximum of 10% of the total target assembly bolt load. No single bolt should be tightened above 20% of the single target bolt load.

(e) When no external alignment devices are used, flanges should meet the alignment tolerances for PRL and GP (see Table E-2-1 and Figure E-2-3) using a maximum of 20% of the total target assembly bolt load.

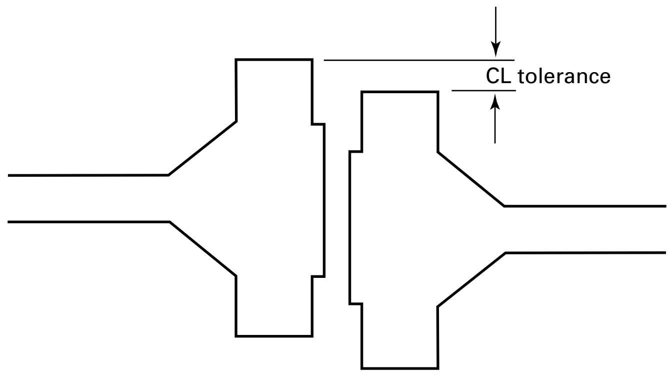
E-4 ENGINEERING EVALUATION

(a) When the alignment of flanges requires more force than can be exerted by hand or common hand and hammer alignment tools, such as spud wrenches and alignment pins, engineering should be consulted.

(b) For alignment of flanges connected to pumps or rotating equipment, care should be taken to prevent the introduction of strain into the equipment housing or bearings (see API RP 686).

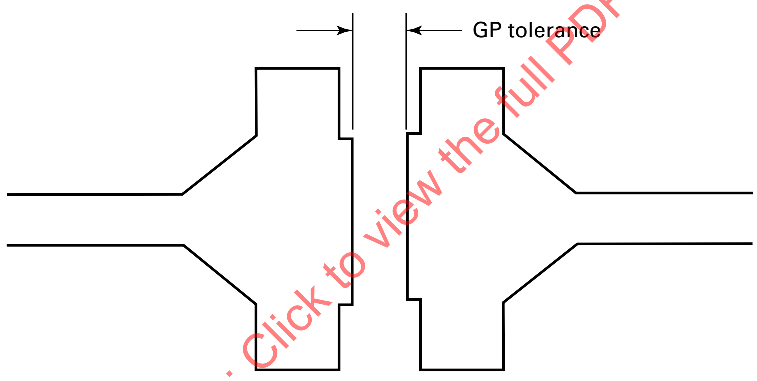
(c) If excessive force is required to bring flange gaps into compliance, a pipe stress analysis should be considered, especially if it is suspected the walls have thinned or the piping has been modified from the original design.

Figure E-2-1
Centerline High/Low



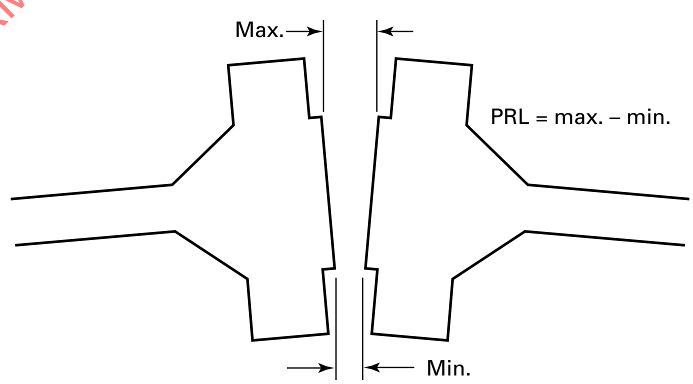
GENERAL NOTE: See para. E-2(c).

Figure E-2-2
Excessive Spacing Gap



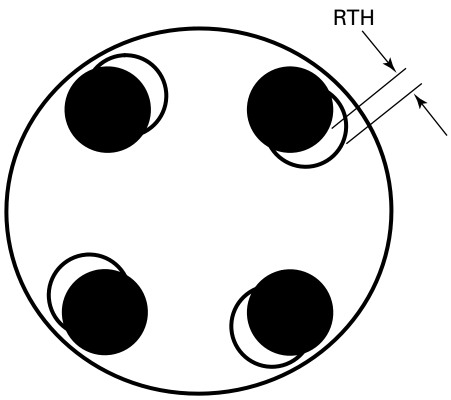
GENERAL NOTE: See para. E-2(d).

Figure E-2-3
Parallelism



GENERAL NOTE: See para. E-2(e).

Figure E-2-4
Rotational Two-Hole



GENERAL NOTE: See para. E-2(f).

Table E-2-1
Common Alignment Tolerances

Property	Maximum Tolerance, mm (in.) [Note (1)]
CL	1.5 ($^1/_{16}$)
GP	Gasket thickness × 2
PRL	0.8 ($^1/_{32}$)
RTH	3 ($^1/_8$)

NOTE: (1) These common alignment tolerances are to be used with section E-3 and Figures E-2-1 through E-2-4.

NONMANDATORY APPENDIX F
(22) # JOINT-TIGHTENING PRACTICES AND PATTERNS

F-1 INTRODUCTION

Tightening practices depend on the target bolt stress (see Nonmandatory Appendix O) and tightening method, including load control and tool selection. User-accepted patterns and practices should also include load verification or experience.

The patterns in para. F-6.1 have received wide acceptance in the industry for their performance as proven patterns. These patterns may be modified based on user experience. However, new patterns should be verified as acceptable by the user. New patterns should be developed using measurement of key indicators of assembly effectiveness, such as sealing performance, residual bolt load, uniformity of gasket compression, assembly effort, or complexity (ref. [1]). Hydrostatic testing does not provide sufficient evidence to confirm an assembly procedure's effectiveness.

The applicability of a pattern may or may not be transferable to other facilities or applications. The user should use sound engineering practice and judgment to determine a specific pattern's applicability to a given application.

Users should review the following cautions and concerns with the use of any alternative assembly patterns:

(a) localized overcompression of the gasket
(b) uneven tightening resulting in flange distortion or gasket compression
(c) nonuniform application of gasket seating load
(d) excessive load or unloading of the gasket during assembly
(e) resulting nonparallel flanges

F-2 BOLT-LOAD CONTROL

Load control is applying a determined amount of force during the tightening process. Common load-control methods include torque, tension, and turn-of-nut, a prescribed amount of nut rotation. The use of impact wrenches is an example of uncontrolled turning.

The user should determine the target assembly bolt stress and target torque. Nonmandatory Appendix O provides guidance on computing assembly bolt stress. Other acceptable sources for bolt stress calculation include target torque or load values from equipment manufacturers, the user's existing procedures, and industry-recognized bolting standards.

Turn-of-nut is generally used for adjusting previously tightened bolts or for live tightening and is not usually used for initial assembly (see Mandatory Appendix I). Torque turn does not depend on a K-factor, requires the back nut not to turn, and is an alternative method for otherwise inaccessible bolts.

F-3 BOLT-LOAD VERIFICATION

The user should decide the levels of tightening controls and verification the assembler should apply to any particular joint or group of joints to be tightened.

Load verification involves an additional step to confirm the desired bolt load. Load-verification methods include bolt elongation and direct load measurement.

Bolt elongation measurement (see Nonmandatory Appendix J, section J-3) is a way to verify bolt stress; it typically requires temperature monitoring and measurement of the bolts both before and after tightening. It also requires specially prepared bolts, measuring equipment, a knowledgeable operator, and a calibrated micrometer or ultrasonic measurement equipment.

Load cells or other proprietary devices can make direct load measurements. Load cells can provide real-time feedback but may have temperature limitations. There are various load-sensing devices that the user may select based on the specific situation. Most direct load measurement methods depend on operator training and calibration.

F-4 TIGHTENING PRACTICES

Not all pressure boundary bolted joints demand the same level of systematic care and scrutiny. Table F-4-1 shows examples of tightening methods and load-control techniques based on the service application. Users should consider the risks (safety, environmental, financial) associated with potential joint failure according to the service category of the joint under consideration. The user should also consider the history of the joint and the likelihood of leakage (see Nonmandatory Appendix O).

Table F-4-1
Example Tightening Practices Based on Service Application

Service Application	Tools	Tightening Method	Load-Control Technique
Mild	Manual or auxiliary-powered tools	Single- or multitool tightening patterns	Consistent procedures per industry best practices or torque control
Intermediate	Manual or auxiliary-powered tools or torque- or tension-measuring tools	Single- or multitool tightening patterns	Torque or tension control
Critical	Torque- or tension-measuring tools	Single- or multitool tightening patterns	Torque or tension control User specifies requirements for final bolt elongation/load verification

F-5 TOOL SELECTION FOR LOAD CONTROL

(a) Users should select the tooling to ensure it meets the safety, accuracy, repeatability, and efficiency goals. Tool selection should consider the assembly procedures, lubrication, joint component conditions, specific material properties, stud load requirements, proper calibration and maintenance of the tool, and bolting assembler training and competency.

(b) Hand-operated torque wrenches are generally practical for bolts 25 mm (1 in.) in diameter or less or bolts with assembly torque less than 680 N·m (500 ft-lb).

(c) Powered torque and tensioning tools are available to create bolt preload. (See Nonmandatory Appendix A for guidance on training for the proper handling of powered equipment.)

(d) Proprietary devices that create or measure applied torque or achieved loads may also be part of the tooling decision.

F-6 TIGHTENING PATTERNS

Users should select a tightening pattern that uses a sequence with passes that counters elastic interaction effects. The term "sequence" refers to the numbering protocol used to indicate the bolts' tightening order. The term "passes" refers to the incremental loading and tightening steps leading to the assembly target bolt stress. The term "pattern" refers to the application of passes in a specified sequence. The patterns listed in this Appendix demonstrate efficiency by less tool movement (torque values quickly step up).

The patterns in this Appendix

(a) provide experience-proven examples that may be followed with confidence on most applications, avoiding unproductive experimentation or trial-and-error

(b) demonstrate how past patterns may be accelerated by some combination of

(1) eliminating the need to tighten every bolt in every pass

(2) accelerating the target torque values between passes

(c) have advantages and disadvantages when applied to certain types of flange joints

All of the patterns discussed in this Appendix involve incremental tightening in steps expressed as percentages of target torque. The percentage values assigned to these intermediate passes are acceptable ranges and are not exact or required point values. Multiple tools can be used with all these patterns to increase assembly efficiency and tool movement. However, using more than four tools is not in the scope of this Appendix.

F-6.1 Torque Tightening Patterns

This Appendix presents multiple proven torque tightening patterns. The traditional Star Pattern is a gradual and conservative pattern that applies the same torque to every bolt on each pass. This controlled approach may render more even loading of highly compressible gaskets and reduce the potential for damage to thin, nonstandard, or fragile flanges. The other patterns described in this Appendix speed up the assembly process by reducing the number of bolts touched at the same torque value per pass and accelerating the percentage of target torque applied per pass. In addition to less effort, these patterns have been found to result in improved gasket compression for typical industry gaskets and are, therefore, preferred (ref. [2]). See Nonmandatory Appendix J, section J-5 for information on bolt grouping for flanges with large amounts of studs.

F-6.1.1 Pattern #1 — Star Pattern. Referred to as the Legacy Pattern in previous editions of ASME PCC-1, the Star Pattern was historically the industry's most-used tightening pattern. While assemblers are familiar with this pattern, it is the most conservative of the bolting patterns listed in ASME PCC-1 because it touches every bolt at the same torque value on each pass.

F-6.1.1.1 Sequence. Table F-6.1.1.1-1 involves marking the tightening sequence number in the correct order on the flange so the assembler can follow tool movement.

Establish one primary method of marking the tightening sequence on a given flange. It is recommended to use Table F-6.1.1.1-1 to mark the bolt-tightening sequence so that a separate reference table is not required during the

Table F-6.1.1.1-1
Star and Modified Star Pattern Sequencing

No. of Bolts	Bolt-Numbering Sequence to Be Marked Clockwise on the Flange
4	1, 3, 2, 4
8	1, 5, 3, 7, 2, 6, 4, 8
12	1, 9, 5, 3, 11, 7, 2, 10, 6, 4, 12, 8
16	1, 9, 5, 13, 3, 11, 7, 15, 2, 10, 6, 14, 4, 12, 8, 16
20	1, 17, 9, 5, 13, 3, 19, 11, 7, 15, 2, 18, 10, 6, 14, 4, 20, 12, 8, 16
24	1, 17, 9, 5, 13, 21, 3, 19, 11, 7, 15, 23, 2, 18, 10, 6, 14, 22, 4, 20, 12, 8, 16, 24
28	1, 25, 17, 9, 5, 13, 21, 3, 27, 19, 11, 7, 15, 23, 2, 26, 18, 10, 6, 14, 22, 4, 28, 20, 12, 8, 16, 24
32	1, 25, 17, 9, 5, 13, 21, 29, 3, 27, 19, 11, 7, 15, 23, 31, 2, 26, 18, 10, 6, 14, 22, 30, 4, 28, 20, 12, 8, 16, 24, 32
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72	1, 65, 57, 49, 41, 33, 25, 17, 9, 5, 13, 21, 29, 37, 45, 53, 61, 69, 3, 67, 59, 51, 43, 35, 27, 19, 11, 7, 15, 23, 31, 39, 47, 55, 63, 71, 2, 66, 58, 50, 42, 34, 26, 18, 10, 6, 14, 22, 30, 38, 46, 54, 62, 70, 4, 68, 60, 52, 44, 36, 28, 20, 12, 8, 16, 24, 32, 40, 48, 56, 64, 72
76	1, 73, 65, 57, 49, 41, 33, 25, 17, 9, 5, 13, 21, 29, 37, 45, 53, 61, 69, 3, 75, 67, 59, 51, 43, 35, 27, 19, 11, 7, 15, 23, 31, 39, 47, 55, 63, 71, 2, 74, 66, 58, 50, 42, 34, 26, 18, 10, 6, 14, 22, 30, 38, 46, 54, 62, 70, 4, 76, 68, 60, 52, 44, 36, 28, 20, 12, 8, 16, 24, 32, 40, 48, 56, 64, 72
80	1, 73, 65, 57, 49, 41, 33, 25, 17, 9, 5, 13, 21, 29, 37, 45, 53, 61, 69, 77, 3, 75, 67, 59, 51, 43, 35, 27, 19, 11, 7, 15, 23, 31, 39, 47, 55, 63, 71, 79, 2, 74, 66, 58, 50, 42, 34, 26, 18, 10, 6, 14, 22, 30, 38, 46, 54, 62, 70, 78, 4, 76, 68, 60, 52, 44, 36, 28, 20, 12, 8, 16, 24, 32, 40, 48, 56, 64, 72, 80
84	1, 81, 73, 65, 57, 49, 41, 33, 25, 17, 9, 5, 13, 21, 29, 37, 45, 53, 61, 69, 77, 3, 83, 75, 67, 59, 51, 43, 35, 27, 19, 11, 7, 15, 23, 31, 39, 47, 55, 63, 71, 79, 2, 82, 74, 66, 58, 50, 42, 34, 26, 18, 10, 6, 14, 22, 30, 38, 46, 54, 62, 70, 78, 4, 84, 76, 68, 60, 52, 44, 36, 28, 20, 12, 8, 16, 24, 32, 40, 48, 56, 64, 72, 80
88	1, 81, 73, 65, 57, 49, 41, 33, 25, 17, 9, 5, 13, 21, 29, 37, 45, 53, 61, 69, 77, 85, 3, 83, 75, 67, 59, 51, 43, 35, 27, 19, 11, 7, 15, 23, 31, 39, 47, 55, 63, 71, 79, 87, 2, 82, 74, 66, 58, 50, 42, 34, 26, 18, 10, 6, 14, 22, 30, 38, 46, 54, 62, 70, 78, 86, 4, 84, 76, 68, 60, 52, 44, 36, 28, 20, 12, 8, 16, 24, 32, 40, 48, 56, 64, 72, 80, 88

tightening process. Maintaining two numbering systems on the same flange may confuse assemblers.

Nonmandatory Appendix J, Table J-6-1 is identical to a table in a previous edition (ASME PCC-1–2019, Table 3). This table refers to a Legacy Cross-Pattern numbering system. This numbering system allows, e.g., the quick identification of bolt number 20 in a 40-bolt flange but requires Table 3 as a reference for the tightening sequence during the tightening process. Numbering the bolts in a clockwise order can also help reference leak locations.

Nonmandatory Appendix J, Figure J-5-1 is identical to a figure in a previous edition (ASME PCC-1–2019, Figure 4). This figure has information on grouping bolts for flanges with a large number of bolts.

F-6.1.1.2 Passes. There are two options for applying the passes with the Star Pattern. Option 1 applies the traditional sequence and passes. Option 2 is the Modified Star Pattern as it requires tightening fewer bolts per pass, which has the advantage of resulting in more uniform gasket compression as the residual gasket stress upon commencement of the circular passes is substantially higher.

NOTE: When the flange consists of soft or soft-faced gaskets (see Mandatory Appendix I), they may be more susceptible to damage. Therefore a gap measurement is recommended during the assembly process. (See also section F-8 for additional guidance on highly compressible gaskets.)

F-6.1.1.2.1 Option 1 — Star Pattern. The Star Pattern follows a prescribed tightening sequence as set in Table F-6.1.1.1-1, and progressive tightening passes as outlined in (a) through (c).

(a) Mark the tightening sequence numbers (per Table F-6.1.1.1-1) on the flange, beginning with the bolt at an arbitrary 12 o'clock position.

(b) After numbering the bolts, it is no longer necessary for the assembler to have a copy of Table F-6.1.1.1-1 in hand.

(c) Following the sequence numbers as marked per (a), tighten each bolt as described in (1) through (4) below. See also Figure F-6.1.1.2.1-1.

(1) Pass #1. All bolts in sequence to 20% to 30% of the target torque

(2) Pass #2. All bolts in sequence to 50% to 70% of the target torque

(3) Pass #3. All bolts in sequence to 100% of the target torque

(4) Check Pass. All bolts in circular order at 100% of target torque until there is no further nut rotation

F-6.1.1.2.2 Option 2 — Modified Star Pattern. The Modified Star Pattern is an accelerated version of the Star Pattern. The Modified Star Pattern involves touching fewer bolts in the early passes and simultaneously increasing the target torque in each pass. See Figure F-6.1.1.2.2-1.

(a) Mark the tightening sequence numbers using the same procedure as the basic Star Pattern from Table F-6.1.1.1-1.

(b) Following the sequence numbers as marked per (a), tighten each bolt as described in (1) through (5) below.

(1) Pass #1. 20% to 30% of target torque on bolts numbered 1 to 4

(2) Pass #2. 50% to 70% of target torque on bolts numbered 5 to 8

(3) Pass #3. 100% of target torque on the remaining bolts in the sequence

(4) Pass #4. 100% of target torque on all bolts in the sequence may be required for soft gaskets (see Mandatory Appendix I); also recommended for problematic joints

(5) Check Pass. 100% of target torque on all bolts using a rotational or circular sequence until there is no further nut rotation

Figure F-6.1.1.2.2-2 shows an example of how to use multiple tools with the Modified Star Pattern.

F-6.1.2 Pattern #2 — Quadrant Pattern. The Quadrant Pattern has been successful in applications across the full range of gaskets and joint configurations. The Quadrant Pattern speeds assembly efficiency by

(a) reducing sequence marking time

(b) tightening only selected bolts in the initial pass

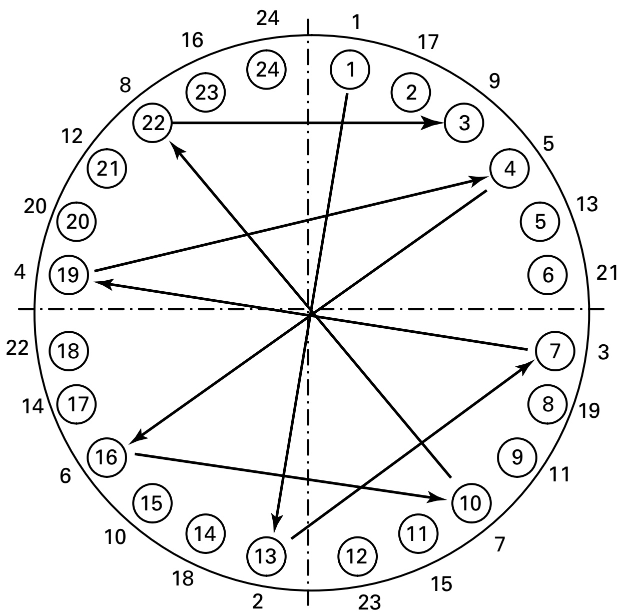
(c) rapidly increasing the torques applied in subsequent passes to the final values

F-6.1.2.1 Sequence. There are two options for the numbering sequence with the Quadrant Pattern (see Figure F-6.1.2.1-1). Option 1 (cross sequence) requires numbering the bolts as would occur in a cross sequence, while Option 2 (circular sequence) numbers the quadrants in a circular manner (effectively swapping quadrants 2 and 3 when compared to the cross sequence). The quadrant circular sequence allows for optimal assembler efficiency by eliminating unnecessary tool movement but is only suitable for joints with 15 or more bolts. It has the advantage of eliminating the need to number the bolts, since the next bolt to be assembled is the first loose bolt in each quadrant.

F-6.1.2.1.1 Option 1 — Cross Sequence. Number four primary bolts as follows: mark the bolt at the 12 o'clock position #1, the bolt at the 3 o'clock position #3, the bolt at the 6 o'clock position #2, and the bolt at the 9 o'clock position #4. For each of the four primary bolts, mark the adjacent bolt in the clockwise direction by adding 4 to the previous bolt number until the next primary bolt is reached. Table F-6.1.2.1.1-1 provides a tightening sequence chart that follows the cross sequence numbering.

F-6.1.2.1.2 Option 2 — Circular Sequence. Number the four primary bolts as follows: mark the bolt at the 12 o'clock position #1, the bolt at the

Figure F-6.1.1.2.1-1
Pattern #1 (Star Pattern): 24-Bolt Basic Example



GENERAL NOTE: Outer numbers indicate the tightening sequence.

3 o'clock position #2, the bolt at the 6 o'clock position #3, and the bolt at the 9 o'clock position #4. For each of the four primary bolts, mark the adjacent bolt in the clockwise direction by adding 4 to the previous number until the next primary bolt is reached. Table F-6.1.2.1.2-1 provides a tightening sequence chart that follows the circular sequence numbering.

F-6.1.2.2 Passes. Tighten each bolt as described in (a) through (e) below. See Figure F-6.1.2.2-1.

(a) Pass #1. 20% to 30% of target torque on bolts numbered 1 through 4.

(b) Pass #2. 50% to 70% of target torque on bolts numbered 5 through 8.

(c) Pass #3. 100% of target torque on the remaining bolts in the sequence.

(d) Pass #4. 100% of target torque on all bolts in the sequence may be required for soft gaskets such as spiral-wound and double-jacketed gaskets or problematic joints.

(e) Check Pass. All bolts in circular order at 100% of target torque until there is no further nut rotation.

F-6.1.3 Pattern #3 — Circular Pattern. The Circular Pattern consists of initially tightening only four bolts to align the joint and begin seating the gasket before commencing circular passes. It is much simpler and requires less tool movement. This pattern lends itself best to applications using hard gaskets (see Mandatory Appendix I). It is generally not recommended for gaskets susceptible to damage from uneven loading (see sections F-8 and F-9).

This method has been successfully used in limited applications using harder gaskets in joint configurations. The Circular Pattern is suitable for soft gaskets but might not be suitable for highly compressible gaskets (ref. [3]).

F-6.1.3.1 Sequence. Number the bolt at the 12 o'clock position #1, the bolt at the 3 o'clock position #3, the bolt at the 6 o'clock position #2, and the bolt at the 9 o'clock position #4. See Figure F-6.1.3.1-1.

F-6.1.3.2 Passes. Following the sequence numbers, tighten each bolt as described in (a) through (d) below. See Figure F-6.1.3.2-1.

(a) Pass #1. Tighten the four marked bolts in sequence to 20% to 30% of target torque.

(b) Pass #2. Repeat tightening the same four marked bolts in sequence to 50% to 70% of target torque.

(c) Pass #3. Repeat tightening the same four marked bolts in sequence to 100% of target torque.

(d) Check Pass #4. Starting at the bolt marked #1, torque all bolts to 100% of target torque using a rotational or circular sequence until there is no further nut rotation.

F-6.1.3.3 Circular Pattern With Multiple Tools. Introducing multiple tools into the Circular Pattern extends this pattern's usage to softer, more highly compressible gaskets. See Figure F-6.1.3.3-1 for an example of two tools being used to tighten the flange.

F-6.2 Tension Tightening Patterns

See Nonmandatory Appendix Q.

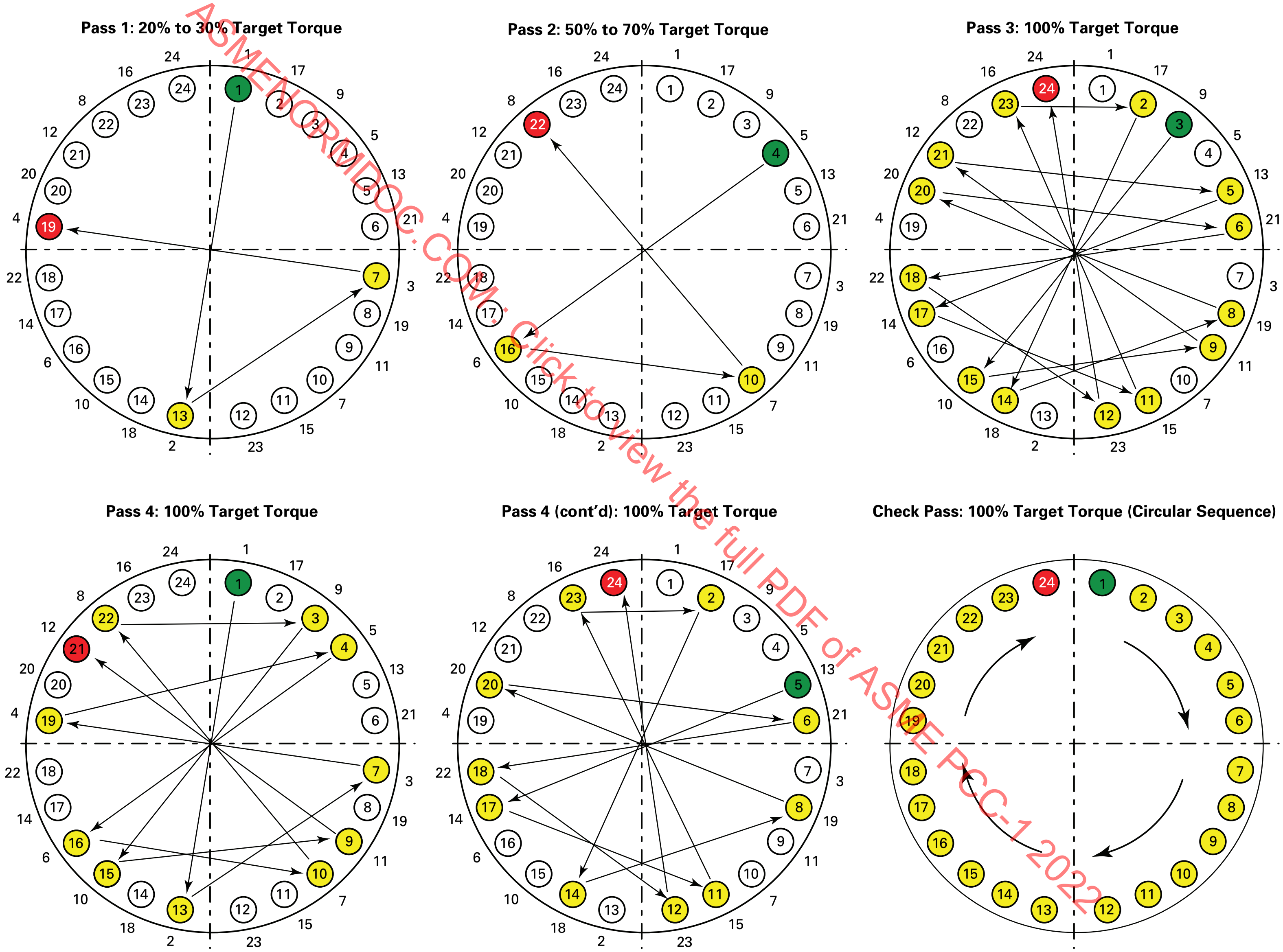
F-7 DEVELOPING NEW PROCEDURES

The procedures contained in sections F-1 through F-6 are not intended to be all-encompassing or to limit the development of application-specific alternative procedures. New alternative procedures may be developed that may be more effective and result in better sealing performance or less assembly effort for a given application. However, caution should be used in accepting new assembly procedures. There are, generally, two viable options for accepting bolted joint assembly procedures that are not listed in these guidelines.

(a) Option 1 is to use the procedure and learn if it works by experience.

This is difficult to implement across the industry because it requires people who closely monitor their bolting success rate and are able to differentiate between bolting procedure–induced failure and other causes of failure (incorrect flange design, incorrect bolt load specification, incorrect gasket selection, incorrect bolt assembly, etc.). Successful completion of a hydrostatic test is not considered sufficient evidence to confirm the acceptability of an assembly procedure. Bolting contractors may not have sufficient knowledge of the long-term

Figure F-6.1.1.2.2-1
Pattern #1 (Star Pattern): 24-Bolt Modified Star Example



GENERAL NOTE: Outer numbers indicate the tightening sequence.

Figure F-6.1.1.2.2-2
Modified Star Pattern With Multiple Tools

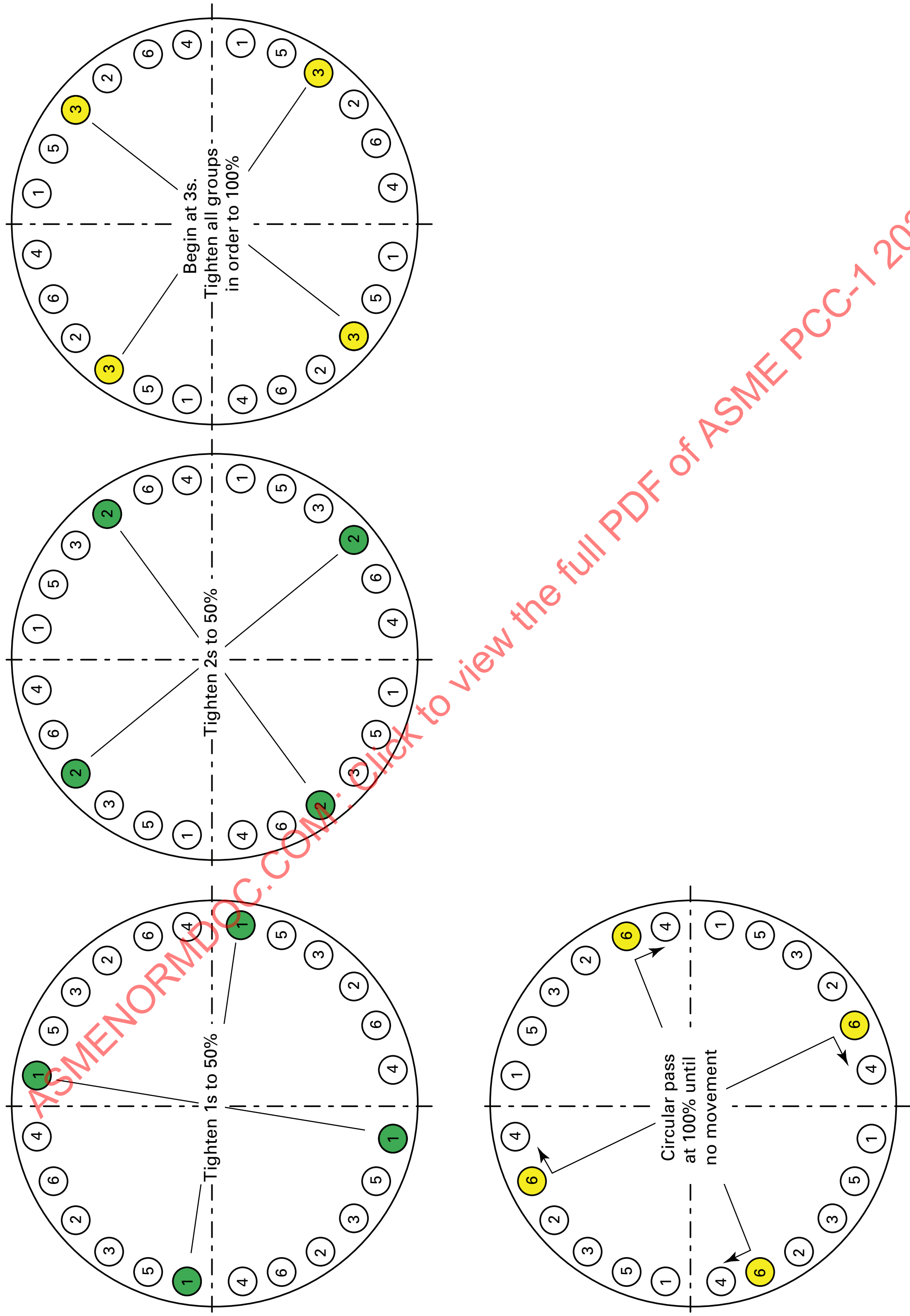
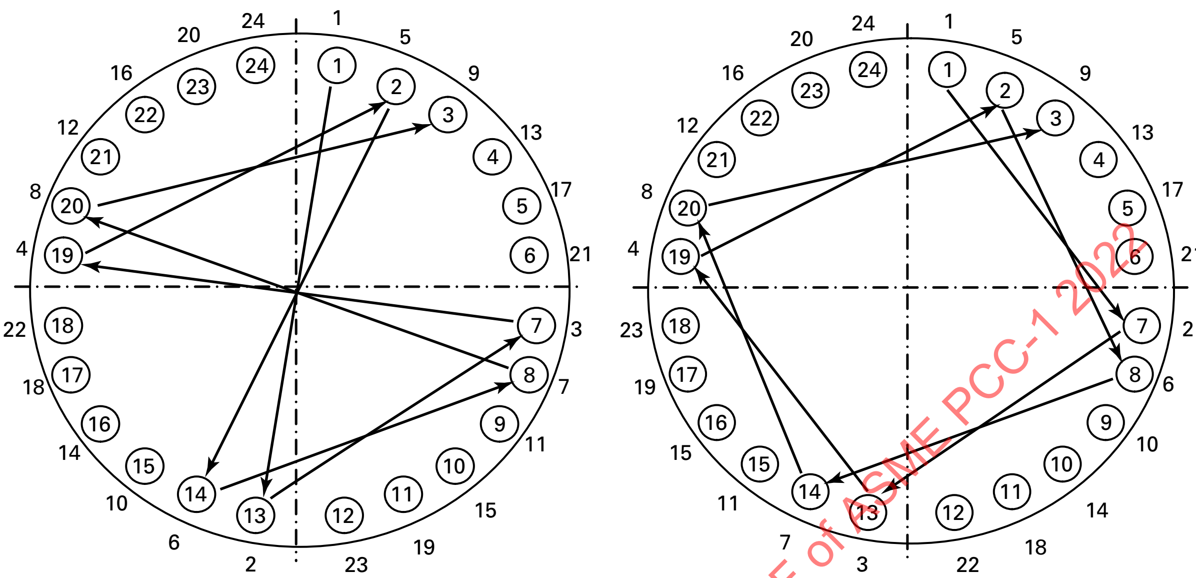


Figure F-6.1.2.1-1
Pattern #2 (Quadrant Pattern): 24-Bolt Examples



(a) Option 1: Quadrant Cross Pattern **(b) Option 2: Quadrant Circular Pattern**

GENERAL NOTE: Outer numbers indicate the tightening sequence.

operating success of their procedure to be able to comment on the applicability of the procedure to a given application.

Implementing a new procedure to "see if it works" should be done with caution and may not be an option, as the consequences of failure will usually outweigh any advantage gained. Another possibility to implement this option is to use a bolting contractor's or other facility's experience to prove the method works (this often means relying on secondhand information). However, this process also requires the input of someone knowledgeable enough to determine if the experience in the other facilities will translate into your facility. The user is required to determine if his particular application is within the limits of the procedure.

(b) Option 2 is to test a proposed procedure in an experimental setting and to measure certain parameters (such as uniformity of bolt preload; even gasket compression; and physical damage to the gaskets, flanges, and bolts) versus defined pass–fail criteria. Limitations of applying the experimental results to facility applications and comparison to existing procedures (see section F-1) should be considered.

Many facilities are successfully using alternative procedures developed over time and thereby are reducing their workload considerably, but over a limited range of gasket and flange types and operating conditions. Their experience and the applicability of the procedure may or may not be transferable to other facilities and applications. Sound engineering practice and judgment should be used to determine the applicability of a specific procedure or part of a procedure to a given application.

F-8 RTJ AND LENS-TYPE GASKETS

RTJ and lens-type gaskets have additional considerations that should be accounted for when determining the assembly sequence to use. The axial movement of the flanges is significant for these gasket types. Also, they are sensitive to flange misalignment either before or during joint assembly. Due to a large amount of axial movement of the flanges during assembly, the elastic interaction is significant. Therefore, it is necessary to perform multiple pattern passes to ensure uniform joint closure. These joints typically require multiple final circular passes to ensure the desired target load.

For large-diameter RTJ flanges (>NPS 12), this may mean performing four pattern passes and six or more circular passes.

A significant advantage of fewer passes is possible if using multiple tightening heads (two, four, or more) to tighten bolts on the joint simultaneously. This process has the effect of bringing the joint together more uniformly and reducing mechanical interaction. Gap measurement between the outer diameter of the raised faces or flange is recommended (see Nonmandatory Appendix J, section J-2). The reduction in the gap should be

Table F-6.1.2.1.1-1
Quadrant Pattern Cross Sequence

No. of Bolts	Bolt-Numbering Sequence to Be Marked Clockwise on the Flange [Note (1)]
4	1, 3, 2, 4
8	1, 5, 3, 7, 2, 6, 4, 8
12	1, 5, 9, 3, 7, 11, 2, 6, 10, 4, 8, 12
16	1, 5, 9, 13, 3, 7, 11, 15, 2, 6, 10, 14, 4, 8, 12, 16
20	1, 5, 9, 13, 17, 3, 7, 11, 15, 19, 2, 6, 10, 14, 18, 4, 8, 12, 16, 20
24	1, 5, 9, 13, 17, 21, 3, 7, 11, 15, 19, 23, 2, 6, 10, 14, 18, 22, 4, 8, 12, 16, 20, 24
28	1, 5, 9, 13, 17, 21, 25, 3, 7, 11, 15, 19, 23, 27, 2, 6, 10, 14, 18, 22, 26, 4, 8, 12, 16, 20, 24, 28
32	1, 5, 9, 13, 17, 21, 25, 29, 3, 7, 11, 15, 19, 23, 27, 31, 2, 6, 10, 14, 18, 22, 26, 30, 4, 8, 12, 16, 20, 24, 28, 32
36	1, 5, 9, 13, 17, 21, 25, 29, 33, 3, 7, 11, 15, 19, 23, 27, 31, 35, 2, 6, 10, 14, 18, 22, 26, 30, 34, 4, 8, 12, 16, 20, 24, 28, 32, 36
40	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40
44	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44
48	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48
52	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52
56	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56
60	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60
64	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64
68	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68
72	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72
76	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 75, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76
80	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 77, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 75, 79, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 78, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76, 80
84	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 77, 81, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 75, 79, 83, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 78, 82, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76, 80, 84
88	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 77, 81, 85, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 75, 79, 83, 87, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 78, 82, 86, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76, 80, 84, 88

NOTE: (1) This sequence was established using the following procedure:

(a) Establish the reference locations corresponding to 12:00, 3:00, 6:00, and 9:00 on the flange face.
(b) Mark the bolts corresponding to the reference locations as follows: #1 at 12:00, #3 at 3:00, #2 at 6:00, and #4 at 9:00.
(c) Mark the next bolt that is clockwise from bolt #1 by adding 4, i.e., mark the next bolt clockwise from bolt #1 (1 + 4), or #5.
(d) Repeat (c) for each succeeding bolt until bolt #3 is reached.
(e) Start on the next bolt that is clockwise from bolt #3 and repeat (c), i.e., mark the next bolt clockwise from bolt #3 (3 + 4), or #7.
(f) Repeat (e) for each succeeding bolt until bolt #2 is reached.
(g) Start on the next bolt that is clockwise from bolt #2 and repeat (c), i.e., mark the next bolt clockwise from bolt #2 (2 + 4), or #6.
(h) Repeat (g) for each succeeding bolt until bolt #4 is reached.
(i) Start on the next bolt that is clockwise from bolt #4 and repeat (c), i.e, mark the next bolt clockwise from bolt #4 with (4 + 4), or #8.
(j) Repeat (i) until the last bolt is reached.

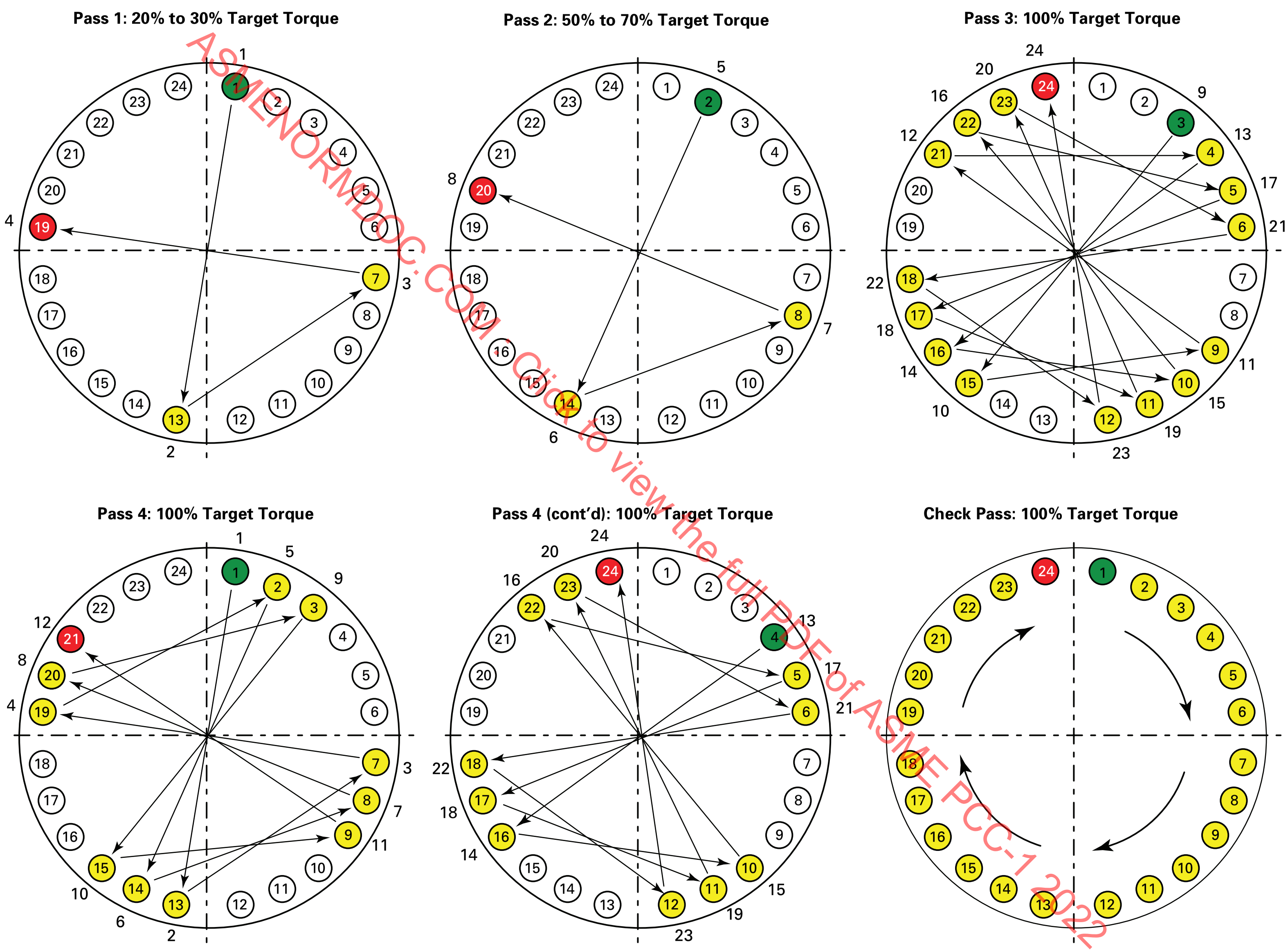
Table F-6.1.2.1.2-1
Quadrant Pattern Circular Sequence

No. of Bolts	Bolt-Numbering Sequence to Be Marked Clockwise on the Flange [Note (1)]
4	1, 2, 3, 4
8	1, 5, 2, 6, 3, 7, 4, 8
12	1, 5, 9, 2, 6, 10, 3, 7, 11, 4, 8, 12
16	1, 5, 9, 13, 2, 6, 10, 14, 3, 7, 11, 15, 4, 8, 12, 16
20	1, 5, 9, 13, 17, 2, 6, 10, 14, 18, 3, 7, 11, 15, 19, 4, 8, 12, 16, 20
24	1, 5, 9, 13, 17, 21, 2, 6, 10, 14, 18, 22, 3, 7, 11, 15, 19, 23, 4, 8, 12, 16, 20, 24
28	1, 5, 9, 13, 17, 21, 25, 2, 6, 10, 14, 18, 22, 26, 3, 7, 11, 15, 19, 23, 27, 4, 8, 12, 16, 20, 24, 28
32	1, 5, 9, 13, 17, 21, 25, 29, 2, 6, 10, 14, 18, 22, 26, 30, 3, 7, 11, 15, 19, 23, 27, 31, 4, 8, 12, 16, 20, 24, 28, 32
36	1, 5, 9, 13, 17, 21, 25, 29, 33, 2, 6, 10, 14, 18, 22, 26, 30, 34, 3, 7, 11, 15, 19, 23, 27, 31, 35, 4, 8, 12, 16, 20, 24, 28, 32, 36
40	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40
44	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44
48	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48
52	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52
56	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56
60	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60
64	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64
68	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68
72	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72
76	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 75, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76
80	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 77, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 78, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 75, 79, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76, 80
84	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 77, 81, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 78, 82, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 75, 79, 83, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76, 80, 84
88	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 77, 81, 85, 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 78, 82, 86, 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63, 67, 71, 75, 79, 83, 87, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 72, 76, 80, 84, 88

NOTE: (1) This sequence was established using the following procedure:

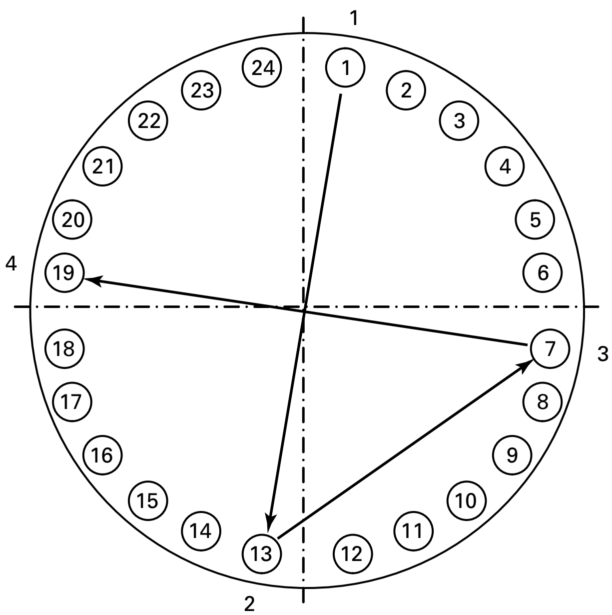
(a) Establish the reference locations corresponding to 12:00, 3:00, 6:00, and 9:00 on the flange face.
(b) Mark the bolts corresponding to the reference locations as follows: #1 at 12:00, #2 at 3:00, #3 at 6:00, and #4 at 9:00.
(c) Mark the next bolt that is clockwise from bolt #1 by adding 4, i.e., mark the next bolt clockwise from bolt #1 (1 + 4), or #5.
(d) Repeat (c) for each succeeding bolt until bolt #2 is reached.
(e) Start on the next bolt that is clockwise from bolt #2 and repeat (c), i.e., mark the next bolt clockwise from bolt #2 (2 + 4), or #6.
(f) Repeat (e) for each succeeding bolt until bolt #3 is reached.
(g) Start on the next bolt that is clockwise from bolt #3 and repeat (c), i.e., mark the next bolt clockwise from bolt #3 (3 + 4), or #7.
(h) Repeat (g) for each succeeding bolt until bolt #4 is reached.
(i) Start on the next bolt that is clockwise from bolt #4 and repeat (c), i.e, mark the next bolt clockwise from bolt #4 with (4 + 4), or #8.
(j) Repeat (i) until the last bolt is reached.

Figure F-6.1.2.2-1
Pattern #2 (Quadrant Pattern): 24-Bolt Accelerated Cross Example



GENERAL NOTE: Outer numbers indicate the tightening sequence.

Figure F-6.1.3.1-1
Pattern #3 (Circular Pattern): 24-Bolt Example



GENERAL NOTE: Outer numbers indicate the tightening sequence.

uniform during assembly, which indicates the correct seating of the gasket.

F-9 HIGHLY COMPRESSIBLE SOFT GASKETS VULNERABLE TO UNEVEN COMPRESSION

Highly compressible gaskets pose additional assembly challenges. Uneven gasket compression due to misaligned flanges or loading too quickly during tightening can cause permanent uneven compression of the gasket, leading to leaks. PTFE gaskets, particularly the virgin and the expanded types, are examples of gaskets that are susceptible to this kind of permanent, uneven deformation. When using highly compressible gaskets, it is important to use tightening sequences that apply load as gradually as possible.

Sequences in which faster tightening is required may not be appropriate for highly compressible gaskets. Multiple check passes (often three or more) will almost certainly be needed to achieve even compression and accurate final bolt stress. For critical or problematic joints, monitoring the amount and uniformity of flange gaps per Nonmandatory Appendix J, section J-2 may be necessary.

When using a pattern that consists of multiple tools that are not relocated, it is important to allow sufficient time (10 min to 15 min) between passes for these gaskets to conform to the applied loads.

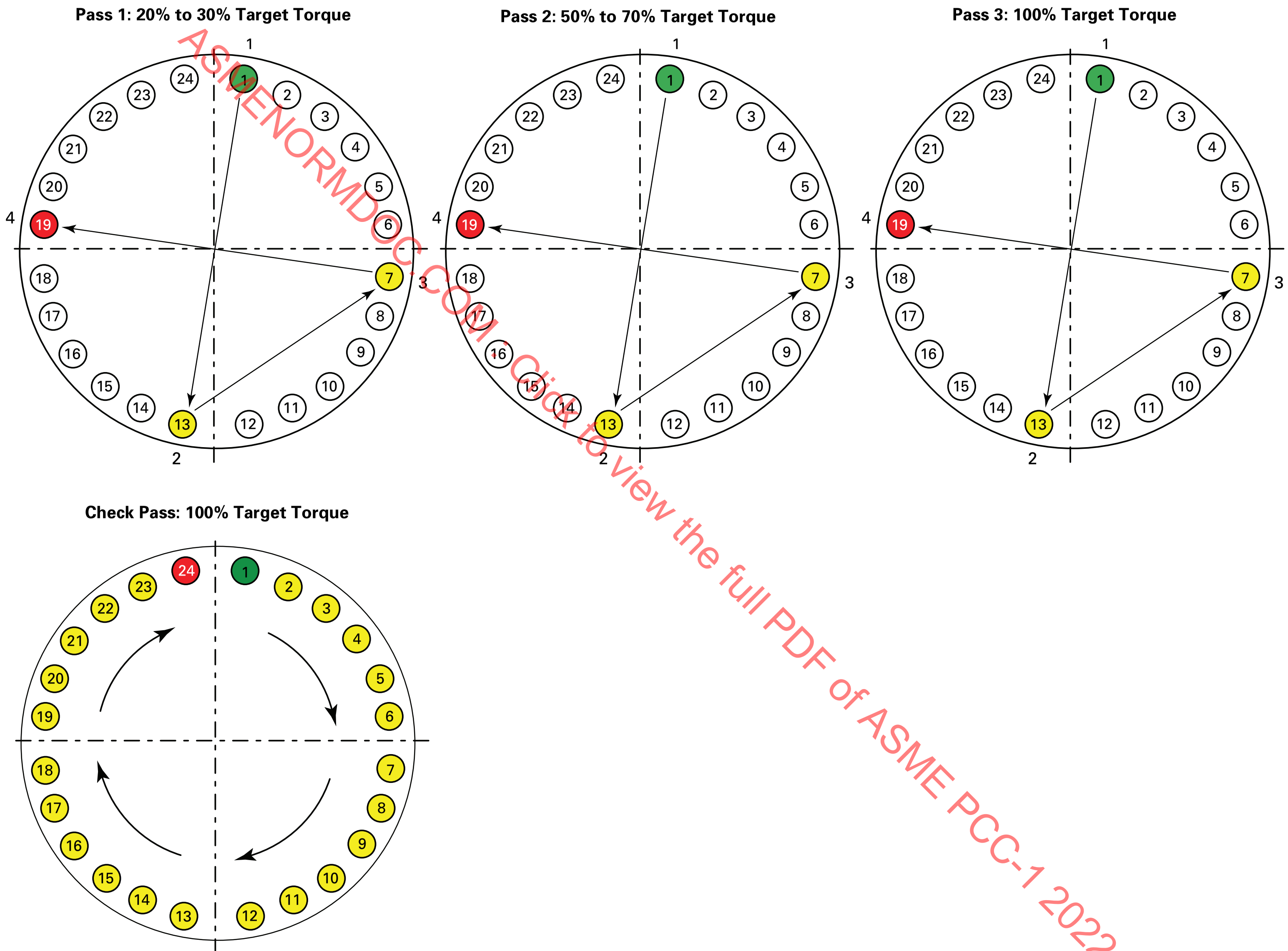
F-10 REFERENCES

[1] Brown, W., "Efficient Assembly of Bolted Joints," ASME 2004 Pressure Vessels and Piping Conference, PVP2004-2635, San Diego, CA, July 25–29, 2004, DOI: 10.1115/PVP2004-2635

[2] Brown, W., Waterland, J., and Lay, D., 2010, "Background on the New ASME PCC-1:2010 Appendix F 'Alternatives to Legacy Tightening Sequence/Pattern,'" ASME 2010 Pressure Vessels and Piping Conference, PVP2010-25772, Bellevue, WA, July 18–22, 2010, DOI: 10.1115/PVP2010-25772

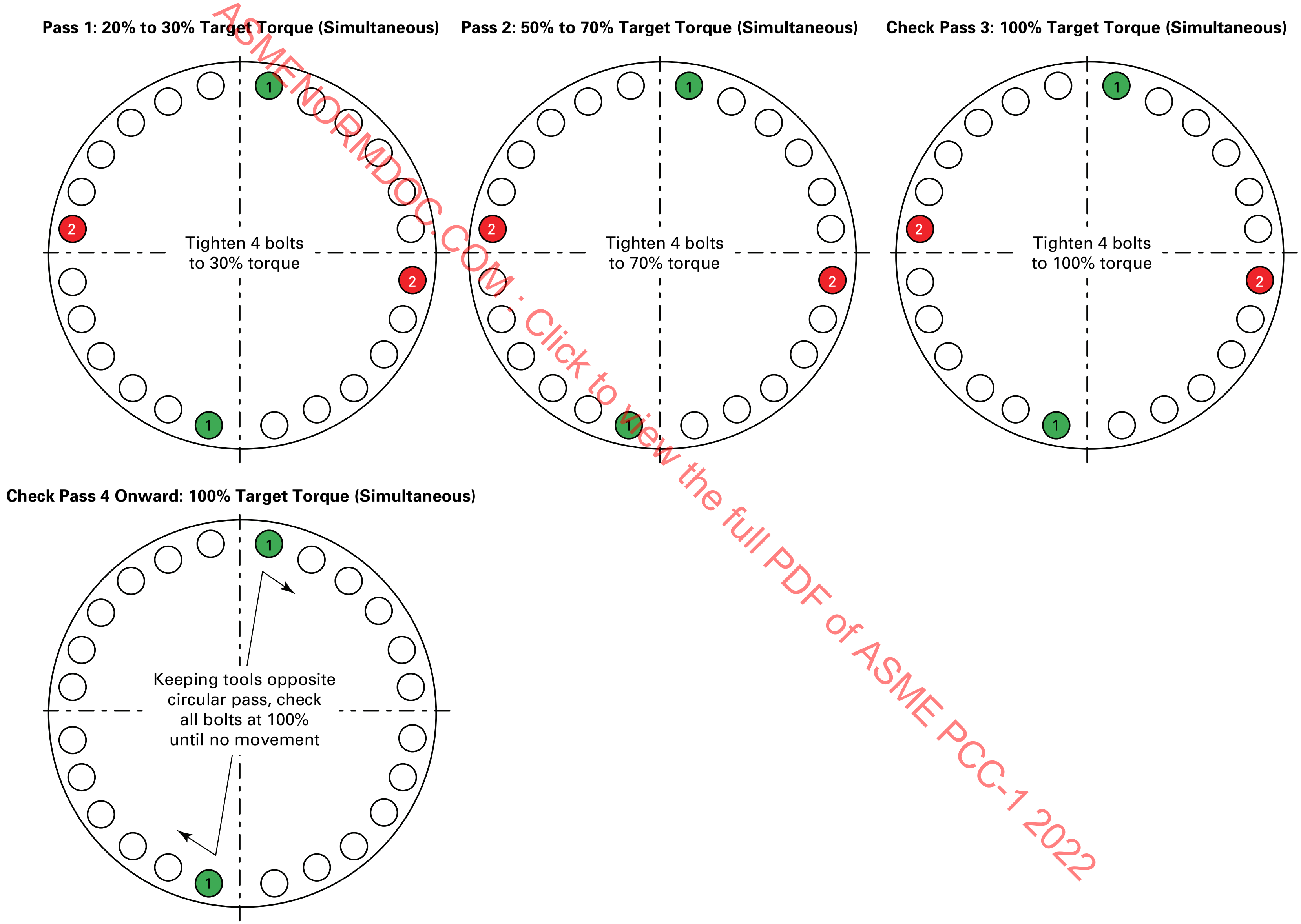
[3] "Bolt Tightening Procedure for Pressure Boundary Flanged Joint Assembly," JSA JIS B 2251, 2008

Figure F-6.1.3.2-1
Pattern #3 (Circular Pattern): 24-Bolt Step-by-Step Example



GENERAL NOTE: Outer numbers indicate the tightening sequence.

Figure F-6.1.3.3-1
Pattern #3 (Simultaneous Multibolt Circular Pattern): 24-Bolt Step-by-Step Example (Two Tools)



(22)

NONMANDATORY APPENDIX G
SINGLE-STUD REPLACEMENT

Nonmandatory Appendix G is in the course of preparation.

NONMANDATORY APPENDIX H
BOLT ROOT AND TENSILE STRESS AREAS

See Tables H-1M and H-1.

Table H-1M
Bolt Root and Tensile Stress Areas (Metric Threads) (22)

Bolt Size, Basic Thread Designation [Note (1)]	Root Area		Tensile Stress Area	
	mm^2 [Notes (2), (3)]	in.^{2} [Note (4)]	mm^2 [Notes (2), (5)]	in.^{2} [Note (4)]
M12 × 1.75	72	0.1122	84	0.1307
M14 × 2	100	0.1546	115	0.1788
M16 × 2	138	0.214	157	0.243
M20 × 2.5	217	0.336	245	0.379
M22 × 2.5	272	0.422	303	0.470
M24 × 3	313	0.485	353	0.547
M27 × 3	414	0.641	459	0.712
M30 × 3.5	503	0.780	561	0.869
M33 × 3.5	629	0.975	694	1.075
M36 × 4	738	1.144	817	1.266
M39 × 4	890	1.379	976	1.513
M42 × 4.5	1 018	1.578	1 121	1.738
M45 × 4.5	1 195	1.852	1 306	2.024
M48 × 5	1 343	2.082	1 473	2.283
M52 × 5	1 615	2.504	1 758	2.725
M56 × 5.5	1 863	2.887	2 030	3.147
M64 × 6	2 467	3.824	2 676	4.148
M72 × 6	3 222	4.994	3 460	5.362
M80 × 6	4 077	6.319	4 344	6.733
M90 × 6	5 287	8.195	5 591	8.666
M100 × 6	6 652	10.31	6 995	10.84

NOTES:
(1) Metric thread designations are given in bolt size (millimeters) and pitch (millimeters) (e.g., M14 × 2 refers to a 14-mm-diameter bolt with a 2-mm-pitch thread).
(2) The root and tensile stress areas are based on coarse-thread series for sizes M64 and smaller, and 6-mm-pitch thread series for sizes M72 and larger.
(3) The root area is computed from the cross-sectional area taken from the "Minimum Minor Diameter (Rounded Form), d_3," found in ASME B1.13M, Table 14 for the respective basic thread designation, assuming a tolerance class of 6g.
(4) The equivalent root and tensile stress areas in U.S. Customary units represent a soft conversion of their respective values in SI units.
(5) The tensile stress area is computed from the formula provided in ASME B1.13M, Nonmandatory Appendix B, para. B-1.

Table H-1
Bolt Root and Tensile Stress Areas (Inch Series)

Bolt Size, in.	Threads per Inch	Root Area: in.^{2} [Notes (1), (2)]	Root Area: mm^2 [Note (3)]	Tensile Stress Area: in.^{2} [Notes (1), (4)]	Tensile Stress Area: mm^2 [Note (3)]
1/2	13	0.1257	81	0.1419	92
5/8	11	0.202	130	0.226	146
3/4	10	0.302	195	0.334	215
7/8	9	0.419	271	0.462	298
1	8	0.551	356	0.606	391
1 1/8	8	0.728	470	0.790	510
1 1/4	8	0.929	599	1.000	645
1 3/8	8	1.155	745	1.233	795
1 1/2	8	1.405	907	1.492	963
1 5/8	8	1.68	1 084	1.78	1 148
1 3/4	8	1.98	1 277	2.08	1 342
1 7/8	8	2.30	1 486	2.41	1 555
2	8	2.65	1 711	2.77	1 787
2 1/4	8	3.42	2 208	3.56	2 297
2 1/2	8	4.29	2 769	4.44	2 865
2 3/4	8	5.26	3 393	5.43	3 503
3	8	6.32	4 080	6.51	4 200
3 1/4	8	7.49	4 831	7.69	4 961
3 1/2	8	8.75	5 645	8.96	5 781
3 3/4	8	10.11	6 522	10.34	6 671
4	8	11.57	7 462	11.81	7 619

NOTES:
(1) The root and tensile stress areas are based on coarse-thread series for sizes 1 in. and smaller, and 8-pitch thread series for sizes 1 1/8 in. and larger.
(2) The root area is taken from ASME B1.1, Table 6 (Basic Dimensions for Coarse-Thread Series) and Table 11 (Basic Dimensions for 8-Thread Series) under the column labeled "Section at Minor Diameter at $D - 2h_b$."
(3) The equivalent root and tensile stress areas in SI units are a soft conversion of their respective values in U.S. Customary units.
(4) The tensile stress area is taken from ASME B1.1 Table 6 (Basic Dimensions for Coarse-Thread Series) and Table 11 (Basic Dimensions for 8-Thread Series). See ASME B1.1, Nonmandatory Appendix B, para. B-1 for thread tensile stress area formulas.

NONMANDATORY APPENDIX I
INTERACTION DURING TIGHTENING (22)

DELETED

NONMANDATORY APPENDIX J
(22) # OPTIONAL PRACTICES FOR FLANGE JOINT ASSEMBLY

J-1 INTRODUCTION

The assembly procedure may include the optional assembly practices described in this Appendix, in addition to those described in section 10 and Nonmandatory Appendix F.

J-2 MEASUREMENT OF GAPS

The primary purpose for measuring the gap between flanges is to verify parallelism to ensure even gasket compression before, during, and after tightening or leak-mitigation troubleshooting (see Nonmandatory Appendix P).

The owner determines when measurement and recording are required. The assembler should consider the final gap closure alignment for all joints.

The assembler should control the gaps between the flanges of all critical service joints (see Mandatory Appendix I). The assembler may omit detailed gap measurement and adjustment for intermediate and mild service applications but should maintain parallelism of flange surfaces on all joints as a best practice.

Gap measurements are not intended to be indicators of gasket stress. For gap measurements to have validity, flanges should conform to the flatness standards shown in Nonmandatory Appendix D, Table D-2-1M/ Table D-2-1. If gap measurement is required, the assembly procedure should include the following instructions:

(a) Measure the gap between flanges at eight or more equally spaced locations of good-quality flange surface around the circumference.

(b) Label where the measurements are taken so that subsequent measurements are taken at the same points.

(c) Use a measuring device, such as Vernier calipers or a tapered wedge gauge, that allows for practical comparison between points.

(d) During initial tightening, ensure measurements are within 0.25 mm (0.010 in.) of one another.

(e) Loosen bolts in the vicinity of the low readings (the smallest gap between flanges) until the gap is uniform to within 0.25 mm (0.010 in.).

(f) If necessary, tighten bolts at the location of the highest readings (the largest gap between flanges). However, if the difference in torque required to keep the gap uniform is greater than 50% of the target torque, disassemble the joint and locate the source of the problem.

J-3 BOLT ELONGATION (BOLT STRETCH) MEASUREMENT

Bolt elongation measurement is the measurement of the bolt's change in length. Bolt elongation measurement is typically completed by measuring the initial bolt length and comparing it to the final bolt length after tightening.

If ultrasonic or micrometer measurement methods are used, the following items should be considered during the measurement:

(a) Compensation shall be made for temperature changes in the bolt after the initial length measurement. These temperature changes may be caused by factors such as environmental changes or incidental friction during the tightening process.

(b) For accuracy, the instrument should be calibrated to properly read the bolts being tightened.

(c) For bolts constructed with a centerline indicator (gauge) rod, neither initial length measurements nor temperature compensation is required, thereby allowing direct determination of the true bolt elongation (and hence bolt stress) for both initial assembly and trouble-shooting purposes during operation.

If bolt elongation (bolt stretch) measurement is selected as the load-control technique, the following equation may be used to calculate the bolt elongation:

$$\Delta L = \left(\frac{S_b \times L_{\text{eff}}}{E}\right)\left(\frac{A_r}{A_{ts}}\right)$$

where

A_r = root area, mm^2 (in.^{2}) (see Nonmandatory Appendix H for bolt root areas).

A_{ts} = tensile stress area, mm^2 (in.^{2}) (see Nonmandatory Appendix H for bolt tensile stress areas).

E = modulus of elasticity, MPa (ksi).

L_{eff} = effective stretching length, mm (in.). The conventional assumption is that the effective stretching length in a through-bolted joint system is the distance between the midthickness of the nuts, where the nominal thickness of a heavy hex series nut is one nominal bolt diameter. By the same standard, the effective length of the portion of a bolt that is studded into a tapped hole is one-half of a nominal bolt diameter.

S_b = target bolt stress (root area), MPa (ksi).

NOTE: Bolt stresses computed in accordance with ASME BPVC, Section VIII, Division 1, Mandatory Appendix 2 are based on root area. If target bolt stress (tensile stress area) is used, drop the A_r/A_{ts} term from the ΔL computation.

ΔL = bolt elongation (bolt stretch), mm (in.). The user should select a tolerance on this computed value and include it in the joint assembly procedure.

J-4 START-UP RETORQUE

On joints that are problematic or that have been determined to have an insufficient buffer against leakage in accordance with Nonmandatory Appendix O, a start-up retorque may be specified to decrease the likelihood of leakage during operation.[1]

Start-up retorque is performed when the temperature of the flange or bolts is between 150°C (300°F) and 230°C (450°F) or within 24 h of unit start-up if the joint temperature remains below 150°C (300°F). This temperature range and time window are selected to allow for the maximum amount of gasket relaxation prior to retightening while avoiding significant evaporation of lubricating oils from the antiseize product. Loss of lubricating oils greatly reduces the accuracy of the torque. The applied torque is sometimes adjusted to account for changes in antiseize nut factor at the average start-up retorque temperature. Where start-up retorque is not practical, live tightening at a later stage of operation using turn-of-nut may be used as an alternative.

Start-up retorque is typically not recommended for PTFE-based gaskets. However, pre-start-up retorque at ambient temperature is encouraged for PTFE-based gaskets to offset gasket creep from cold flow.

If a start-up retorque is required, the following instructions should be included in the assembly procedure:

(a) Adjust the ambient-temperature assembly target torque value to account for any change in nut factor with temperature.

(b) Once the unit is brought online and the metal temperature is between 150°C (300°F) and 230°C (450°F) (commence once the flange reaches the lower temperature) or within 24 h of a unit start-up if the joint temperature remains below 150°C (300°F), tighten each bolt, proceeding in a circular pattern. The use of multitool tightening on opposing bolts is acceptable, but use a circular pattern.

(c) Continue tightening in the circular pattern until the nuts no longer turn.

[1] If joint-tightening activities are performed on pressurized equipment, there is a risk of gasket blowout due to the disruption of the joint. Gasket blowout or leakage may occur at a location around the periphery of a joint other than the one being tightened. This risk should be considered, particularly with respect to personnel in the vicinity of the joint.

A risk assessment of the proposed start-up retorque operation should be carried out to establish that the operation can be performed safely. Start-up retorque should not be considered the same as live tightening or single-stud replacement. Live tightening or single-stud replacement are post-assembly activities usually undertaken due to leakage or maintenance requirements and are covered further in ASME PCC-2.

J-5 GROUPED BOLTING FOR LARGE FLANGES

Grouped bolting is the practice of grouping sets of adjacent bolts together and treating the sets as if they were individual bolts for patterned tightening purposes. The practice reduces unnecessary tool movements and avoids potentially overstressing individual bolts in large-diameter flanges with many bolts (usually 36 or more). Figure J-5-1 illustrates the bolt-grouping concept for a 48-bolt flange.

J-6 ALTERNATIVE LEGACY CROSS-PATTERN TIGHTENING SEQUENCE AND BOLT-NUMBERING SYSTEM

As mentioned in Nonmandatory Appendix F, it may be desirable to identify bolt locations around the flange, e.g., to help reference leak locations. Table J-6-1 is an acceptable option (see ASME PCC-1–2019, Table 3).

J-7 CONTROLLED DISASSEMBLY

J-7.1 General

For problematic joints, it may help to gradually reduce stud load in multiple passes. One method to accomplish this is using turn-of-nut principles.

J-7.2 Turn-of-Nut Disassembly Example

Step 1. Loosen one bolt completely. Note the total nut turn required to fully relieve the bolt load from assembled to the finger-tight condition.

Step 2. Retighten the loose bolt to $^7/_8$ of the total nut turn noted in Step 1.

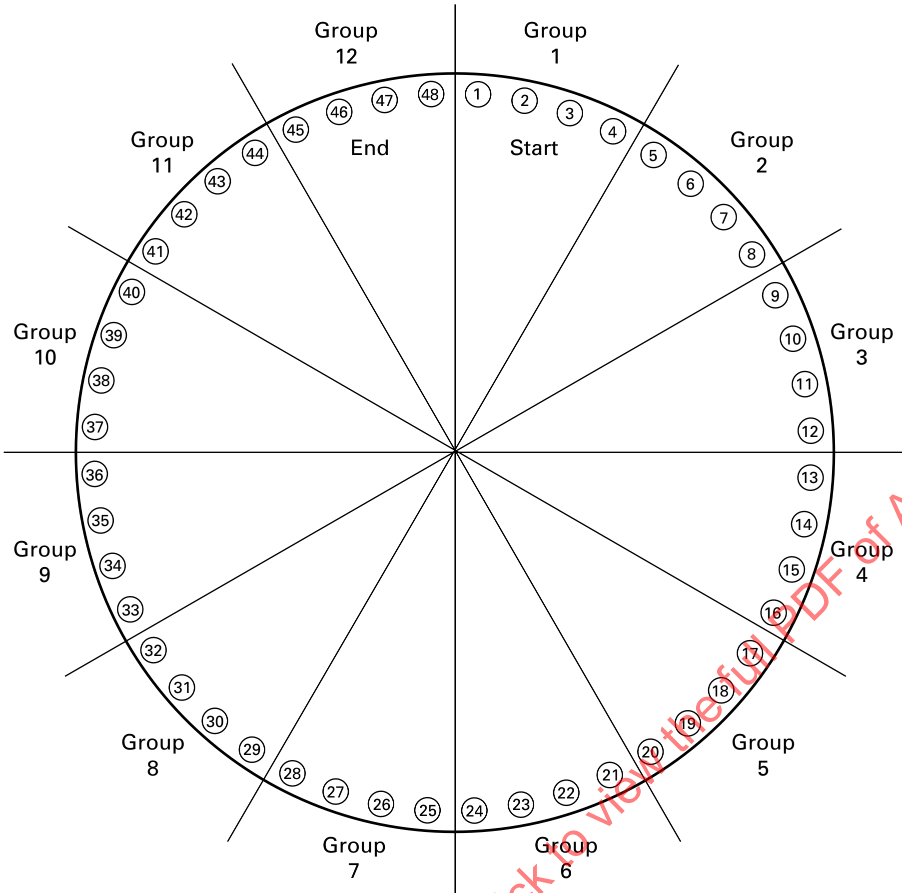
Step 3. In a circular pattern, loosen each bolt by $^1/_8$ of the total nut turn noted in Step 1.

NOTE: For problematic joints, perform Step 3 twice.

Step 4. Proceed with nut loosening in a circular pattern, removing all load on each stud.

NOTE: If a stud starts galling during final disassembly, retighten all loosened bolts (if possible) to the position obtained prior to Step 4 and then recommence at Step 3.

Figure J-5-1
Example of Bolt Grouping for a 48-Bolt Flange



Group	Bolts
1	1-2-3-4
2	5-6-7-8
3	9-10-11-12
4	13-14-15-16
5	17-18-19-20
6	21-22-23-24
7	25-26-27-28
8	29-30-31-32
9	33-34-35-36
10	37-38-39-40
11	41-42-43-44
12	45-46-47-48

Treat the 12 groups as if they were single bolts. That is, tighten all bolts in a group before proceeding to the next group in the pattern. Follow incremental steps per the Star sequence in Table F-6.1.1.1-1 as if this were a 12-bolt pattern.

GENERAL NOTE: This figure is an illustration of how bolts may be grouped for tightening. Each group is treated as one bolt in the tightening pattern. A suggested number of bolts for a group is the number contained within a 30-deg arc. However, the assembler should assess the potential gasket damage or flange misalignment when grouping bolts and should consider adjusting the group size to prevent these issues.

Table J-6-1
Legacy Cross-Pattern Tightening Sequence and Bolt-Numbering System When Using a Single Tool

No. of Bolts	Tightening Sequence for Cross-Pattern Passes
4	1, 3, 2, 4
8	1-5-3-7 → 2-6-4-8
12	1-7-4-10 → 2-8-5-11 → 3-9-6-12
16	1-9-5-13 → 3-11-7-15 → 2-10-6-14 → 4-12-8-16
20	1-11-6-16 → 3-13-8-18 → 5-15-10-20 → 2-12-7-17 → 4-14-9-19
24	1-13-7-19 → 4-16-10-22 → 2-14-8-20 → 5-17-11-23 → 3-15-9-21 → 6-18-12-24
28	1-15-8-22 → 4-18-11-25 → 6-20-13-27 → 2-16-9-23 → 5-19-12-26 → 7-21-14-28 → 3-17-10-24
32	1-17-9-25 → 5-21-13-29 → 3-19-11-27 → 7-23-15-31 → 2-18-10-26 → 6-22-14-30 → 4-20-12-28 → 8-24-16-32
36	1-2-3 → 19-20-21 → 10-11-12 → 28-29-30 → 4-5-6 → 22-23-24 → 13-14-15 → 31-32-33 → 7-8-9 → 25-26-27 → 16-17-18 → 34-35-36
40	1-2-3-4 → 21-22-23-24 → 13-14-15-16 → 33-34-35-36 → 5-6-7-8 → 25-26-27-28 → 17-18-19-20 → 37-38-39-40 → 9-10-11-12 → 29-30-31-32
44	1-2-3-4 → 25-26-27-28 → 13-14-15-16 → 37-38-39-40 → 5-6-7-8 → 29-30-31-32 → 17-18-19-20 → 41-42-43-44 → 9-10-11-12 → 33-34-35-36 → 21-22-23-24
48	1-2-3-4 → 25-26-27-28 → 13-14-15-16 → 37-38-39-40 → 5-6-7-8 → 29-30-31-32 → 17-18-19-20 → 41-42-43-44 → 9-10-11-12 → 33-34-35-36 → 21-22-23-24 → 45-46-47-48
52	1-2-3-4 → 29-30-31-32 → 13-14-15-16 → 41-42-43-44 → 5-6-7-8 → 33-34-35-36 → 17-18-19-20 → 45-46-47-48 → 21-22-23-24 → 49-50-51-52 → 25-26-27-28 → 9-10-11-12 → 37-38-39-40
56	1-2-3-4 → 29-30-31-32 → 13-14-15-16 → 41-42-43-44 → 21-22-23-24 → 49-50-51-52 → 9-10-11-12 → 37-38-39-40 → 25-26-27-28 → 53-54-55-56 → 17-18-19-20 → 45-46-47-48 → 5-6-7-8 → 33-34-35-36
60	1-2-3-4 → 29-30-31-32 → 45-46-47-48 → 13-14-15-16 → 5-6-7-8 → 37-38-39-40 → 21-22-23-24 → 53-54-55-56 → 9-10-11-12 → 33-34-35-36 → 49-50-51-52 → 17-18-19-20 → 41-42-43-44 → 57-58-59-60 → 25-26-27-28
64	1-2-3-4 → 33-34-35-36 → 17-18-19-20 → 49-50-51-52 → 9-10-11-12 → 41-42-43-44 → 25-26-27-28 → 57-58-59-60 → 5-6-7-8 → 37-38-39-40 → 21-22-23-24 → 53-54-55-56 → 13-14-15-16 → 45-46-47-48 → 29-30-31-32 → 61-62-63-64
68	1-2-3-4 → 37-38-39-40 → 21-22-23-24 → 53-54-55-56 → 9-10-11-12 → 45-46-47-48 → 29-30-31-32 → 61-62-63-64 → 17-18-19-20 → 57-58-59-60 → 33-34-35-36 → 5-6-7-8 → 41-42-43-44 → 13-14-15-16 → 49-50-51-52 → 25-26-27-28 → 65-66-67-68

NONMANDATORY APPENDIX K
(22) # NUT FACTOR CALCULATION OF TARGET TORQUE

K-1 COMMON TARGET TORQUE FORMULA

A common method for calculating target torque is to use the nut factor:

(SI Units)

$$T = KDF/1\,000 \tag{K-1M}$$

(*U.S. Customary Units*)

$$T = KDF/12 \tag{K-1}$$

where

D = nominal diameter of the bolt, mm (in.)
F = target bolt load, N (lb)
K = nut factor (see para. K-1.1)
T = target torque, N·m (ft-lb)

K-1.1 Nut Factor, *K*

The nut factor, K, is an experimentally determined dimensionless constant related to the coefficient of friction. The value of K in most applications at ambient temperature is considered to be approximately equal to the coefficient of friction plus 0.04 (ref. [1]) (e.g., coefficient of friction = 0.16; nut factor = 0.16 + 0.04 ~ 0.20). Published tables of experimental nut factors are available from several sources; however, care should be taken to understand the factors for the application being considered. Typical nut factors for industrial pressure vessel and piping applications using ASME SA-193 low-alloy steel bolts range from 0.16 to 0.23 at ambient temperature.

K-1.2 Effects of Changes in Nut Factor

It is important to understand the sensitivity of the obtained load to an applied torque from changes in nut factor. For example, a small change in nut factor from 0.10 to 0.30 does not result in a 20% change in torque but a 200% change.

Insufficient application of lubricant to the working surfaces adds significant variability to the obtained bolt load. Research has shown that the nut factor is dependent on lubrication, bolt material, bolt diameter, bolt and nut coating, and assembly temperature. In tests using one lubricant at ambient temperature [0°C to 40°C (32°F to 100°F)], the nut factor was found to vary by 50% (from 0.155 to 0.105). In addition, in material tests, ASME SA-193 B8M bolts have been found to have a 30% higher nut factor than ASME SA-193 B7 bolts. These variables are significant and should not be ignored when selecting the lubricant and determining the nut factor (refs. [2]–[5]).

A lubricant in combination with stud material and coatings will have a specific nut factor. A change to the fastening system will change the nut factor, and the torque values will need to be adjusted accordingly. Users should use test results from nut factor trials that are similar to their own conditions (lubrication, bolt material, bolt diameter, bolt and nut coating, assembly temperature) or conduct their own nut factor trials. Nut factor trials can be conducted by applying torque to a bolt and measuring the obtained bolt load using a calibrated load cell or instrumented bolt or calibrated ultrasonic measurement.

The manufacturer's maximum temperature for a given lubrication product has not been a reliable indicator that the product improves the joint's disassembly after operation at an elevated temperature. Typically, the maximum temperature is listed as the melting point or degradation point of the solid with the highest temperature in the lubricant and is not a reflection of how the lubricant works at that higher temperature. Users should obtain test results on similar materials and in similar operating conditions to guide them in selecting the appropriate product for that service.

K-2 ADDITIONAL INFORMATION ON TARGET TORQUE FORMULAS

Additional information on torque formulas and the effect of friction factors may be found in the *Handbook of Bolts and Bolted Joints* (ref. [1]). Chapter 3 provides detailed formulas. Chapters 12 and 32 provide substantial additional theoretical and experimental information and equations, including eq. (K-2) shown in this Appendix. Equation (K-2) applies to standard 60-deg thread angle fasteners. It reflects the three specific resistance components: the thread pitch, the thread coefficient of friction, and the nut face coefficient of friction. This approach has been used in EN 1591-1, ISO 27509, and VDI 2230. Long experience has shown the nut factor method to be equally effective as the more complex formulas. While the nut factor method does not address all of the torque-preload relationship variables, it produces similar and fully acceptable values for the assembly of flanges.

For completeness, the mathematical model is given here:

$$T = \frac{F}{2}\left(\frac{p}{\pi} + \frac{\mu_t d_2}{\cos\beta} + D_e\mu_n\right) \quad \text{(K-2)}$$

This can be simplified for metric and Unified thread forms to

$$T = F\left(0.15915p + 0.57735\mu_t d_2 + \frac{D_e\mu_n}{2}\right)$$

or more approximately (from VDI 2230) to

$$T = F\left(0.16p + 0.58\mu_t d_2 + \frac{D_e\mu_n}{2}\right)$$

NOTE:

- $0.16p$ is the torque to stretch the bolt.
- $0.58\mu_t d_2$ is the torque to overcome thread friction.
- $\frac{D_e\mu_n}{2}$ is the torque to overcome face friction.

where

D_e = effective bearing diameter of the nut face, mm (in.)
= $(d_o + d_i)/2$

d_2 = basic pitch diameter of the thread, mm (in.) (For metric threads, $d_2 = d - 0.6495p$; for inch threads, $d_2 = d - 0.6495/n$.)

d_i = inner bearing diameter of the nut face, mm (in.)

d_o = outer bearing diameter of the nut face, mm (in.)

F = target bolt load, N (lb)

n = number of threads per inch, in.$^{-1}$ (applies to inch threads)

p = pitch of the thread, mm (For inch threads, this is normally quoted as threads per inch, n; i.e., $p = 1/n$.)

T = target torque, N·mm (in.-lb)

β = half included angle for the threads, deg (i.e., 30 deg for metric and Unified threads)

μ_n = coefficient of friction for the nut face or bolt head

μ_t = coefficient of friction for the threads

The target bolt load, F, can be determined from

$$F = A_s\sigma_y P_{\%}$$

where

A_s = tensile stress area of the thread, mm^2 (in.^{2}) (see Nonmandatory Appendix H)

$P_{\%}$ = percentage utilization factor for material yield strength (default value typically 50%; i.e., $P_{\%}$ = 0.5)

σ_y = minimum yield strength of the bolt material, N/mm^2 (lb/in.^{2})

K-3 REFERENCES

[1] Bickford, J. H., *Handbook of Bolts and Bolted Joints*, Marcel Dekker, Inc., New York (1995), p. 233

[2] Brown, W., "Efficient Assembly of Bolted Joints," ASME 2004 Pressure Vessels and Piping Conference, PVP2004-2635, San Diego, CA, July 25–29, 2004, DOI: 10.1115/PVP2004-2635

[3] Brown, W., Marchand, L., Evrard, A., and Reeves, D., "Effect of Bolt Size on Assembly Nut Factor," ASME 2007 Pressure Vessels and Piping Conference, PVP2007-26644, San Antonio, TX, July 22–26, 2007, DOI: 10.1115/PVP2007-26644

[4] Brown, W., and Lim, T., "The Effect of Bolt Size on the Assembly Nut Factor," ASME 2015 Pressure Vessels and Piping Conference, PVP2015-45945, Boston, MA, July 19–23, 2015, DOI: 10.1115/PVP2015-45945

[5] Brown, W., and Long, S., "Factors Influencing Nut Factor Test Results," ASME 2017 Pressure Vessels and Piping Conference, PVP2017-65506, Waikoloa, HI, July 16–20, 2017, DOI: 10.1115/ PVP2017-65506

NONMANDATORY APPENDIX L
ASME B16.5 FLANGE BOLTING INFORMATION

See Table L-1.

Table L-1
ASME B16.5 Flange Bolting Information

Flange Size (NPS)	Class 150		Class 300		Class 400		Class 600		Class 900		Class 1500		Class 2500	
	#	Size	#	Size	#	Size	#	Size	#	Size	#	Size	#	Size
½	4	½	4	½	4	½	4	½	4	¾	4	¾	4	¾
¾	4	½	4	⅝	4	⅝	4	⅝	4	¾	4	¾	4	¾
1	4	½	4	⅝	4	⅝	4	⅝	4	⅞	4	⅞	4	⅞
1¼	4	½	4	⅝	4	⅝	4	⅝	4	⅞	4	⅞	4	1
1½	4	½	4	¾	4	¾	4	¾	4	1	4	1	4	1⅛
2	4	⅝	8	⅝	8	⅝	8	⅝	8	⅞	8	⅞	8	1
2½	4	⅝	8	¾	8	¾	8	¾	8	1	8	1	8	1⅛
3	4	⅝	8	¾	8	¾	8	¾	8	⅞	8	1⅛	8	1¼
3½	8	⅝	8	¾	8	⅞	8	⅞	...	...	...	...	...	...
4	8	⅝	8	¾	8	⅞	8	⅞	8	1⅛	8	1¼	8	1½
5	8	¾	8	¾	8	⅞	8	1	8	1¼	8	1½	8	1¾
6	8	¾	12	¾	12	⅞	12	1	12	1⅛	12	1⅜	8	2
8	8	¾	12	⅞	12	1	12	1⅛	12	1⅜	12	1⅝	12	2
10	12	⅞	16	1	16	1⅛	16	1¼	16	1⅜	12	1⅞	12	2½
12	12	⅞	16	1⅛	16	1¼	20	1¼	20	1⅜	16	2	12	2¾
14	12	1	20	1⅛	20	1¼	20	1⅜	20	1½	16	2¼	...	...
16	16	1	20	1¼	20	1⅜	20	1½	20	1⅝	16	2½	...	...
18	16	1⅛	24	1¼	24	1⅜	20	1⅝	20	1⅞	16	2¾	...	...
20	20	1⅛	24	1¼	24	1½	24	1⅝	20	2	16	3	...	...
24	20	1¼	24	1½	24	1¾	24	1⅞	20	2½	16	3½	...	...

NONMANDATORY APPENDIX M
WASHER USAGE GUIDANCE AND PURCHASE SPECIFICATIONS FOR THROUGH-HARDENED WASHERS

M-1 WASHER USAGE GUIDANCE

(22) M-1.1 Usage

The use of washers on pressure boundary bolted flange joints is optional. However, it is generally recognized that the use of through-hardened steel washers will improve the translation of torque input into bolt preload by providing a smooth and low-friction bearing surface for the nut.

Washers protect the contact surface of the flange from damage caused by a turning nut. These are important considerations when torquing methods (either manual or hydraulic) are used for bolt tightening.

This Appendix specifies the procurement of through-hardened washers for bolted flange joints covered within the scope of this Standard. The use of surface-hardened washers is not recommended since the soft interior material under direct compression will flow plastically, causing washer cupping and thinning with the associated reduction in preload.

M-1.2 Dimensions

The outside diameter of the washers detailed in this Appendix was selected to enable their use on flanges with spot faces or back facing meeting the requirements of standard ISO 7005-1 for metric flanges and MSS SP-9 for inch flanges.

The inside diameter of these washers was selected to enable their use under the nut. Use of these washers under the head of a bolt may lead to interference with the bolt shank or underhead fillet.

M-1.3 Washer Temperature

Washer temperature limits are shown in Table M-1.3-1. Note that in operation, actual bolting (studs, nuts, and washers) temperature may be lower than process fluid temperature.

For uninsulated joints, ASME B31.3 considers flange bolting temperature to be 80% of fluid temperature.

M-1.4 Existing Standards

Washers in accordance with ASTM F436 have been used previously on piping flanges. However, the use of ASTM F436 washers may lead to interference with the spot face/back facing on the flanges. Also, ASTM F436 does not provide dimensions for certain nominal sizes needed for pipe or vessel flanges. The intent of the Type 1 washer in this Appendix is to specify a washer of the same general material as an ASTM F436 washer but with revised dimensions to make them compatible with pipe or vessel flanges.

M-1.5 Previous Material

Figures 1 and 2 in the original edition of ASME PCC-1 referenced ASME SA-540 for the manufacture of washers for elevated temperatures. This Appendix does not continue the use of this material due to material cost and manufacturing concerns. Discontinuation of the use of SA-540 material does not imply that this material is technically deficient.

Table M-1.3-1
Recommended Washer Temperature Limits

Material Type	Single-Use [Note (1)]	Reuse [Note (2)]
1	425°C (800°F) [Note (3)]	205°C (400°F)
4	540°C (1,000°F)	400°C (750°F)
5	650°C (1,200°F)	425°C (800°F)
6	815°C (1,500°F)	550°C (1,025°F)
7	...	...

NOTES:
(1) Single-use temperature limits are based on replacement whenever the existing washer has been exposed to a temperature in excess of the corresponding reuse limit.
(2) Reuse temperature limits are based on not exceeding the tempering temperature of the particular material such that the material is not subject to annealing (softening).
(3) Field experience indicates that the use of Type 1 material at temperatures above 315°C (600°F) can lead to difficulty at disassembly due to galling between washer and nut as a result of softening of the washer.

M-1.6 Material Application

Types 1 and 4 washer materials are intended for use with steel fasteners such as Grade 2H, 4, or 7 steel nuts per ASME SA-194. The Type 4 washer material is an alloy steel with a higher temperature limit. Types 5 and 6 washer materials are intended for use with austenitic steel fasteners such as Grade 8 austenitic steel nuts per ASME SA-194. The Type 6 washer material is a precipitation hardening stainless steel that has increased corrosion resistance as compared to Type 5 washer material. Type 7 washer material is intended for use with austenitic steel fasteners such as Grade 8 nuts per ASME SA-194 in low-temperature applications where other materials may become brittle. For the purposes of this Appendix, low-temperature applications refer to temperatures between −45°C (−50°F) and −185°C (−300°F).

M-1.7 Installation

To avoid any concerns about the effect of washer markings on the performance of the washer to nut interface, it is recommended that these washers be installed with the marked face toward the flange surface.

M-2 PURCHASE SPECIFICATION FOR THROUGH-HARDENED WASHERS

M-2.1 Scope

M-2.1.1 This Appendix covers the chemical, mechanical, and dimensional requirements for through-hardened steel washers for use with fasteners having nominal sizes of 14 mm to 100 mm and ½ in. to 4 in. These washers are intended for use on pressure-containing flanges with bolts or studs and nuts. These washers are suitable for use with low-alloy steel and austenitic steel fasteners covered in ASME SA-193 and ASME SA-194.

M-2.1.2 The types of washers covered are
(a) Type 1 — carbon steel
(b) Type 4 — low-alloy steel
(c) Type 5 — martensitic steel
(d) Type 6 — precipitation hardening steel
(e) Type 7 — austenitic steel

M-2.2 Ordering Information

Orders for washers under this specification shall include the following:
(a) nominal size
(b) type (see para. M-2.1.2)
(c) quantity (number of pieces)

M-2.3 Materials and Manufacture

M-2.3.1 Steel used in the manufacture of washers shall be produced by the open-hearth, basic-oxygen, or electric-furnace process.

M-2.3.2 Washers up to and including 100 mm (4 in.) nominal size shall be through-hardened, except Type 7 material.[1]

M-2.3.3 Minimum tempering (precipitation) temperatures shall be as follows:
(a) for Type 1, 205°C (400°F)
(b) for Type 4, 370°C (700°F)
(c) for Type 5, 425°C (800°F)
(d) for Type 6, 550°C (1,025°F)

M-2.4 Chemical Composition

Washers shall conform to the chemical composition specified in Table M-2.4-1.

M-2.5 Mechanical Properties

Types 1, 4, and 5 washers shall have a hardness of 38 HRC to 45 HRC. Type 6 washers shall have a hardness of 33 HRC to 42 HRC. Type 7 washers shall have a hardness of 20 HRC to 23 HRC.

M-2.6 Dimensions and Tolerances

M-2.6.1 Washers shall conform to the dimensions shown in Table M-2.6.1-1 or Table M-2.6.1-2 with tolerances shown in Table M-2.6.1-3 or Table M-2.6.1-4 as applicable.

M-2.6.2 Washers shall have a multidirectional lay with a surface roughness not exceeding 3.2 μm (125 μin.) in height including any flaws in or on the surface. Surface roughness shall be as defined in ASME B46.1.

M-2.7 Workmanship, Finish, and Appearance

Washers shall be free of excess mill scale, excess coatings, and foreign material on bearing surfaces. Arc and gas cut washers shall be free of metal spatter.

M-2.8 Sampling and Number of Tests

M-2.8.1 A lot of washers shall consist of all material offered for inspection at one time that has the following common characteristics:
(a) same nominal size
(b) same material grade
(c) same heat treatment

M-2.8.2 From each lot described in para. M-2.8.1, the number of specimens tested for each required property shall be as specified in Table M-2.8.2-1.

[1] Type 7 material is an austenitic steel that does not harden through heat treatment. This alloy derives galling resistance through chemical composition rather than hardness.

Table M-2.4-1
Chemical Requirements

Washer Type	Composition, % max. Phosphorus	Sulfur
1	0.050	0.060
4 [Note (1)]	0.040	0.050
5 [Note (2)]	0.040	0.030
6 [Note (3)]	0.040	0.030
7 [Note (4)]	0.060	0.030

NOTES:
(1) Type 4 low-alloy steel washers shall be manufactured from SAE number 4130 or 4140 steel listed in ASTM A829.
(2) Type 5 martensitic steel washers shall be manufactured from UNS S41000 steel listed in ASTM A240.
(3) Type 6 precipitation hardening steel washers shall be manufactured from UNS S17400 steel listed in ASTM A693.
(4) Type 7 austenitic steel washers shall be manufactured from UNS S21800 steel listed in ASTM A240.

M-2.9 Test Methods: Hardness

M-2.9.1 A minimum of two readings shall be taken 180 deg apart on at least one face at a minimum depth of 0.38 mm (0.015 in.).

M-2.9.2 Hardness tests shall be performed in accordance with the Rockwell test method specified in ASTM F606/F606M.

M-2.10 Decarburization (22)

M-2.10.1 Washers shall meet the following limits for decarburization after completion of all manufacturing operations:

(a) maximum depth of free ferrite: 0.08 mm (0.003 in.)

(b) maximum total affected depth (free ferrite plus partial decarburization): 0.20 mm (0.008 in.)

M-2.10.2 Decarburization testing shall be performed in accordance with SAE J419.

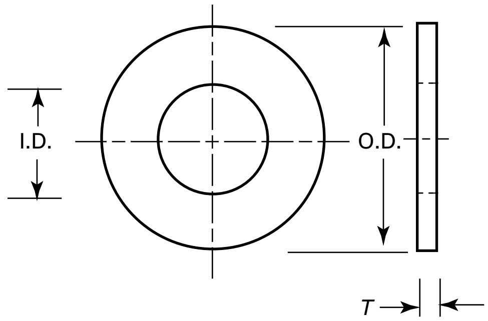
M-2.11 Product Marking

M-2.11.1 Washers shall be marked with a symbol, or other distinguishing marks, to identify the manufacturer or private label distributor, as appropriate.

M-2.11.2 Washers shall be marked with the type, "1," "4," "5," "6," or "7," as applicable.

M-2.11.3 All markings shall be depressed and located on the same face of the washer.

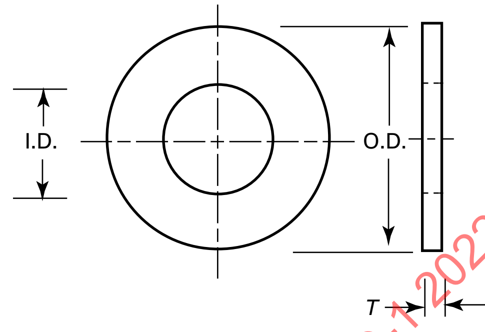
Table M-2.6.1-1
Dimensional Requirements for Metric Washers



Nominal Size, mm	Outside Diameter, O.D., mm	Inside Diameter, I.D., mm	Thickness, *T*, mm
14	28	15	3
16	30	17	4
20	37	21	5
24	44	25	6
27	50	28	6
30	56	31	6
33	60	34	6
36	66	37	6
39	72	42	6
42	78	45	6
45	85	48	6
48	92	52	6
52	98	56	6
56	105	62	6
64	115	70	6
70	125	76	6
76	135	82	6
82	145	88	6
90	160	96	6
95	165	101	6
100	175	107	6

GENERAL NOTE: Tolerances are as noted in Table M-2.6.1-3.

Table M-2.6.1-2
Dimensional Requirements for U.S. Customary Washers



	Outside Diameter, O.D.		Inside Diameter, I.D.		Thickness, *T*	
Nominal Size, in.	mm	in.	mm	in.	mm	in.
$\frac{1}{2}$	27.0	1.063	14.3	0.563	3.2	0.125
$\frac{5}{8}$	33.4	1.313	17.5	0.688	4.0	0.156
$\frac{3}{4}$	38.1	1.500	20.7	0.813	4.8	0.188
$\frac{7}{8}$	43.6	1.718	23.8	0.938	5.6	0.219
1	50.0	1.968	27.0	1.063	6.4	0.250
$1\frac{1}{8}$	54.8	2.156	30.2	1.188	6.4	0.250
$1\frac{1}{4}$	60.3	2.375	33.4	1.313	6.4	0.250
$1\frac{3}{8}$	65.9	2.593	36.5	1.438	6.4	0.250
$1\frac{1}{2}$	71.4	2.812	39.7	1.563	6.4	0.250
$1\frac{5}{8}$	77.8	3.062	42.9	1.688	6.4	0.250
$1\frac{3}{4}$	82.6	3.250	46.1	1.813	6.4	0.250
$1\frac{7}{8}$	87.3	3.438	49.2	1.938	6.4	0.250
2	93.7	3.688	54.0	2.125	6.4	0.250
$2\frac{1}{4}$	104.8	4.125	60.3	2.375	6.4	0.250
$2\frac{1}{2}$	115.9	4.563	66.7	2.625	6.4	0.250
$2\frac{3}{4}$	127	5.000	73.0	2.875	6.4	0.250
3	138.1	5.438	79.4	3.125	6.4	0.250
$3\frac{1}{4}$	149.2	5.875	85.7	3.375	6.4	0.250
$3\frac{1}{2}$	160.4	6.313	92.1	3.625	6.4	0.250
$3\frac{3}{4}$	173.1	6.813	98.4	3.875	6.4	0.250
4	182.6	7.188	104.8	4.125	6.4	0.250

GENERAL NOTE: Tolerances are as noted in Table M-2.6.1-4.

Table M-2.6.1-3 Dimensional Tolerances for Metric Washers

Dimensional Characteristics	Tolerance, mm, for Nominal Size of 14 mm Through 16 mm	20 mm Through 27 mm	30 mm Through 42 mm	45 mm Through 76 mm	82 mm Through 100 mm
Inside diameter, I.D.	−0, +0.4	−0, +0.5	−0, +0.6	−0, +0.7	−0, +0.9
Outside diameter, O.D.	−1.3, +0	−1.6, +0	−1.9, +0	−2.2, +0	−2.5, +0
Thickness, *T*	±0.15	±0.20	±0.20	±0.20	±0.20
Flatness (max. deviation from straight edge placed on cut side)	0.25	0.30	0.40	0.50	0.80
Concentricity, FIM [Note (1)] (inside diameter to outside diameter)	0.3	0.5	0.5	0.5	0.5
Burr height (max. projection above adjacent washer surface)	0.25	0.40	0.40	0.50	0.65

NOTE: (1) Full indicator movement.

Table M-2.6.1-4 Dimensional Tolerances for U.S. Customary Washers

Dimensional Characteristics	Tolerance for Nominal Size of <1 in.		1 in. Through 1½ in.		>1½ in. Through 3 in.		>3 in.	
	mm	in.	mm	in.	mm	in.	mm	in.
Inside diameter, I.D.	−0, +0.81	−0, +0.032	−0, +0.81	−0, +0.032	−0, +1.60	−0, +0.063	−0, +1.60	−0, +0.063
Outside diameter, O.D.	±0.81	±0.032	±0.81	±0.032	±1.60	±0.063	±1.60	±0.063
Thickness, *T*	±0.13	±0.005	±0.13	±0.005	±0.13	±0.005	±0.13	±0.005
Flatness (max. deviation from straight edge placed on cut side)	0.25	0.010	0.38	0.015	0.51	0.020	0.81	0.032
Concentricity, FIM [Note (1)] (inside diameter to outside diameter)	0.81	0.032	0.81	0.032	1.60	0.063	1.60	0.063
Burr height (max. projection above adjacent washer surface)	0.25	0.010	0.38	0.015	0.51	0.020	0.64	0.025

NOTE: (1) Full indicator movement.

Table M-2.8.2-1 Sampling

Number of Pieces in Lot	Number of Specimens
800 and under	1
801 to 8 000	2
8 001 to 22 000	3
Over 22 000	5

NONMANDATORY APPENDIX N DEFINITIONS, COMMENTARY, AND GUIDELINES ON THE REUSE OF BOLTS

(22) N-1 TERMS AND DEFINITIONS

See Mandatory Appendix I.

N-2 GENERAL COMMENTARY

The following discussions are limited to site and field application:

(a) Successful flange joint assembly is subject to a large number of variables in both joint design and field conditions. The fastener system materials, quality, and condition have a large influence over the total outcome.

(b) While it is recognized that even new fasteners may produce ±30% variation in bolt load when torqued, it is also recognized that when properly installed and well lubricated, the majority of the fasteners will produce loads in the ±15% variation range with many falling into the ±10% variation range. This is why torque is successful for many applications. Keeping as many fasteners in the 10% to 15% variation range is very important.

(c) When the threads of new fasteners engage under load, they wear on each other. The surfaces and friction change and therefore their performance is forever changed. Dry or poorly lubricated fasteners tend to create higher friction conditions, while well-lubricated fasteners tend to create lower friction conditions. Each subsequent engagement of the same threads will produce similar results until an optimum or minimum condition occurs. Depending on the fastener size, the load change may vary from a few hundred pounds to a few thousand pounds.

(d) The axial compression of a nut, and the extension of the bolt within the nut, have to be reconciled by means of other types of deformation, since thread contact requires the same deformation of nut and bolt along the bearing surfaces of the two thread systems. The reconciling influences of this incompatible simple axial strain have been identified to be

(1) thread bending (threads act as cantilevers)

(2) thread recession (lateral expansion of the nut accompanying the compressive axial stress, plus lateral expansion due to radial component of thread load)

(3) nut wall bending (nut becomes slightly conically shaped due to higher radial loadings at first engaged threads, thereby shifting some load to the adjacent threads)

The bottom-line result of this load transfer from bolt to nut is that the first threads of engagement are subjected to a high unit loading since a major part of the load tends to transfer through these first threads.

(e) From the previous points it can be seen that working and reworking the same threads in a proper installation can be beneficial.

(1) In the case of bolts with an integral head, it is very simple to rework the same threads over and over from assembly to assembly by simply properly installing the same nut on the same bolt each time. Since the flange determines the grip length (effective stretching length), the same threads are always being worked.

(2) In the case of bolts without integral head, it is virtually impossible to work and rework the same threads given the current workforce practices. When it becomes necessary to reuse bolts without integral heads, strict control is advised to ensure that the threaded fasteners are correctly installed with some means of determining that you are working the same threads. A complete change of the nuts is also a step that may create more uniformity.

(f) When using torque devices without a measurement of load or elongation, determination of the friction condition of a fastener is difficult. However, creating similar and fairly predictable conditions on a group of fasteners is more practical. Starting with new threaded fasteners and treating them all the same is an effective and common way to minimize load variability from bolt to bolt.

(g) Continuous reuse is an option when you have adequately attended to the issues herein discussed.

(h) If an adequate bolt reuse system is used, it is advised that the fasteners be periodically replaced based on the following:

(1) operational fatigue or abuse, surface and/or integral inspections, mechanical integrity inspections, galling, nut not running freely, difficult disassembly, or joint leakage.

(2) if one bolt in a joint is replaced, it is recommended that all bolts be replaced. If all bolts cannot be changed, and more than one bolt is changed, space them

symmetrically around the bolt circle so that they are surrounded by old fasteners.

(i) Tightening methods that do not apply friction loads to the threads during the loading process, such as hydraulic or mechanical tensioning, usually do not have a detrimental effect on the threads due to the lack of friction during the loading.

(j) While factors such as handling, transporting, and storage are very important, suffice it to say that those shall be done in a manner to preserve both the quality and integrity of the fastener and fastener threads.

(k) Working with and reconditioning fasteners in the field is expensive and unpredictable when compared to the cost of new. Reconditioning/replacement considerations could include

(1) number of bolts to recondition
(2) availability of new bolts
(3) labor cost
(4) criticality of the bolted flange joint
(5) condition of previously applied coatings

N-3 GUIDELINES FOR REUSE OF BOLTS AND NUTS

(a) When using bolts and nuts of common grade for fasteners up to M30 ($1\frac{1}{8}$ in.) diameter, the use of new bolts and nuts is recommended when bolt-load control methods such as torque or tension are deemed necessary. For larger diameters, it is recommended that the cost of cleaning, deburring, and reconditioning be compared to the replacement cost and considered in the assessment of critical issues of the assembly.

(b) Strong consideration should be given to replacing bolts of any size should it be found that they have been abused or nonlubricated during previous assemblies.

(c) Thread dies generally do not yield a highly cleaned reconditioned surface; therefore, turning bolt threads in a lathe is the preferred method to recondition costly fasteners. Although preferred, this process will remove thread material and tolerance limits specified in ASME B1.1 must be maintained.

(d) Nuts are not generally reconditioned.

N-4 GUIDELINES FOR REUSE OF GASKETS (22)

(a) Reuse of a gasket is not recommended. However, grooved-metal gaskets may be reused after the substrates have been reconditioned and refaced in a manner consistent with the original product specification. The reinstallation of gaskets so refurbished is not considered gasket reuse since the sealing performance of the gasket has been restored.

(b) Experience has clearly shown that only a new gasket will reliably provide the necessary plastic deformation and elastic recovery characteristics essential to achieve an effective seal. Visual or physical inspection of a used gasket for apparent damage is not sufficient to detect such sealing surface factors as work hardening, brittleness, or the effects of heat or interaction with the service fluid.

NONMANDATORY APPENDIX O
ASSEMBLY BOLT STRESS DETERMINATION

O-1 INTRODUCTION

(22) **O-1.1 Scope**

This Appendix intends to provide guidance for the determination of an appropriate assembly bolt stress with due consideration for joint integrity. The detailed procedures provided in this Appendix are intended for flange joints for which controlled assembly methods are to be used. Provisions are made for two simple approaches and a joint component approach.

The historic use of a common single bolt stress across all flange sizes and ratings [e.g., 345 MPa (50 ksi)] can result in a gasket stress that does not provide sufficient margin to overcome the effects of creep/relaxation, pressure/external loads, and thermal loading. In addition, the use of this bolt stress can result in either loading bolts past their yield strength, as in the case of austenitic stainless steels, or loading flanges past their flange strength limit, causing permanent flange deformation. For this reason, the joint component approach outlined in this Appendix is preferred. However, for some sites, due to their limited range of operating conditions and flange configurations, the simpler gasket stress or single bolt stress approaches may offer sufficient joint integrity and simpler site execution.

The calculations contained in this Appendix should be used to assist in the selection of other aspects of joint assembly, such as the assembly method and whether additional steps, such as start-up retorque, are required. For example, the calculations may indicate that the required bolt load is close to the flange strength limit, which may require the use of more accurate assembly methods and/or the use of a start-up retorque to recover initial bolt load relaxation. A smaller range of bolt load between the minimum required and the maximum permissible indicates that greater care should be taken with assembly method selection, assembly procedure selection, and load control method.

O-1.2 Cautions

The provisions of this Appendix consider that the ASME PCC-1 guidelines for the joint component condition (flange surface finish, bolt spacing, flange rigidity, bolt condition, etc.) are within acceptable limits.

The methodology outlined in this Appendix assumes that the gaskets being used undergo a reasonable amount (>15%) of relaxation during the initial stages of operation, such that the effects of operational loads in increasing the bolt stress need not be considered (i.e., gasket relaxation will exceed any operational bolt-load increase). In some rare cases, this may not be the case, and the limits should then also be checked at both the ambient and operating bolt stress and temperatures. For most standard applications, this will not be necessary.

In addition, the methodology is for ductile materials (strain at tensile failure in excess of 15%). For brittle materials, the margin between the specified assembly bolt stress and the point of component failure may be considerably reduced and, therefore, additional safety factors should be introduced to guard against such failure.

The method does not consider the effect of fatigue, creep, or environmental damage mechanisms on either the bolt or flange. These additional modes of failure may also need to be considered for applications where they are found and additional reductions in assembly bolt stress may be required to avoid joint component failure.

O-1.3 Definitions (22)

A_b = bolt root area, mm^2 (in.^{2})

A_g = gasket area [$\pi/4$ ($G_{O.D.}{}^2 - G_{I.D.}{}^2$)], mm^2 (in.^{2})[1]

$G_{I.D.}$ = larger of the gasket sealing element or flange seating surface inner diameter, mm (in.)

$G_{O.D.}$ = smaller of the gasket sealing element or the flange seating surface outer diameter, mm (in.)

K = nut factor (for bolt material, lubricant/anti-seize, and temperature)

n_b = number of bolts

P_{max} = maximum design pressure, MPa (psi)

S_{ya} = flange yield stress at assembly, MPa (psi)

S_{yo} = flange yield stress at operation, MPa (psi)

Sb_{max} = maximum permissible bolt stress, MPa (psi)

Sb_{min} = minimum permissible bolt stress, MPa (psi)

Sb_{sel} = selected assembly bolt stress, MPa (psi)

[1] Where a gasket has additional gasket area, such as a pass partition gasket, which may not be as compressed as the main outer sealing element due to flange rotation, a reduced portion of that area, such as half the additional area, should be added to A_g.

Sf_{max} = maximum permissible bolt stress prior to flange damage, MPa (psi)
Sg_{max} = maximum permissible gasket stress, MPa (psi)
$Sg_{min\text{-}O}$ = minimum gasket operating stress, MPa (psi)
$Sg_{min\text{-}S}$ = minimum gasket seating stress, MPa (psi)
Sg_T = target assembly gasket stress, MPa (psi)
T_b = assembly bolt torque, N·m (ft-lb)
T_i = Target Torque Index based on a unit bolt stress, N·m/MPa (ft-lb/ksi)
θf_{max} = single flange rotation at Sf_{max}, deg
θg_{max} = maximum permissible single flange rotation for gasket at the maximum operating temperature, deg
ϕ_b = bolt diameter, mm (in.)
ϕ_g = fraction of gasket load remaining after relaxation

(22) **O-2 ASSEMBLY BOLT STRESS SELECTION**

It is recommended that bolt assembly stresses be established with due consideration of the following joint integrity issues:

(a) Sufficient Gasket Stress to Seal the Joint. The assembly bolt stress should provide sufficient gasket stress to seat the gasket and sufficient gasket stress during operation to maintain a seal.

(b) Damage to the Gasket. The assembly bolt stress should not be high enough to cause overcompression (physical damage) of the gasket or excessive rotation of the flange, which might lead to localized gasket overcompression or damage to the flange sealing surface.

(c) Damage to the Bolts. The specified bolt stress should be below the bolt yield point, such that bolt failure does not occur. In addition, the life of the bolt can be extended by specifying an even lower load. If hydraulic tensioners are used for assembly, then the appropriate load loss factors, per Nonmandatory Appendix Q, should be considered.

(d) Damage to the Flange. The assembly bolt stress should be selected such that permanent deformation of the flange does not occur. If the flange is deformed during assembly, it might leak during operation or successive assemblies might cause joint leakage due to excessive flange rotation. Leakage due to flange rotation may be due to the concentration of the gasket stress on the gasket outer diameter causing damage or additional relaxation. Another potential issue is the flange face outer diameter touching, which reduces the effective gasket stress. If hydraulic tensioners are used for assembly, then the pass B load loss factors, per Nonmandatory Appendix Q, should be considered against flange and gasket damage.

However, it is also important to consider the practicalities involved with the in-field application of the specified bolt stress. If a different assembly stress is specified for each flange in a plant, including all variations of standard piping flanges, then it is unlikely, without a significant assembly quality assurance plan, that success will be improved in the field by comparison to a simpler method. Depending on the complexity of the joints in a given plant, a simple approach (e.g., standard bolt stress per size across all standard flanges) may be more effective in preventing leakage than a more complex approach that includes consideration of the integrity of all joint components.

This Appendix outlines two approaches: the simpler single-assembly bolt stress approach (which is simpler to use but may result in damage to joint components) and a more complex joint component-based approach that considers the integrity of each component.

O-3 SIMPLE APPROACH

O-3.1 Required Information (22)

In order to determine a standard assembly bolt stress for a single joint or across all flanges, it is recommended that, as a minimum, the target gasket stress, Sg_T, for a given gasket type be considered. Further integrity issues, as outlined in section O-4 on the joint component approach, may also be considered, as deemed necessary.

O-3.2 Determining the Appropriate Bolt Stress (22)

The appropriate bolt stress for a range of typical joint configurations may be determined via eq. (O-1).

$$Sb_{sel} = Sg_T \frac{A_g}{n_b A_b} \quad \text{(O-1)}$$

The average bolt stress across the joints considered may then be selected and this value can be converted into a torque value using eq. (O-2M) for metric units or eq. (O-2) for U.S. Customary units.

$$T_b = Sb_{sel} K\, A_b \phi_b / 1\,000 \quad \text{(O-2M)}$$

$$T_b = Sb_{sel} K\, A_b \phi_b / 12 \quad \text{(O-2)}$$

As an alternative to these equations, Tables O-3.2-1M and O-3.2-1 provide reference tables that tabulate Target Torque Indices, T_i, based on eqs. (O-2M) and (O-2) using a unit bolt stress (e.g., substituting a value of 1 for Sb_{sel}), with nut factors of 0.15, 0.18, and 0.2. The final assembly bolt torque may then be obtained by using eq. (O-3). An example is shown in Notes (b)(2) and (b)(3) in Table O-3.2-1M and Notes (b)(2) and (b)(3) in Table O-3.2-1.

The nut factors provided in Tables O-3.2-1M and O-3.2-1 represent examples and may vary from actual values. Refer to Nonmandatory Appendix K for guidance in determining nut factors.

If another bolt stress or nut factor is required, then the table may be converted to the new values using eq. (O-3), where Sb'_{sel}, T'_b, and K' are the original values.

$$T_b = \frac{K}{K'}\frac{Sb_{sel}}{Sb'_{sel}}T'_b = T_i\frac{K}{K'}Sb_{sel} \quad \text{(O-3)}$$

O-4 JOINT COMPONENT APPROACH

(22) O-4.1 Required Information

There are several values that should be known prior to calculating the appropriate assembly bolt stress using the joint component approach.

(a) The maximum permissible flange rotation, θg_{max}, at the assembly gasket stress and the gasket operating temperature should be obtained from industry test data or from the gasket manufacturer. There is presently no standard test for determining this value; however, typical limits vary from 0.3 deg for expanded PTFE gaskets to 1.0 deg for typical graphite-filled metallic gaskets (per flange). A suitable limit may be determined for a given site or application based on the calculation of the amount of rotation that presently exists in flanges in a given service using the gasket type in question, provided that rotation has not been associated with leakage.

(b) The maximum permissible bolt stress, Sb_{max}, should be selected by the user. This value is intended to eliminate damage to the bolt or assembly equipment during assembly and may vary from site to site. It is typically in the range of 40% to 70% of ambient bolt yield stress (see section 10), and the bolt load is sufficiently high to prevent self-loosening.

(c) The minimum permissible bolt stress, Sb_{min}, should be selected by the user. This value is intended to provide a lower limit such that bolting inaccuracies do not become a significant portion of the specified assembly bolt stress, Sb_{sel}, and the bolt load is sufficiently high to prevent self-loosening. The value is typically in the range of 140 MPa to 245 MPa (20 ksi to 35 ksi).

(d) The maximum permissible bolt stress for the flange, Sf_{max}, should be determined, based on the particular flange configuration. This may be found using either elastic closed-form solutions or elastic–plastic finite element analysis, as outlined in section O-5. In addition, when the limits are being calculated, the flange rotation at that load, θf_{max}, should also be determined. Example flange limit loads for elastic closed-form solutions and elastic–plastic finite element solutions are outlined in Tables O-4.1-1M through O-4.1-7.[2]

(e) The target assembly gasket stress, Sg_T, should be selected by the user considering user experience and industry test data or in consultation with the gasket manufacturer. The target gasket stress is based on the full gasket area and should be selected to be near the upper end of the acceptable gasket stress range, as this will give the most amount of buffer against joint leakage.

(f) The maximum assembly gasket stress, Sg_{max}, should be obtained from industry test data or the gasket manufacturer. This value is the maximum compressive stress at the assembly temperature, based on the full gasket area, which the gasket can withstand without permanent damage (excessive leakage or lack of elastic recovery) to the gasket sealing element. Any value provided should include consideration of the effects of flange rotation for the type of flange being considered in increasing the gasket stress locally on the outer diameter.

(g) The minimum gasket seating stress, $Sg_{min\text{-}S}$, should be obtained from industry test data or the gasket manufacturer. This value is the minimum recommended compressive stress at the assembly temperature and is based on the full gasket area. The value is the stress that the gasket should be assembled to in order to obtain adequate redistribution of any filler materials into filler serrations and ensure an initial seal between the gasket and the flange faces.

(h) The minimum gasket operating stress, $Sg_{min\text{-}O}$, should be obtained from industry test data or the gasket manufacturer. This value is the minimum recommended compressive stress after offloading of the gasket by operational loads and is based on the full gasket area. This is the gasket stress that should be maintained on the gasket during operation in order to ensure that leakage does not occur.

(i) The gasket relaxation fraction, ϕ_g, should be obtained from industry test data or the gasket manufacturer for the gasket in flange assemblies of similar configuration (geometry, dimensions, and rigidity) to the ones being assessed. A default value of 0.7 may be used if data are not available.

O-4.2 Determining the Appropriate Bolt Stress (22)

Once the limits are defined, the following process may be used for each joint configuration. This process may be performed using a spreadsheet or software program, which allows the determination of many values simultaneously.

Step 1. Determine the target bolt stress in accordance with eq. (O-1).

Step 2. Determine if the bolt upper limit controls

$$Sb_{sel} = \min.\,(Sb_{sel},\ Sb_{max}) \quad \text{(O-4)}$$

Step 3. Determine if the bolt lower limit controls

$$Sb_{sel} = \max.\,(Sb_{sel},\ Sb_{min}) \quad \text{(O-5)}$$

[2] Limits are not presented for flanges less than NPS 2 (DN 50), as the consequence of gross plastic deformation of such small flanges is generally inconsequential to joint integrity. The smaller joint dimensions mean that the residual flange rotation must be significantly more severe when compared to a larger flange before it can be detected, let alone affect joint integrity. The joint component method may be applied to flange sizes or classes not listed in this Appendix or to small bore flanges using the method outlined in WRC Bulletin 538, but for small bore flanges the bolt load should not be excessively limited due to flange strength (i.e., minimum gasket stress levels should control the calculation, over flange strength).

Step 4. Determine if the flange limit controls[3]

$$Sb_{sel} = \min.\left(Sb_{sel},\ Sf_{max}\right) \quad \text{(O-6)}$$

Step 5. Check if the gasket assembly seating stress is achieved.

$$Sb_{sel} \geq Sg_{min\text{-}S}[A_g/(A_b n_b)] \quad \text{(O-7)}$$

Step 6. Check if the gasket operating stress is maintained.[4]

$$Sb_{sel} \geq \left[Sg_{min\text{-}O} A_g + \left(\pi/4\right)P_{max}G_{I.D.}{}^2\right]/\left(\phi_g A_b n_b\right) \quad \text{(O-8)}$$

Step 7. Check if the gasket maximum stress is achieved.

$$Sb_{sel} \leq Sg_{max}[A_g/(A_b n_b)] \quad \text{(O-9)}$$

Step 8. Check if the flange rotation limit is exceeded.

$$Sb_{sel} \leq Sf_{max}\left(\theta g_{max}/\theta f_{max}\right) \quad \text{(O-10)}$$

If one of the final checks (Step 5 through Step 8) is exceeded, then judgment should be used to determine which controlling limit is more critical to the integrity and, therefore, what the selected bolt load ought to be. A table of assembly bolt torque values can then be calculated using eq. (O-2M) or eq. (O-2). An example table of assembly bolt stresses and torque values using this approach is outlined in Tables O-4.2-1 and O-4.2-2, respectively.

(22) O-4.3 Example Calculation

NPS 3 Class 300 Carbon Steel RFWN Flange Operating at Ambient Temperature (Identical Limits Used as Those in Table O-4-2.1) with a spiral-wound gasket per ASME B16.20 and nut factor per Table O-4.2-2

A_b = 0.3019 in.^{2}
$A_b \cdot n_b$ = 2.42 in.^{2}
A_g = 5.17 in.^{2}
$G_{I.D.}$ = 4.00 in.
n_b = 8
P_{max} = 750 psig (0.75 ksi)
ϕ_b = 0.75 in.
ϕ_g = 0.7

Determine Bolt Stress

Step 1.	Equation (O-1)	Sb_{sel} = 30(5.17/2.42) = 64 ksi
Step 2.	Equation (O-4)	Sb_{sel} = min. (64, 75) = 64 ksi
Step 3.	Equation (O-5)	Sb_{sel} = max. (64, 35) = 64 ksi
Step 4.	Table O-4.1-2	Sf_{max} = 63 ksi (note: $S_{yo} = S_{ya}$)
Step 5.	Equation (O-6)	Sb_{sel} = min. (64, 63) = 63 ksi

Additional Checks

Step 6.	Equation (O-7)	Sb_{sel} ≥ 12.5 (5.17/2.42) ≥ 26.7 ksi ✓
Step 7.	Equation (O-8)	Sb_{sel} ≥ [6.0 × 5.17 + (π/4) × 0.75 × 4.00^2]/(0.7 × 2.42) ≥ 24 ksi ✓
Step 8.	Equation (O-9)	Sb_{sel} ≤ 40 (5.17/2.42) ≤ 85 ksi ✓
	Table O-4.1-4	θf_{max} = 0.32 deg
	Equation (O-10)	Sb_{sel} ≤ 63 (1.0/0.32) ≤ 197 ksi ✓
	Equation (O-2)	T_b = 63,000 × 0.2 × 0.3019 × 0.75/12 T_b ≈ 240 ft-lb
	Alternative: Use Table O-3.2-1	T_b = 63 ksi × 3.78 ft lb/ksi = 238 ft-lb

Note that for some flanges (e.g., NPS 8, class 150) the additional limits [eq. (O-7) through eq. (O-10)] are not satisfied. In those cases, engineering judgment should be used to determine which limits are more critical to the joint integrity, and the value of Sb_{sel} should be modified accordingly. It should be noted that the values presented are not hard limits (i.e., flange leakage will not occur if the gasket stress falls 0.1 psi below the limit) and therefore some leeway in using the values is to be considered normal.

O-5 DETERMINING FLANGE LIMITS

O-5.1 Elastic Analysis (22)

A series of elastic analysis limits have been determined that allow the calculation of the approximate assembly bolt stress that will cause significant permanent deformation of the flange. Since this bolt stress is approximate, and the flange specified minimum yield tends to be lower bound (i.e., the actual material yield will exceed the specified minimum yield strength), it is considered appropriate to use these limits without modification or additional safety factor. An explanation of the limits and equations used to determine the bolt stress can be found in WRC Bulletin 538. The inaccuracy of applied bolt stress may be considered in this process; however, caution is urged that including such considerations may lead to

[3] In some cases (e.g., high-temperature stainless steel flanges), the yield strength of the flange may reduce significantly during operation. While this is important to consider, in some cases consideration of this effect will result in the selection of an assembly bolt load that will result in joint leakage. Once in operation, the bolt load becomes a secondary load (i.e., the load decreases with component yield). Therefore, the effect of temperature-driven component yield will be seen only as additional joint relaxation and minor permanent deformation. Often, the actual material yield for stainless steel is significantly above the specified minimum yield, and therefore it is considered more prudent to tighten to a higher load initially and risk possible permanent deformation than to tighten to a lower load and risk certain joint leakage. However, if the selected load minus bolt relaxation remains well above the flange strength at operating temperature, permanent deformation can eventually cause issues (such as not being able to insert the bolts due to residual flange rotation). In that case, it may be appropriate to use a higher level of analysis than that presented in this Appendix.

[4] Note that this simple treatment does not take into account the changes in bolt load during operation due to component elastic interaction. A more complex relationship for the operational gasket stress may be used in lieu of this equation that includes the effects of elastic interaction in changing the bolt stress. Note also that the use of the G term from ASME BPVC, Section VIII, Division 1, Mandatory Appendix 2 in place of $G_{I.D.}$ in this equation is considered acceptable.

the selection of bolt stress levels that risk leakage. For simplicity and to err on the side of a higher bolt load, scatter is not considered essential to include in this method.

O-5.2 Finite Element Analysis

A more accurate approach to determining the appropriate limit on assembly bolt load is to analyze the joint using elastic–plastic nonlinear finite element analysis (FEA). An explanation of the requirements for performing such an analysis is outlined in WRC Bulletin 538. It is not necessary to rerun the analysis for minor changes to the joint configuration (such as different gasket dimensions or minor changes to the flange material yield strength) as linear interpolation using the ratio of the change in gasket moment arm or ratio of the different yield strength can be used to estimate the assembly bolt stress limit for the new case.

Table O-3.2-1M Reference Values (Target Torque Index) for Calculating Target Torque Values for Low-Alloy Steel Bolting Based on Unit Prestress of 1 MPa (Root Area) (Metric Series Threads) (22)

Basic Thread Designation	Target Torque Index, T_i, N·m/MPa (ft-lb/ksi), at Nut Factor, K, of		
	0.15	0.18	0.2
M12 × 1.75	0.13 (0.66)	0.16 (0.80)	0.17 (0.88)
M14 × 2	0.21 (1.07)	0.25 (1.28)	0.28 (1.42)
M16 × 2	0.33 (1.69)	0.40 (2.03)	0.44 (2.25)
M20 × 2.5	0.65 (3.31)	0.78 (3.97)	0.87 (4.42)
M22 × 2.5	0.90 (4.57)	1.08 (5.49)	1.20 (6.10)
M24 × 3	1.13 (5.73)	1.35 (6.87)	1.50 (7.63)
M27 × 3	1.68 (8.52)	2.01 (10.2)	2.23 (11.4)
M30 × 3.5	2.26 (11.5)	2.72 (13.8)	3.02 (15.3)
M33 × 3.5	3.11 (15.8)	3.74 (19.0)	4.15 (21.1)
M36 × 4	3.99 (20.3)	4.78 (24.3)	5.31 (27.0)
M39 × 4	5.20 (26.5)	6.24 (31.8)	6.94 (35.3)
M42 × 4.5	6.41 (32.6)	7.70 (39.1)	8.55 (43.5)
M45 × 4.5	8.07 (41.0)	9.68 (49.2)	10.8 (54.7)
M48 × 5	9.67 (49.2)	11.6 (59.0)	12.9 (65.6)
M52 × 5	12.6 (64.1)	15.1 (76.9)	16.8 (85.4)
M56 × 5.5	15.6 (79.6)	18.8 (95.5)	20.9 (106)
M64 × 6	23.7 (120)	28.4 (145)	31.6 (161)
M72 × 6	34.8 (177)	41.8 (212)	46.4 (236)
M80 × 6	48.9 (249)	58.7 (299)	65.2 (332)
M90 × 6	71.4 (363)	85.7 (436)	95.2 (484)
M100 × 6	99.8 (507)	120 (609)	133 (677)

GENERAL NOTES:

(a) The root areas are based on coarse-thread series for sizes M68 and smaller, and 6-mm pitch thread series for sizes M70 and larger. The determination of root area for metric threads is based on a 6g tolerance.

(b) There are many ways of calculating target torque values for bolted pressure joints. The basis for Target Torque Index values in this table are described below. When conditions vary from those considered in this table, such as different bolt materials or different coatings, refer to Nonmandatory Appendix K to compute appropriate torque values.

(1) The tabulated target torque values are based on working surfaces that comply with sections 4 and 8.

(2) The Target Torque Index, T_i, is determined from eq. (O-2), for the nut factor indicated and applying a unit bolt load of 1 MPa for Sb_{sel}. For example, for an M20 bolt using a nut factor of 0.2

$$T_i = Sb_{sel}\, K\, A_b\, \phi_b / 1000 = 1 \times 0.2 \times 217 \times 20 / 1000 = 0.87$$

(3) When the Target Torque Index, T_i, is determined, this value is multiplied by the selected assembly bolt load Sb_{sel} to arrive at the final torque value, T_b. For example, the M20 bolt in (2) is in the NPS 3 Class 300 flange described in the example calculation in para. O-4.3, for which the selected assembly bolt stress, Sb_{sel}, is 434 MPa. The target torque becomes

$$T_b = Sb_{sel} \times T_i = 434\ \text{MPa} \times 0.87\ \text{N·m/MPa} = 378\ \text{N·m}$$

This calculated value is rounded up to the nearest 5 N·m to become 380 N·m.

(22)

Table O-3.2-1 Reference Values (Target Torque Index) for Calculating Target Torque Values for Low-Alloy Steel Bolting Based on Unit Prestress of 1 ksi (Root Area) (Inch Series Threads)

Nominal Bolt Size, in.	Target Torque Index, T_i, ft-lb/ksi (N·m/MPa), at Nut Factor, K, of		
	0.15	0.18	0.2
½	0.79 (0.15)	0.94 (0.19)	1.05 (0.21)
⅝	1.58 (0.31)	1.89 (0.37)	2.10 (0.41)
¾	2.83 (0.56)	3.40 (0.67)	3.78 (0.74)
⅞	4.58 (0.90)	5.50 (1.08)	6.11 (1.20)
1	6.89 (1.35)	8.27 (1.63)	9.18 (1.81)
1⅛	10.2 (2.01)	12.3 (2.42)	13.7 (2.68)
1¼	14.5 (2.85)	17.4 (3.43)	19.4 (3.81)
1⅜	19.9 (3.90)	23.8 (4.68)	26.5 (5.20)
1½	26.3 (5.18)	31.6 (6.22)	35.1 (6.91)
1⅝	34.1 (6.71)	41.0 (8.05)	45.5 (8.95)
1¾	43.3 (8.52)	52.0 (10.2)	57.8 (11.4)
1⅞	53.9 (10.6)	64.7 (12.7)	71.9 (14.1)
2	66.3 (13.0)	79.5 (15.6)	88.3 (17.4)
2¼	96.2 (18.9)	115 (22.7)	128 (25.2)
2½	134 (26.4)	161 (31.6)	179 (35.2)
2¾	181 (35.6)	217 (42.7)	241 (47.4)
3	237 (46.6)	284 (55.9)	316 (62.1)
3¼	304 (59.8)	365 (71.8)	406 (79.8)
3½	383 (75.3)	459 (90.3)	510 (100)
3¾	474 (93.2)	569 (112)	632 (124)
4	579 (114)	694 (137)	771 (152)

GENERAL NOTES:

(a) The root areas are based on coarse-thread series for sizes 1 in. and smaller, and 8-pitch thread series for sizes 1⅛ in. and larger. The determination of root area for inch series threads is based on a 2A tolerance.

(b) There are many ways of calculating target torque values for bolted pressure joints. The basis for Target Torque Index values in this table are described below. When conditions vary from those considered in this table, such as different bolt materials or different coatings, refer to Nonmandatory Appendix K to compute appropriate torque values.

(1) The tabulated target torque values are based on working surfaces that comply with sections 4 and 8.

(2) The Target Torque Index, T_i, is determined from eq. (O-2), for the nut factor indicated and applying a unit bolt load of 1 ksi for Sb_{sel}. For example, for a ¾ in. bolt using a nut factor of 0.2

$$T_i = Sb_{sel}\, K\, A_b\, \phi_b/12 = 1{,}000 \times 0.2 \times 0.302 \times 0.75/12 = 3.78$$

where the value of 1,000 represents 1,000 psi rather than 1 ksi to maintain consistency in units.

(3) When the Target Torque Index, T_i, is determined, this value is multiplied by the selected assembly bolt load Sb_{sel} to arrive at the final torque value, T_b. For example, the ¾ in. bolt in (2) is in the NPS 3 Class 300 flange described in the example calculation in para. O-4.3, for which the selected assembly bolt stress, Sb_{sel}, is 63 ksi. The target torque becomes

$$T_b = Sb_{sel} \times T_i = 63\,\text{ksi} \times 3.78\,\text{ft-lb/ksi} = 238\,\text{ft-lb}$$

This calculated value is rounded up to the nearest 5 ft-lb to become 240 ft-lb.

Table O-4.1-1M
Pipe Wall Thickness Used for Following Tables (mm)

	Class					
NPS	150	300	600	900	1500	2500
2	1.65	1.65	3.91	2.77	5.54	8.74
2½	2.11	2.11	3.05	5.16	7.01	14.02
3	2.11	2.11	3.05	5.49	7.62	15.24
4	2.11	2.11	6.02	6.02	11.13	17.12
5	2.77	2.77	6.55	9.52	12.70	19.05
6	2.77	2.77	7.11	10.97	14.27	23.12
8	2.77	3.76	8.18	12.70	20.62	30.10
10	3.40	7.80	12.70	15.09	25.40	37.49
12	3.96	8.38	12.70	17.48	28.58	44.47
14	3.96	6.35	12.70	19.05	31.75	...
16	4.19	7.92	14.27	23.83	34.93	...
18	4.78	9.53	20.62	26.19	44.45	...
20	4.78	9.53	20.62	32.54	44.45	...
24	5.54	14.27	24.61	38.89	52.37	...
26	7.92	12.70	23.73	35.09	...	...
28	7.92	12.70	25.56	37.79	...	...
30	6.35	15.88	27.38	40.49	...	...
32	7.92	15.88	29.21	43.19	...	...
34	7.92	15.88	31.03	45.89	...	...
36	7.92	19.05	32.86	48.59	...	...
38	9.53	17.60	34.69	51.29	...	...
40	9.53	18.52	36.51	53.99	...	...
42	9.53	19.45	38.34	56.69	...	...
44	9.53	20.37	40.16	59.39	...	...
46	9.53	21.30	41.99	62.09	...	...
48	9.53	22.23	43.81	64.79	...	...

Table O-4.1-1
Pipe Wall Thickness Used for Following Tables (in.)

	Class					
NPS	150	300	600	900	1500	2500
2	0.065	0.065	0.154	0.109	0.218	0.344
2½	0.083	0.083	0.120	0.203	0.276	0.552
3	0.083	0.083	0.120	0.216	0.300	0.600
4	0.083	0.083	0.237	0.237	0.438	0.674
5	0.109	0.109	0.258	0.375	0.500	0.750
6	0.109	0.109	0.280	0.432	0.562	0.910
8	0.109	0.148	0.322	0.500	0.812	1.185
10	0.134	0.307	0.500	0.594	1.000	1.476
12	0.156	0.330	0.500	0.688	1.125	1.751
14	0.156	0.250	0.500	0.750	1.250	...
16	0.165	0.312	0.562	0.938	1.375	...
18	0.188	0.375	0.812	1.031	1.750	...
20	0.188	0.375	0.812	1.281	1.750	...
24	0.218	0.562	0.969	1.531	2.062	...
26	0.312	0.500	0.934	1.382	...	...
28	0.312	0.500	1.006	1.488	...	...
30	0.250	0.625	1.078	1.594	...	...
32	0.312	0.625	1.150	1.700	...	...
34	0.312	0.625	1.222	1.807	...	...
36	0.312	0.750	1.294	1.913	...	...
38	0.375	0.693	1.366	2.019	...	...
40	0.375	0.729	1.437	2.126	...	...
42	0.375	0.766	1.509	2.232	...	...
44	0.375	0.802	1.581	2.338	...	...
46	0.375	0.839	1.653	2.444	...	...
48	0.375	0.875	1.725	2.551	...	...

Table O-4.1-2M
Bolt Stress Limit for SA-105 Steel Flanges Using Elastic–Plastic FEA (MPa)

ASME B16.5 and ASME B16.47 Series A — Weld Neck						
	Class					
NPS	150	300	600	900	1500	2500
2	579	398	579	434	471	471
2½	688	326	434	398	471	543
3	724	434	615	579	471	579
4	543	615	688	434	507	507
5	543	724	652	507	543	543
6	724	579	579	579	615	579
8	724	579	615	507	579	579
10	579	543	543	507	615	579
12	724	543	507	543	579	615
14	579	434	471	543	543	...
16	543	434	471	579	507	...
18	724	471	579	543	543	...
20	615	507	507	579	507	...
24	615	471	507	543	507	...
26	253	253	362	434	...	...
28	217	253	326	398	...	...
30	253	290	434	434	...	...
32	217	253	398	434	...	...
34	190	290	434	398	...	...
36	217	253	398	434	...	...
38	253	579	579	543	...	...
40	217	543	615	543	...	...
42	253	543	615	579	...	...
44	226	579	615	543	...	...
46	253	615	652	543	...	...
48	253	507	579	579	...	...

Table O-4.1-2
Bolt Stress Limit for SA-105 Steel Flanges Using Elastic–Plastic FEA (ksi)

ASME B16.5 and ASME B16.47 Series A — Weld Neck						
	Class					
NPS	150	300	600	900	1500	2500
2	84	58	84	63	68	68
2½	100	47	63	58	68	79
3	105	63	89	84	68	84
4	79	89	100	63	74	74
5	79	105	95	74	79	79
6	105	84	84	84	89	84
8	105	84	89	74	84	84
10	84	79	79	74	89	84
12	105	79	74	79	84	89
14	84	63	68	79	79	...
16	79	63	68	84	74	...
18	105	68	84	79	79	...
20	89	74	74	84	74	...
24	89	68	74	79	74	...
26	37	37	53	63	...	...
28	32	37	47	58	...	...
30	37	42	63	63	...	...
32	32	37	58	63	...	...
34	28	42	63	58	...	...
36	32	37	58	63	...	...
38	37	84	84	79	...	...
40	32	79	89	79	...	...
42	37	79	89	84	...	...
44	33	84	89	79	...	...
46	37	89	95	79	...	...
48	37	74	84	84	...	...

Table O-4.1-3
Flange Rotation for SA-105 Steel Flanges Loaded to Table O-4.1-2M/Table O-4.1-2 Bolt Stress Using Elastic–Plastic FEA (deg)

ASME B16.5 and ASME B16.47 Series A — Weld Neck						
	Class					
NPS	150	300	600	900	1500	2500
2	0.37	0.34	0.23	0.21	0.20	0.16
$2\frac{1}{2}$	0.36	0.31	0.24	0.20	0.21	0.17
3	0.23	0.32	0.26	0.26	0.22	0.16
4	0.50	0.37	0.29	0.26	0.21	0.17
5	0.56	0.33	0.29	0.28	0.20	0.17
6	0.61	0.41	0.30	0.27	0.21	0.16
8	0.46	0.45	0.31	0.28	0.21	0.17
10	0.70	0.43	0.34	0.30	0.21	0.17
12	0.74	0.48	0.35	0.34	0.22	0.16
14	0.68	0.48	0.39	0.33	0.24	...
16	0.83	0.48	0.39	0.34	0.23	...
18	0.88	0.51	0.41	0.33	0.24	...
20	0.87	0.58	0.40	0.32	0.24	...
24	0.95	0.59	0.41	0.31	0.26	...
26	0.87	0.59	0.43	0.35	...	...
28	0.84	0.50	0.40	0.37	...	...
30	0.97	0.60	0.43	0.35	...	...
32	0.98	0.49	0.48	0.37	...	...
34	0.87	0.52	0.41	0.35	...	...
36	0.85	0.51	0.44	0.38	...	...
38	1.09	0.51	0.39	0.34	...	...
40	0.93	0.52	0.43	0.37	...	...
42	1.04	0.60	0.43	0.35	...	...
44	0.91	0.54	0.43	0.35	...	...
46	1.00	0.52	0.43	0.37	...	...
48	1.04	0.63	0.42	0.35	...	...

Table O-4.1-4M
Bolt Stress Limit for SA-105 Steel Flanges Using Elastic Closed Form Analysis (MPa)

ASME B16.5 and ASME B16.47 Series A — Weld Neck						
	Class					
NPS	150	300	600	900	1500	2500
2	450	310	515	332	413	447
2½	576	284	388	377	441	496
3	724	394	545	517	432	531
4	445	561	633	417	492	454
5	402	724	663	468	528	501
6	541	593	630	543	605	535
8	724	614	657	463	576	557
10	503	639	566	444	627	543
12	712	607	563	494	554	594
14	583	454	513	526	485	…
16	563	398	508	532	487	…
18	614	472	594	534	521	…
20	568	451	482	545	501	…
24	479	365	450	546	481	…
26	218	242	359	448	…	…
28	193	264	354	399	…	…
30	228	290	447	465	…	…
32	173	272	396	460	…	…
34	160	296	463	418	…	…
36	207	261	404	436	…	…
38	211	557	623	551	…	…
40	199	536	634	532	…	…
42	218	581	626	585	…	…
44	221	676	638	570	…	…
46	238	724	687	563	…	…
48	222	524	605	625	…	…

ASME B16.5 — Slip-On					
	Class				
NPS	150	300	600	900	1500
2	724	360	572	423	413
2½	534	321	410	377	441
3	714	446	563	518	…
4	394	594	601	467	…
5	446	678	507	492	…
6	603	458	495	536	…
8	724	538	515	456	…
10	477	472	430	429	…
12	674	476	421	468	…
14	445	283	344	504	…
16	453	320	370	509	…
18	561	376	546	514	…
20	487	428	499	524	…
24	535	395	500	528	…

Table O-4.1-4
Bolt Stress Limit for SA-105 Steel Flanges Using Elastic Closed Form Analysis (ksi)

ASME B16.5 and ASME B16.47 Series A — Weld Neck						
	Class					
NPS	150	300	600	900	1500	2500
2	65	45	75	48	60	65
2½	83	41	56	55	64	72
3	105	57	79	75	63	77
4	65	81	92	61	71	66
5	58	105	96	68	77	73
6	78	86	91	79	88	78
8	105	89	95	67	83	81
10	73	93	82	64	91	79
12	103	88	82	72	80	86
14	84	66	74	76	70	…
16	82	58	74	77	71	…
18	89	69	86	77	76	…
20	82	65	70	79	73	…
24	69	53	65	79	70	…
26	32	35	52	65	…	…
28	28	38	51	58	…	…
30	33	42	65	67	…	…
32	25	40	58	67	…	…
34	23	43	67	61	…	…
36	30	38	59	63	…	…
38	31	81	90	80	…	…
40	29	78	92	77	…	…
42	32	84	91	85	…	…
44	32	98	93	83	…	…
46	35	105	100	82	…	…
48	32	76	88	91	…	…

ASME B16.5 — Slip-On					
	Class				
NPS	150	300	600	900	1500
2	105	52	83	61	60
2½	77	47	60	55	64
3	103	65	82	75	…
4	57	86	87	68	…
5	65	98	74	71	…
6	87	66	72	78	…
8	105	78	75	66	…
10	69	68	62	62	…
12	98	69	61	68	…
14	65	41	50	73	…
16	66	46	54	74	…
18	81	55	79	75	…
20	71	62	72	76	…
24	78	57	73	77	…

Table O-4.1-5
Flange Rotation for SA-105 Steel Flanges Loaded to Table O-4.1-4M/Table O-4.1-4 Bolt Stress Using Elastic Closed Form Analysis (deg)

ASME B16.5 and ASME B16.47 Series A — Weld Neck						
	Class					
NPS	150	300	600	900	1500	2500
2	0.20	0.20	0.15	0.13	0.09	0.08
2½	0.22	0.19	0.17	0.11	0.09	0.07
3	0.20	0.22	0.19	0.15	0.12	0.08
4	0.28	0.27	0.19	0.17	0.14	0.10
5	0.29	0.26	0.20	0.18	0.14	0.10
6	0.33	0.32	0.24	0.16	0.15	0.10
8	0.35	0.36	0.28	0.18	0.15	0.11
10	0.44	0.40	0.27	0.17	0.16	0.10
12	0.46	0.42	0.32	0.21	0.15	0.11
14	0.46	0.38	0.35	0.24	0.15	...
16	0.54	0.36	0.36	0.23	0.17	...
18	0.54	0.41	0.34	0.26	0.18	...
20	0.60	0.39	0.33	0.24	0.19	...
24	0.59	0.37	0.34	0.26	0.20	...
26	0.77	0.55	0.42	0.33	...	...
28	0.79	0.56	0.43	0.33	...	...
30	0.88	0.58	0.42	0.34	...	...
32	0.84	0.58	0.43	0.34	...	...
34	0.85	0.57	0.43	0.34	...	...
36	0.90	0.56	0.43	0.34	...	...
38	0.93	0.71	0.48	0.35	...	...
40	0.93	0.71	0.48	0.35	...	...
42	0.94	0.71	0.48	0.36	...	...
44	0.96	0.71	0.48	0.36	...	...
46	0.98	0.71	0.48	0.36	...	...
48	0.95	0.71	0.48	0.36	...	...

Table O-4.1-5
Flange Rotation for SA-105 Steel Flanges Loaded to Table O-4.1-4M/Table O-4.1-4 Bolt Stress Using Elastic Closed Form Analysis (deg) (Cont'd)

ASME B16.5 — Slip-On					
	Class				
NPS	150	300	600	900	1500
2	0.34	0.28	0.21	0.14	0.10
2½	0.35	0.29	0.24	0.12	0.10
3	0.40	0.32	0.27	0.21	...
4	0.52	0.38	0.27	0.21	...
5	0.64	0.43	0.30	0.20	...
6	0.73	0.49	0.33	0.20	...
8	0.84	0.57	0.38	0.22	...
10	1.02	0.59	0.40	0.27	...
12	1.09	0.66	0.47	0.33	...
14	1.14	0.70	0.50	0.33	...
16	1.26	0.76	0.52	0.33	...
18	1.34	0.80	0.52	0.34	...
20	1.38	0.86	0.55	0.33	...
24	1.52	0.91	0.58	0.33	...

Table O-4.1-6M Bolt Stress Limit for SA-182 F304 Steel Flanges Using Elastic–Plastic FEA (MPa)

ASME B16.5 and ASME B16.47 Series A — Weld Neck						
	Class					
NPS	150	300	600	900	1500	2500
2	434	326	471	362	362	398
$2\frac{1}{2}$	543	253	362	326	398	434
3	724	362	507	471	362	471
4	362	471	543	362	434	434
5	398	615	543	398	434	434
6	543	471	471	471	471	471
8	579	471	507	434	471	471
10	434	434	434	434	507	471
12	471	434	434	434	471	507
14	434	326	362	434	434	...
16	362	362	362	471	434	...
18	398	398	471	471	434	...
20	362	398	398	471	434	...
24	362	362	398	434	398	...
26	217	181	290	362	...	...
28	181	217	290	326	...	...
30	217	217	362	362	...	...
32	181	217	326	362	...	...
34	172	253	362	326	...	...
36	181	217	326	362	...	...
38	181	471	471	434	...	...
40	145	434	507	434	...	...
42	217	434	507	471	...	...
44	154	471	471	434	...	...
46	217	507	507	434	...	...
48	217	398	471	471	...	...

Table O-4.1-6 Bolt Stress Limit for SA-182 F304 Steel Flanges Using Elastic–Plastic FEA (ksi)

ASME B16.5 and ASME B16.47 Series A — Weld Neck						
	Class					
NPS	150	300	600	900	1500	2500
2	63	47	68	53	53	58
$2\frac{1}{2}$	79	37	53	47	58	63
3	105	53	74	68	53	68
4	53	68	79	53	63	63
5	58	89	79	58	63	63
6	79	68	68	68	68	68
8	84	68	74	63	68	68
10	63	63	63	63	74	68
12	68	63	63	63	68	74
14	63	47	53	63	63	...
16	53	53	53	68	63	...
18	58	58	68	68	63	...
20	53	58	58	68	63	...
24	53	53	58	63	58	...
26	32	26	42	53	...	...
28	26	32	42	47	...	...
30	32	32	53	53	...	...
32	26	32	47	53	...	...
34	25	37	53	47	...	...
36	26	32	47	53	...	...
38	26	68	68	63	...	...
40	21	63	74	63	...	...
42	32	63	74	68	...	...
44	22	68	68	63	...	...
46	32	74	74	63	...	...
48	32	58	68	68	...	...

Table O-4.1-7
Flange Rotation for SA-182 F304 Steel Flanges Loaded to Table O-4.1-6M/Table O-4.1-6 Bolt Stress Using Elastic–Plastic FEA (deg)

ASME B16.5 and ASME B16.47 Series A — Weld Neck						
	Class					
NPS	150	300	600	900	1500	2500
2	0.47	0.34	0.21	0.17	0.15	0.16
2½	0.40	0.29	0.20	0.20	0.24	0.13
3	0.21	0.27	0.29	0.23	0.16	0.12
4	0.55	0.41	0.25	0.21	0.19	0.15
5	0.61	0.32	0.27	0.25	0.20	0.18
6	0.64	0.38	0.27	0.24	0.17	0.15
8	0.46	0.42	0.34	0.25	0.19	0.15
10	0.91	0.47	0.26	0.26	0.17	0.15
12	0.79	0.37	0.31	0.26	0.20	0.17
14	0.89	0.41	0.28	0.25	0.19	...
16	1.02	0.41	0.29	0.31	0.20	...
18	0.93	0.54	0.28	0.25	0.18	...
20	1.02	0.53	0.35	0.29	0.20	...
24	1.12	0.44	0.37	0.24	0.23	...
26	0.81	0.53	0.33	0.29	...	...
28	0.52	0.45	0.37	0.25	...	...
30	0.91	0.41	0.35	0.29	...	...
32	0.59	0.43	0.31	0.31	...	...
34	0.68	0.37	0.34	0.24	...	...
36	0.54	0.44	0.30	0.31	...	...
38	1.00	0.46	0.35	0.26	...	...
40	0.91	0.55	0.35	0.28	...	...
42	0.52	0.64	0.34	0.32	...	...
44	0.54	0.48	0.34	0.27	...	...
46	1.00	0.55	0.41	0.28	...	...
48	0.51	0.55	0.38	0.32	...	...

Table O-4.2-1
Example Bolt Stress for SA-105 Steel Weld-Neck Flanges, SA-193 B7 Steel Bolts, and Spiral-Wound Gasket With Inner Ring (ksi)
ASME B16.5 and ASME B16.47 Series A — Weld Neck

Calculated Bolt Stress (ksi)						
NPS	**150**	**300**	**600**	**900**	**1500**	**2500**
2	75	56	56	43	43	35
$2^1/_2$	75	44	44	40	40	35
3	75	63	64	60	38	35
4	75	75	75	49	42	35
5	75	75	75	48	36	35
6	75	75	74	56	38	35
8	75	75	75	44	35	35
10	75	75	62	40	35	35
12	75	75	66	49	35	35
14	75	63	54	44	35	
16	75	63	58	42	35	
18	75	68	62	45	35	
20	75	74	57	38	35	
24	75	68	50	35	35	
26	37	37	41	35		
28	35	37	38	35		
30	37	42	41	35		
32	35	37	35	35		
34	35	42	36	35		
36	35	37	35	35		
38	37	75	39	35		
40	35	68	36	35		
42	37	71	35	35		
44	35	68	35	35		
46	37	69	35	35		
48	37	63	35	35		

Legend:

(yellow) = limited by min. bolt stress

(red) = limited by max. bolt stress

(green) = limited by max. gasket stress

(olive) = limited by max. flange stress

GENERAL NOTE: Example limits used in the analysis:

Sb_{min} = 35 ksi
Sb_{max} = 75 ksi
Sf_{max} = from Table O-4.1-2
Sg_t = 30 ksi
Sg_{max} = 40 ksi
$Sg_{min\text{-}S}$ = 12.5 ksi
$Sg_{min\text{-}O}$ = 6 ksi
θg_{max} = 1.0 deg