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ASME PCC-1—2000

GUIDELINES FOR PRESSURE BOUNDARY BOLTED FLANGE JOINT ASSEMBLY

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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 non-nuclear 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 possibly 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. The *Inspection Planning Standard* provides guidance on the preparation of a risk-based inspection plan. Defects that are identified are then evaluated, when appropriate, using the procedures provided in the *Flaw Evaluation Standard.* Finally, if it is determined that repairs are required, guidance on repair procedures is provided in the appropriate *Repair of Pressure Equipment and Piping Standard.* These documents are in various stages of preparation.

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 NB-23, and with jurisdictional requirements.

The first edition of ASME PCC-1, *Guidelines for Pressure Boundary Bolted Flange Joint Assembly,* was approved for publication in 2000. ASME PCC-1–2000 was approved by ANSI as an American National Standard on November 15, 2000.

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GUIDELINES FOR PRESSURE BOUNDARY BOLTED FLANGE JOINT ASSEMBLY

1 SCOPE

The bolted flange joint assembly (BFJA) guidelines described in this document apply to pressure-boundary flanged joints with ring-type gaskets that are entirely within the circle enclosed by the bolt holes and with no contact outside this circle.[1] By selection of those features suitable to the specific service or need, these guidelines may be used to develop effective joint assembly procedures for the broad range of sizes and service conditions normally encountered in the process industries.

2 INTRODUCTION

A BFJA is a complex mechanical device; therefore, BFJAs that provide leak-free service are the result of many selections/activities having been made/performed within a relatively narrow band of acceptable limits. One of the activities essential to leak-free performance is the joint assembly process. The guidelines outlined in this document cover the assembly elements essential for consistent leak-tight performance of otherwise properly designed/constructed BFJAs. It is recommended that written procedures, incorporating the features of these guidelines that are deemed suitable to the specific application under consideration, be developed for use by the joint assemblers.

3 QUALIFICATION

The user or his designated agent should provide, or arrange to have provided, as appropriate, essential training and qualification testing of the joint assemblers who will be expected to follow procedures developed from this Guideline. Qualification of the selected joint assembly procedure may be appropriate for critical applications.

Appendix A provides some notes on qualifying flanged joint assemblers.

Appendix B provides a recommended flanged joint assembly procedure qualification test.

4 EXAMINATION OF "WORKING" SURFACES

Clean and examine all "working" surfaces before assembly is started.

(a) Examine the gasket contact surfaces of both joint flanges for appropriate surface finish (see Appendix C) and for damage to surface finish such as scratches, nicks, gouges, and burrs. Indications running radially across the facing are of particular concern. Report any questionable imperfections for appropriate disposition.

(b) Check gasket contact surfaces of both joint flanges for flatness, both radially and circumferentially. Report any questionable results.

Appendix D provides a recommendation for flatness tolerance.

(c) Examine bolt[2] and nut threads and washer faces of nuts for damage such as rust, corrosion, and burrs; replace questionable parts. If separate washers[3] are scored or cupped from previous use, replace with new through-hardened washers (surface-hardened washers are not suitable). Previously used bolts should be thoroughly cleaned (such as wire brushing) before being reused.

(d) Examine nut-bearing surfaces of flanges for scores, burrs, etc.; remove protrusions, spot-face if required.

---

[1] Rules for design of bolted flanges with ring-type gaskets are covered in Mandatory Appendix 2 of ASME Boiler and Pressure Vessel Code, Section VIII, Division 1; see also Nonmandatory Appendix S-2 for supplementary design considerations for bolted flanges, the implementation of which is recommended for custom flanges designed in accordance with Mandatory Appendix 2.

[2] "Bolt" as used herein is an all-inclusive term for any type of threaded fastener that may be used in a pressure-boundary BFJA such as a bolt, stud, studbolt, cap screw, etc.

[3] Use of washers is optional. However, it is generally recognized that the use of through-hardened steel washers will improve the translation of torque input into residual bolt stretch. See Notes on indicator bolt specification sheets, Figs. 1 and 2, for a through-hardened washer specification.

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5 ALIGNMENT OF MATING SURFACES

Ensure flanges are aligned both axially and rotationally to the design plane within engineering design parameters without use of excessive force. Report any questionable misalignment.

Appendix E provides a recommendation for alignment tolerances.

6 INSTALLATION OF GASKET

Place a new gasket in position after determining the absence of unacceptable imperfections or damage.

(a) Verify that the gasket complies with the dimensional (OD, ID, thickness) and material specifications.

(b) Position the gasket to be concentric with the flange ID, taking suitable measures to ensure that it is adequately supported during the positioning process. No portion of the gasket should project into the flow path.

(c) Ensure that the gasket will remain in place during the joint assembly process; a very light dusting of spray adhesive on the gasket (not the flange) may be used. Particular care should be taken to avoid adhesive chemistry that is incompatible with the process fluid or could result in stress corrosion cracking or pitting of the flange surfaces. *Do not use tape strips radially across the gasket to hold it in position. Do not use grease.*

7 LUBRICATION OF "WORKING" SURFACES

With one exception, liberally coat all internal and external thread surfaces and nut/washer faces with appropriate lubricant; the exception is: *lubricant is not to be applied to these "working" surfaces for the initial tightening of new, coated bolts/nuts* [see Note (3) of Table 1M/Table 1]. The torque values for new, coated bolts/nuts shown in Table 1M/Table 1 do not consider lubrication other than that provided by the bolt/nut coating [see Note (2) of Table 1M/Table 1]. *Do not apply lubricant to the gasket or gasket-contact surfaces.*

(a) Ensure that the lubricant is chemically compatible with the bolt/nut/washer materials and the process fluid. Particular care should be taken to avoid lubricant chemistry that could result in stress corrosion cracking.

(b) Ensure that the lubricant is suitable for the expected service temperature(s).

(c) While it is recognized that the inherent lubricity of new coated bolts results in less torque being required during the first tightening application to achieve a given level of tension in the bolt (see Table 1M/Table 1), the major long-term value of coated bolts is to promote ease of joint disassembly [see paras. 8.2.1 and 15, and Note (3) of Table 1M/Table 1].

8 INSTALLATION OF BOLTS

Install bolts and nuts hand-tight, then "snug up" to 15 N·m (10 ft-lb) to 30 N·m (20 ft-lb), but not to exceed 20% of the Target Torque (see para. 12). If nuts will not hand tighten, check for cause and make necessary corrections.

8.1 Bolt/Nut Specifications

Verify compliance with bolt and nut specifications [materials, diameter, length of bolts, thread pitch, and nut thickness equal to the nominal bolt diameter (heavy hex series nuts)].

8.2 Bolt Lengths

Check bolts for adequate length. Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code (1998 Edition, 1999 Addenda) requires that nuts engage the threads for the full depth of the nut (see para. UG-13). The ASME B31.3, Process Piping Code (1999 Edition), has a similar provision but considers the nut to be acceptably engaged if the lack of complete engagement is not more than one thread (see para. 335.2.3). See para. 10.1(c) of this document if use of hydraulic bolt tensioners is planned.

8.2.1 Corrosion of excess threads can hinder joint disassembly. A practice that facilitates joint disassembly (see para. 15) is to fully engage the nut on one end (no bolt projection beyond the nut) so that all excess threads are located on the opposite end; the excess threads should not project more than 13 mm ($^1/_2$ in.) beyond the nut, unless required for the use of hydraulic bolt tensioners [see para. 10.1(c)].

9 NUMBERING OF BOLTS

Number each bolt location 1 through N in a clockwise sequence (where N is the total number of bolts for the flange). An alternative bolt numbering method is described in Appendix F.

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TABLE 1M TARGET TORQUE VALUES FOR LOW-ALLOY STEEL BOLTING (SI UNITS)

Basic Thread Designation	Target Torque (N·m)	
	Noncoated Bolts [Note (1)]	Coated Bolts [Notes (1), (2), and (3)]
M14-2	110	85
M16-2	160	130
M20-2.5	350	250
M24-3	550	450
M27-3	800	650
M30-3	1 150	900
M33-3	1 550	1 200
M36-3	2 050	1 600
M39-3	2 650	2 050
M42-3	3 350	2 550
M45-3	4 200	3 200
M48-3	5 100	3 900
M52-3	6 600	5 000
M56-3	8 200	6 300
M64-3	12 400	9 400
M70-3	16 100	12 200
M76-3	20 900	15 800
M82-3	26 400	20 000
M90-3	35 100	26 500
M95-3	41 600	31 500
M100-3	48 500	36 700

GENERAL NOTE: The values shown are based on a Target Prestress of 345 MPa (root area). See para. 12 (Target Torque). The root areas are based on coarse-thread series for sizes M27 and smaller, and 3 mm pitch thread series for sizes M30 and larger.

NOTES:

(1) Computed values are based on "working" surfaces that comply with para. 4 (Examination of "Working" Surfaces) and para. 7 (Lubrication of "Working" Surfaces), and the following coefficients of friction: 0.16 for noncoated surfaces and 0.12 for new coated surfaces. These coefficients were selected to make the computed Target Torques consistent with that needed for a Target Prestress of 345 MPa as independently verified by accurate bolt elongation measurements by several users. (See Appendix K for equivalent nut factors.)

(2) The coating on coated bolts is polyimide/amide and is considered to be the sole source of "working" surface lubrication; the application of a lubricant to the coated surfaces can result in a considerable reduction in the assumed coefficient of friction of 0.12. (See Appendix K for equivalent nut factor.)

(3) Coated torque values apply only for initial tightening of new, coated bolts using the torque-increment rounds shown in Table 2. For second and subsequent tightening by torquing methods, use of lubricants and torque values as specified for noncoated bolts is recommended.

10 TIGHTENENING OF BOLTS

Using the selected tightening method/load-control technique (see para. 10.1), tighten the joint using the torque increment rounds shown in Table 2 and the cross-pattern tightening sequence as described in para. 11.

NOTE: When hydraulic bolt tensioners are employed, use the procedure recommended by personnel who are experienced and qualified in controlled bolting services. Guidelines on use of bolting services contractors are provided in Appendix G.

10.1 Tightening Method/Load Control Technique

Several tightening methods are available such as hand torque, slug/hand wrench, impact wrench, hydraulic torque, and hydraulic tensioner. Also, several load-control techniques are available. Thus, several combinations of specific joint assembly methods/techniques are available for consideration. Three such combinations that are commonly used are listed as follows in ascending order of bolt-load control accuracy:

(a) manual assembly with hand wrenches or impact wrenches with no supplementary bolt elongation (stretch) control. Hand wrenches are practical only for bolts approximately 25 mm (1 in.) diameter and smaller.

(b) manual or hydraulic torque wrenches with no supplementary bolt elongation (stretch) control. Manual torque wrenches are practical only for bolts approximately 25 mm (1 in.) diameter and smaller.

(c) any tightening or tensioning method with bolt elongation (stretch) control (e.g., bolt elongation measurement or hydraulic tensioning). Use of hy-

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TABLE 1 TARGET TORQUE VALUES FOR LOW-ALLOY STEEL BOLTING (U.S. CUSTOMARY UNITS)

Nominal Bolt Size, in.	Target Torque (ft-lb)	
	Noncoated Bolts [Note (1)]	Coated Bolts [Notes (1), (2), and (3)]
1/2	60	45
5/8	120	90
3/4	210	160
7/8	350	250
1	500	400
1 1/8	750	550
1 1/4	1,050	800
1 3/8	1,400	1,050
1 1/2	1,800	1,400
1 5/8	2,350	1,800
1 3/4	2,950	2,300
1 7/8	3,650	2,800
2	4,500	3,400
2 1/4	6,500	4,900
2 1/2	9,000	6,800
2 3/4	12,000	9,100
3	15,700	11,900
3 1/4	20,100	15,300
3 1/2	25,300	19,100
3 3/4	31,200	23,600
4	38,000	28,800

GENERAL NOTE: The values shown are based on a Target Prestress of 50 ksi (root area). See para. 12 (Target Torque). The root 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.

NOTES:

(1) Computed values are based on "working" surfaces that comply with para. 4 (Examination of "Working" Surfaces) and para. 7 (Lubrication of "Working" Surfaces), and the following coefficients of friction: 0.16 for noncoated surfaces and 0.12 for new coated surfaces. These coefficients were selected to make the computed Target Torques consistent with that needed for a Target Prestress of 50 ksi as independently verified by accurate bolt elongation measurements by several users. (See Appendix K for equivalent nut factors.)

(2) The coating on coated bolts is polyimide/amide and is considered to be the sole source of "working" surface lubrication; the application of a lubricant to the coated surfaces can result in a considerable reduction in the assumed coefficient of friction of 0.12. (See Appendix K for equivalent nut factor.)

(3) Coated torque values apply only for initial tightening of new, coated bolts using the torque-increment rounds shown in Table 2. For second and subsequent tightening by torquing methods, use of lubricants and torque values as specified for noncoated bolts is recommended.

draulic bolt tensioners requires that the threaded portion of the bolt extend at least one bolt diameter beyond the outside nut face on the tensioner side of the joint.

The selection of the tightening method/load-control technique for the joint under consideration should be made based on past experience with similar joints and full consideration of the risks (safety, environmental, financial) associated with potential leaks for the service conditions under consideration. For example, it is widely recognized that the most accurate bolt preload control method (±10% or less) is direct measurement of residual bolt elongation (stretch) (see para. 10.2), whereas bolt load variations of ±30% are not uncommon when torque alone is used as the tightening method/load-control technique. Use of hydraulic bolt tensioners results in accurate application of initial axial load to the bolts; however, this initial load is decreased due to embedment losses when the load from the hydraulic bolt tensioner is transferred to the nut on the tensioner side of the joint. Therefore, if tensioners are employed to obtain the target residual preload, use the procedure recommended by personnel who are experienced and qualified in controlled bolting services.

Regarding direct measurement of residual bolt elongation, it should be recognized that, if ultrasonic or micrometer elongation control is used, initial bolt length readings must be obtained and documented for each bolt for which bolt elongation is to be determined; additionally compensation must be made for temperature changes in the bolt after the initial length measurement. For bolts constructed

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TABLE 2 TORQUE INCREMENT

Step	Loading
Install	Hand tighten, then "snug up" to 15 N·m (10 ft-lb) to 30 N·m (20 ft-lb) (not to exceed 20% of Target Torque). Check flange gap around circumference for uniformity. If the gap around the circumference is not reasonably uniform, make the appropriate adjustments by selective tightening before proceeding.
Round 1	Tighten to 20% to 30% of Target Torque (see para. 12). Check flange gap around circumference for uniformity. If the gap around the circumference is not reasonably uniform, make the appropriate adjustments by selective tightening before proceeding.
Round 2	Tighten to 50% to 70% of Target Torque (see para. 12). Check flange gap around circumference for uniformity. If the gap around the circumference is not reasonably uniform, make the appropriate adjustments by selective tightening before proceeding.
Round 3	Tighten to 100% of Target Torque (see para. 12). Check flange gap around circumference for uniformity. If the gap around the circumference is not reasonably uniform, make the appropriate adjustments by selective tightening before proceeding.
Round 4	Continue tightening the bolts, but on a rotational clockwise pattern until no further nut rotation occurs at the Round 3 Target Torque value. For indicator bolting, tighten bolts until the indicator rod retraction readings for all bolts are within the specified range.
Round 5	Time permitting, wait a minimum of 4 hr and repeat Round 4; this will restore the short-term creep relaxation/embedment losses. If the flange is subjected to a subsequent test pressure higher than its rating, it may be desirable to repeat this round after the test is completed.

with a centerline indicator (gage) rod as shown in Figs. 1 and 2, 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 for troubleshooting purposes during operation.

10.2 Bolt Elongation (Bolt Stretch) Determination

When bolt elongation (bolt stretch) measurement is selected as the load control technique to be used, the required bolt elongation is computed according to the following equation (assumes the bolt is threaded full length):

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

where

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

S_b = Target Bolt Stress (root area), MPa (ksi). It is noted that bolt stresses computed in accordance with Mandatory Appendix 2 of Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code 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.

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 mid-thickness 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.

E = modulus of elasticity, MPa (ksi)

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

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

10.3 Tightening Method/Load Control Technique Selection

Table 3 shows an example of an approach to selecting the tightening method and load-control technique suitable to the need.

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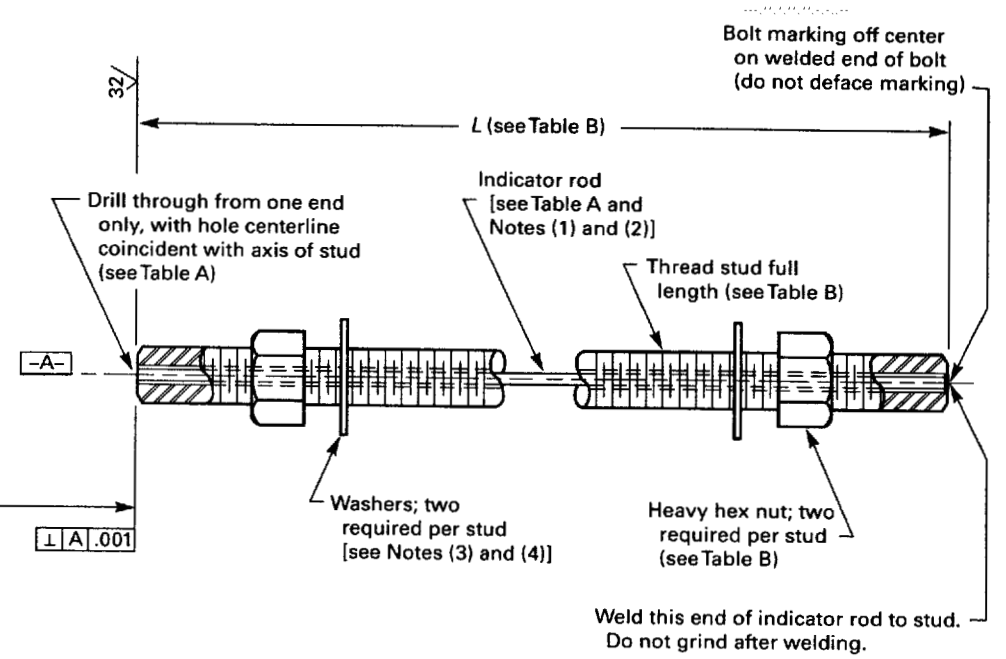
TABLE A

Nominal Stud Diameter, in.	Indicator Rod Diameter, in. [see Note (2)]	Hole Diameter, in.
$^{7}/_{8}$–1$^{1}/_{4}$	$^{1}/_{8}$	0.1875 $^{+0.002}_{-0.000}$
1$^{3}/_{8}$–1$^{7}/_{8}$	$^{3}/_{16}$	0.250 $^{+0.002}_{-0.000}$
Over 2	$^{1}/_{4}$	0.3125 $^{+0.002}_{-0.000}$

TABLE B

Quantity Required	Nominal Stud Diameter, in.	*L*	Materials	
			Stud	Nuts



NOTES:

(1) Indicator rod material for low-alloy steel bolting (e.g., SA-193 GR-B7) shall be nickel alloy UNS N10276 (C-276) bare welding rod per AWS A-5.14. Indicator rod material for other bolting shall be same as stud, or a material having essentially the same coefficient of expansion and a composition suitable for welding to the stud.

(2) Indicator rod diameter to be reduced by centerless grinding if necessary to provide free-fall movement of rod before welding.

(3) Washers are required only when torquing methods (versus use of hydraulic tensioners) are used for bolt tightening.

(4) Outside diameter of washer shall equal the across corner dimension of the nut, rounded up to the nearest $^{1}/_{16}$ in. Inside diameter of washer shall equal the nominal stud diameter plus $^{1}/_{16}$ in. Washers shall be $^{1}/_{4}$ in. nominal thickness and shall be through hardened. For temperatures not exceeding 400°F, the chemical and mechanical property requirements of ASTM F-436 shall be met. For temperatures higher than 400°F, the chemical and mechanical property requirements of SA-540 (any grade) having a minimum yield strength of 120 ksi shall be met. Both sides of washers shall be finish machined to a surface roughness not to exceed 125 μin. as defined in ASME B46.1.

For Item Number _____, see Reference Drawing _____.

Indicator-Type Bolting for Through-Bolted Joints

Drawn by	Checked by	Approved by	Date	Drawing Number

FIG. 1 INDICATOR-TYPE BOLTING FOR THROUGH-BOLTED JOINTS

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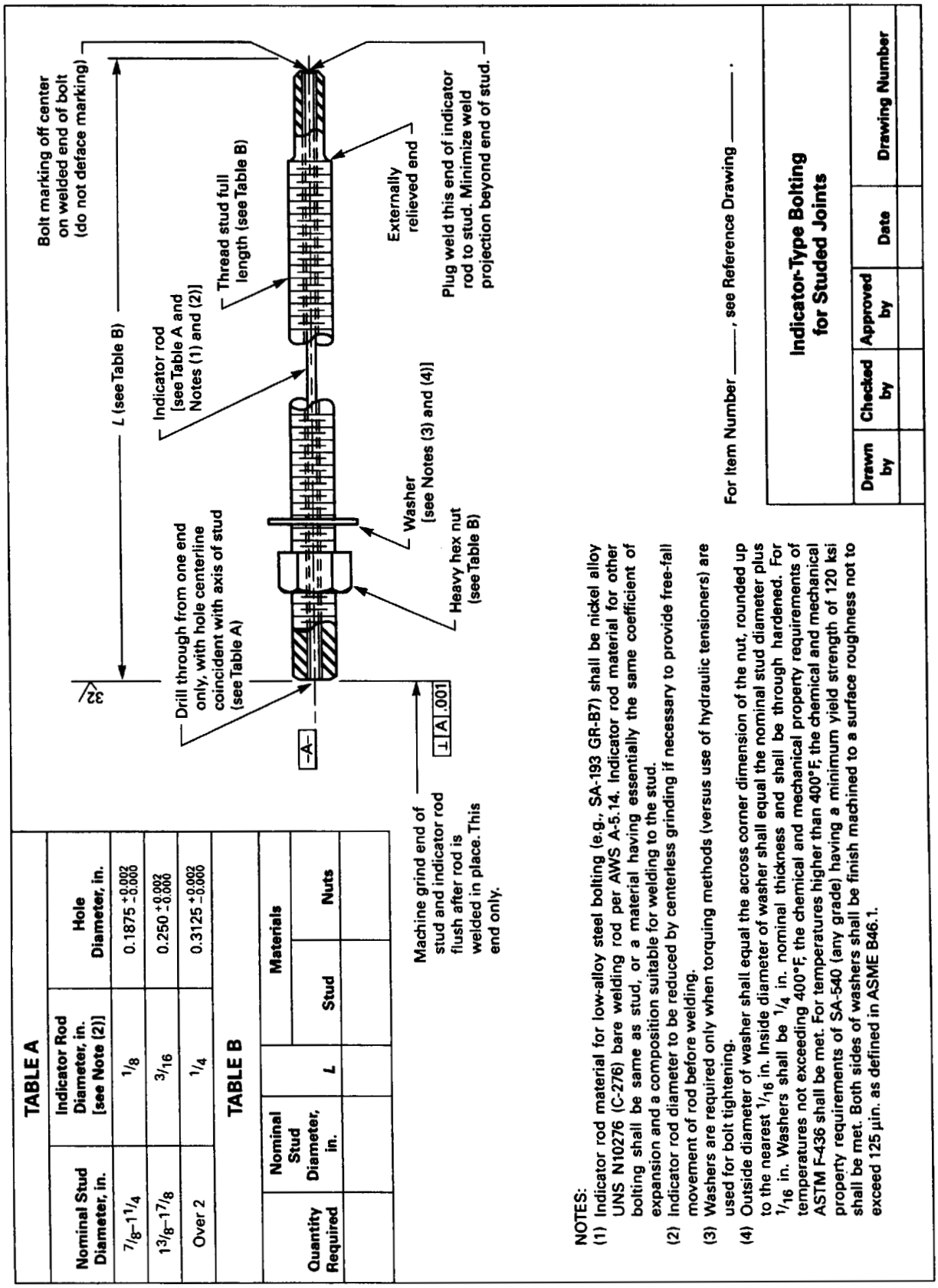

TABLE A

Nominal Stud Diameter, in.	Indicator Rod Diameter, in. [see Note (2)]	Hole Diameter, in.
$^{7}/_{8}$–1$^{1}/_{4}$	$^{1}/_{8}$	0.1875 $^{+0.002}_{-0.000}$
1$^{3}/_{8}$–1$^{7}/_{8}$	$^{3}/_{16}$	0.250 $^{+0.002}_{-0.000}$
Over 2	$^{1}/_{4}$	0.3125 $^{+0.002}_{-0.000}$

TABLE B

Quantity Required	Nominal Stud Diameter, in.	L	Materials		
			Stud	Nuts	

NOTES:
(1) Indicator rod material for low-alloy steel bolting (e.g., SA-193 GR-B7) shall be nickel alloy UNS N10276 (C-276) bare welding rod per AWS A-5.14. Indicator rod material for other bolting shall be same as stud, or a material having essentially the same coefficient of expansion and a composition suitable for welding to the stud.
(2) Indicator rod diameter to be reduced by centerless grinding if necessary to provide free-fall movement of rod before welding.
(3) Washers are required only when torquing methods (versus use of hydraulic tensioners) are used for bolt tightening.
(4) Outside diameter of washer shall equal the across corner dimension of the nut, rounded up to the nearest $^{1}/_{16}$ in. Inside diameter of washer shall equal the nominal stud diameter plus $^{1}/_{16}$ in. Washers shall be $^{1}/_{4}$ in. nominal thickness and shall be through hardened. For temperatures not exceeding 400°F, the chemical and mechanical property requirements of ASTM F-436 shall be met. For temperatures higher than 400°F, the chemical and mechanical property requirements of SA-540 (any grade) having a minimum yield strength of 120 ksi shall be met. Both sides of washers shall be finish machined to a surface roughness not to exceed 125 μin. as defined in ASME B46.1.

For Item Number _____, see Reference Drawing _____.

Indicator-Type Bolting for Studed Joints

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FIG. 2 INDICATOR-TYPE BOLTING FOR STUDDED JOINTS

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TABLE 3 EXAMPLE OF TIGHTENING METHOD/LOAD CONTROL TECHNIQUE SELECTION BASED ON SERVICE APPLICATIONS

Service	Tightening Method/Load Control Technique
Mild Service [Note (1)]	Hand Wrenches or Impact Wrenches [see 10.1(a)]
Intermediate Service [Note (2)]	Hand Wrenches or Impact Wrenches [see 10.1(a)] Manual or Hydraulic Torque Wrenches [see 10.1(b)]
Critical Service [Note (3)]	Any Method with Bolt Elongation Control [see 10.1(c)]

NOTES:
(1) An example of Mild Service could include Category D Fluid Service as defined in ASME B31.3.
(2) An example of Intermediate Service could include Normal Fluid Service as defined in ASME B31.3.
(3) An example of Critical Service could include highly hazardous chemical service as defined in CFR 1910.119 (OSHA PSM rule), Lethal Service as defined in the ASME Section VIII Divisions 1 and 2 Codes, or Category M Fluid Service as defined in ASME B31.3.

NOTE: Table 3 is provided as an illustration; due consideration of specific conditions and factors applicable to the joint under consideration should be given when selecting the appropriate tightening method/load-control technique combination for a given application.

11 TIGHTENING SEQUENCE

Follow the cross-pattern bolt tightening sequence shown in Table 4 (or the alternative in Appendix F) for all rounds except as described for Rounds 4 and 5 in Table 2 (see Figs. 3 and 4 for an illustration of the cross-pattern tightening sequence for a 12-bolt flange and a 48-bolt flange, respectively).

NOTE: The cross-pattern bolt tightening sequence and multi-round tightening are necessary to counter the elastic interaction that occurs when tightening bolts. See Appendix I for additional information regarding elastic interaction (or bolt cross-talk).

11.1 Measurement of Gaps

Except for Rounds 4 and 5, take measurements of the gaps between the flanges around the circumference to verify that the flanges are being brought together evenly. The gap should be measured at four equally spaced locations for up to 8-bolt flanges, at every other bolt for greater than 8-bolt flanges through 32-bolt flanges, and at sixteen equally spaced locations for greater than 32-bolt flanges.

12 TARGET TORQUE

Individually select the Target Prestress for each joint, considering each joint element that will be affected by the prestress. The Target Torque for a Target Prestress of 345 MPa (50 ksi) (root area) is given in Table 1M/Table 1. This 345 MPa (50 ksi) prestress level is generally considered suitable for joint systems designed using SA-193-B7 low-alloy steel bolts, except for joint systems using ring-joint gaskets. Target Torques for different Target Prestress levels may be obtained by reducing (or increasing) the values in Table 1M/Table 1 by the ratio:

$$\frac{\text{Target Prestress (MPa)}}{\text{345 (MPa)}}$$

or

$$\frac{\text{Target Prestress (ksi)}}{\text{50 (ksi)}}$$

See Appendix J for calculation of Target Torque for coefficients of friction other than those listed in Note (1) of Table 1M/Table 1. See Appendix K for an alternative method of calculating Target Torque when nut factors are used.

13 JOINT LEAK TIGHTNESS TEST

Bolted joint assemblies should be leak tested to ensure leak tightness. Subject to code/regulatory requirements, the user should establish:

(a) the type of leak test (e.g., visual, bubble-forming solution, sniffer);

(b) test fluid (e.g., air, inert gas, water, service fluid);

(c) test pressure (e.g., low pressure or up to a code-mandated visual inspection pressure); and

(c) acceptance criteria (often simply "no detectable leaks").

The user is cautioned to consider any hazards that might be associated with the test medium (e.g., toxicity, flammability, reactivity, explosibility), pressure level of fluid, and coincident stress level/temperature of the components.

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TABLE 4 CROSS-PATTERN TIGHTENING SEQUENCENE

No. of Bolts	Sequence [Note (1)]
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 → 25-26-27-29 ↵ 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 → 45-50-51-52 → 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 → 45-46-47-49 ↵ 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

NOTE:
(1) See Figs. 3 and 4 for illustrations of cross-pattern tightening sequences.

14 RECORDS

Consideration should be given to the preparation of a joint assembly record for each assembled joint, particularly those that are deemed to be in critical service. This record, which could be a logbook entry, would serve as a helpful resource for troubleshooting purposes, future assemblies, etc. The record could include but not necessarily be limited to the following information:

(a) date of assembly;

(b) specifications of gaskets and bolts/nuts used;

(c) flatness measurements, when made (see Appendix D);

(d) assembly procedure used, including Target Prestress and, if applicable, Target Torque;

(e) names of the joint assemblers;

(f) unanticipated problems and their solutions;

(g) name of Owner's Inspector (see Appendix G);

(h) recommendations for future assembly procedure.

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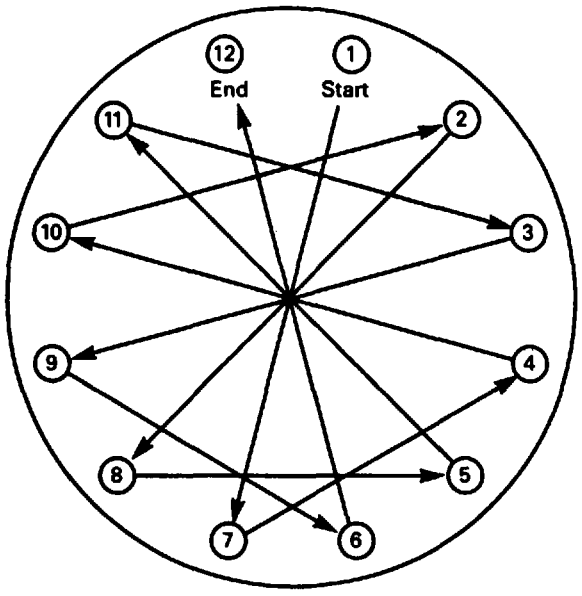

Tightening sequence for 12 bolts (Round 1 through Round 3):

1-7-4-10 → 2-8-5-11 → 3-9-6-12

FIG. 3 12-BOLT FLANGE THIGHTENING SEQUENCE

15 JOINT DISASSEMBLY

When a significant number of bolts is loosened in rotational order, the elastic recovery of the clamped parts can result in excessive loads on the relatively few remaining bolts, making further disassembly difficult and sometimes causing galling[4] between the nut and bolt sufficient to result in torsional failure of the bolt as further loosening is attempted. The reported incidents of disassembly difficulties have typically involved:

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

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

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

Accordingly, use of a joint disassembly procedure may be desirable for joints involving components meeting all the criteria of paras. 15(a), (b), and (c). Also, use of a joint disassembly procedure may be prudent for joints involving components for which high local strains could be detrimental (e.g., glass lined equipment, lens ring joints).

15.1 Disassembly Load Control

When a joint disassembly procedure is deemed appropriate, loosen bolts on a cross-pattern basis, using the appropriate sequence from Table 4 (or Appendix F), as follows:

(a) Start with Round 2 of Table 2, except "loosen" rather than "tighten" to 50% to 70% of the Target Torque.

(b) Check the gap around the circumference and loosen nuts selectively as required to accomplish a reasonably uniform gap.

(c) Loosen to Table 2, Round 1 levels (20% to 30%) of the Target Torque.

(d) If the gap around the circumference is reasonably uniform, proceed with nut removal on a rotational basis.

(e) If the gap around the circumference is not reasonably uniform, make the appropriate adjustments by selective loosening before proceeding with nut removal on a rotational basis.

[4] Experience has shown that, when SA-193 Gr B7 bolts are used, the galling incidents can be avoided by using higher strength SA-194 Gr 4 nuts rather than SA-194 Gr 2 or 2H nuts.

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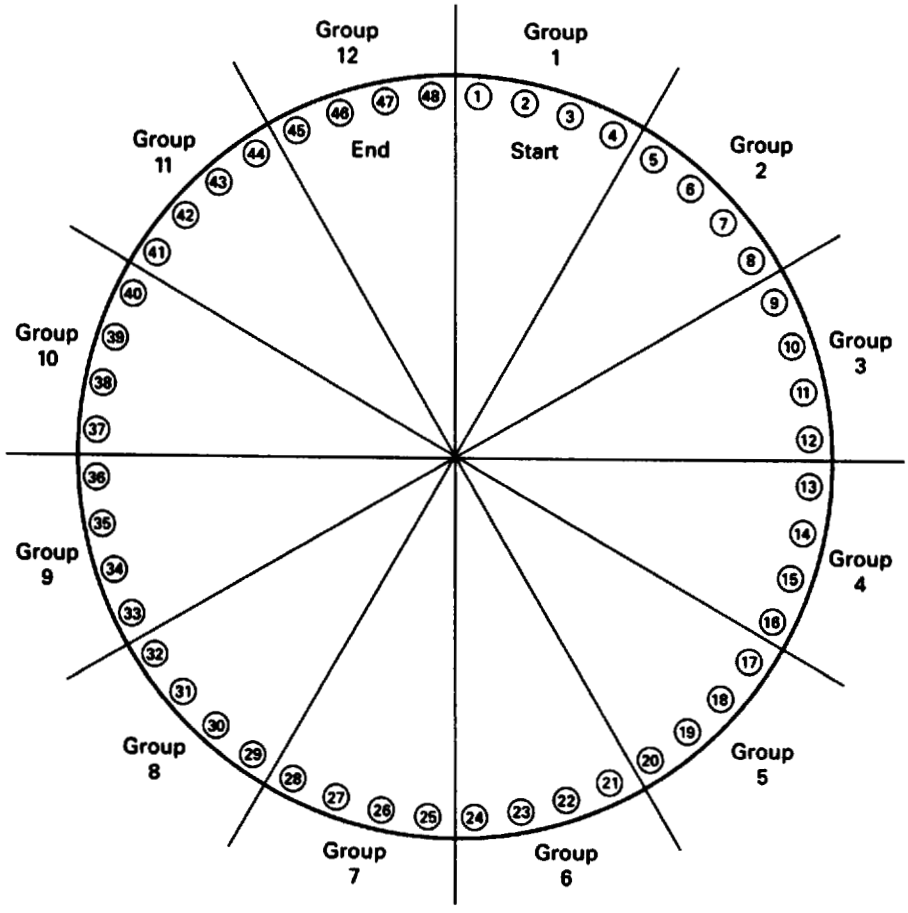

Group	Bolts
1	1-2-3-4
2	5-6-7-8
3	9-10-11-12
4	13-14-15-16
5	17-18-19-20
6	21-22-23-24
7	25-26-27-28
8	29-30-31-32
9	33-34-35-36
10	37-38-39-40
11	41-42-43-44
12	45-46-47-48

Tightening sequence for 12 Groups:

1-7-4-10 ↵
2-8-5-11 ↵
3-9-6-12

(The 12-group sequence is the same as a 12-bolt sequence; see Fig. 3.)

FIG. 4 48-BOLT FLANGE TIGHTENING SEQUENCE

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APPENDIX A
NOTES REGARDING QUALIFYING FLANGED JOINT ASSEMBLERS

A1 PURPOSE

The purpose of qualifying flanged joint assemblers is to ensure that they are sufficiently familiar with the specified tools, joint assembly procedures, and bolt size ranges such that they consistently achieve bolt stresses of approximately 345 MPa (50 ksi), or other specified Target Prestress, within the specified tolerance for the tools and assembly procedure that are to be used.

A2 UTILIZATION OF A COMPETENT INSTRUCTOR

Assemblers should be qualified by instruction and examination by a competent instructor for each joint assembly procedure and bolt size range to be employed.

A3 BOLT ELONGATION CHECK

The first two joints assembled by each assembler should be checked for bolt elongation. The resultant bolt stress should be approximately 345 MPa (50 ksi), or other specified Target Prestress, within specified tolerance for the tools and assembly procedure that were used.

A4 BOLT SIZE QUALIFICATION RANGE

Assemblers should be checked on a sufficient number of different bolt sizes to be considered qualified across the complete range of joints, gaskets, and bolt sizes to be employed.

EXAMPLE: Checking assemblers on an M27 (1 in. diameter) bolt may qualify them for all bolts M27 (1 in. diameter) bolts and smaller; checking assemblers on a M52 (2 in. diameter) bolt may qualify them for all bolts over M27 (1 in. diameter) through M52 (2 in. diameter); checking assemblers on a M56 ($2^1/_4$ in. diameter) bolt may qualify them for bolts M56 ($2^1/_4$ in. diameter) and larger.

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APPENDIX B
RECOMMENDATIONS FOR FLANGED JOINT ASSEMBLY PROCEDURE QUALIFICATION

The following is a recommended flanged joint assembly procedure qualification test:

(a) Prepare bolts for accurate bolt elongation (bolt stretch) measurements as required for the method of elongation measurement used (ultrasonic measurement, micrometer, or indicator bolts).

NOTE: If ultrasonic measurement is used, smooth and parallel bolt ends are required. If a micrometer is used, a ball bearing should be cemented at each end of the bolt to ensure smooth surfaces for taking micrometer measurements.

(b) Monitor at least every fourth bolt for bolt stretch. See para. 10.2 of this Guideline for bolt elongation (bolt stretch) determination.

(c) Following the applicable provisions of paras. 4 through 7 of this Guideline, install the bolts finger tight, and make (and record) initial bolt length measurements to be used as reference points.

(d) Tighten the bolts using the procedure to be qualified. Make bolt elongation measurements 1 hr after tightening has been completed (see Round 5 of Table 2 of this Guideline).

(e) The procedure is qualified if, when applied by qualified assemblers (see Appendix A), the specified target bolt stress is achieved (within tolerance) in the reference bolts.

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APPENDIX C
RECOMMENDED GASKET CONTACT SURFACE FINISH FOR VARIOUS GASKET TYPES

TABLE C1

Gasket Description	Gasket Contact Suface Finish [Note (1)]	
	μm	μin.
Spiral-wound	3.2–6.4	125–250
Corrugated metal jacket with corrugated metal core; full width and circumference of both sides to be covered with adhesive-backed flexible graphite tape	3.2–6.4	125–250
Kammprofile with either flexible graphite or PTFE facing	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, 1.6 mm ($^1/_{16}$ in.)	3.2–6.4	125–250
Soft cut sheet > 1.6 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 contact surface of the flange.

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APPENDIX D
FLATNESS TOLERANCE FLANGE GASKET CONTACT SURFACE

The following is taken from PIP VESV1002, Vessel/ S&T Heat Exchanger Fabrication Specification, ASME Code Section VIII, Divisions 1 and 2 (December 1998):

> For all flanges (except ASME B16.5 flanges) and shop-fabricated lap rings, the gasket contact surface tolerance, in both the radial and circumferential directions, shall be 0.006 in. (0.15 mm) total indicator reading. Measurements shall be made by a dial indicator after all other operations have been completed with regard to fabrication and heat treatment of the flange or lap ring and its attachment to the shell or nozzle neck that can affect flatness tolerance. The total circumferential tolerance shall not occur in less than 20 degrees arc.

It is understood that the above applies to tubesheets that are extended to serve as flanges.

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APPENDIX E
ALIGNMENT TOLERANCES

The following is taken from para. 335.1.1(c) of the ASME B31.3 Process Piping Code (1999 Edition):

> (c) *Flanged Joints.* Before bolting up, flange faces shall be aligned to the design plane within 1 mm in 200 mm ($^1/_{16}$ in./ft) measured across any diameter; flange bolt holes shall be aligned within 3 mm ($^1/_8$ in.) maximum offset.

As stated, the alignment tolerance applies to each individual flange, measured to the design plane. Some practitioners consider this to be excessive and use half of this tolerance, thereby making the alignment tolerance $^1/_2$ mm in 200 mm ($^1/_{32}$ in./ft). Conversely, it is recognized that misalignment greater than that permitted by para. 335.1.1(c) can generally be accepted for small diameter piping, particularly if it is not connected to load-sensitive equipment.

It is understood that more stringent alignment tolerances may be required for large piping connected to load-sensitive equipment such as machinery. For machinery, refer to API/PIP REIE-686, Chapter 6, Sections 4.6 through 4.9 and Fig. B-4.

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APPENDIX F
ALTERNATIVE BOLT NUMBERING AND TIGHTENING SEQUENCE, 324 METHOD[1]

The following is an alternative to the bolt numbering and tightening sequence described in paras. 9 and 11 of this Guideline.

Step 1. Select any bolt and designate it as bolt number "1." Usually the bolt is adjacent to the 12 o'clock position.

Step 2. Proceed clockwise to the next bolt. Add 4 to the previous bolt number to obtain the designation for this bolt (e.g., adding 1 plus 4 equals 5; thus, proceeding clockwise, the bolt adjacent to bolt "1" will be designated bolt "5").

Step 3. Repeat Step 2 until the bolt designation exceeds the number of bolts in the flange. Designate that as bolt number "3."

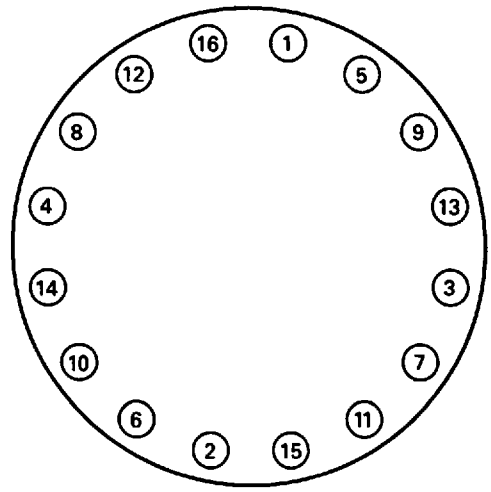
Step 4. Repeat Step 2 until the bolt designation exceeds the number of bolts in the flange. Designate that as bolt number "2."

Step 5. Repeat Step 2 until the bolt designation exceeds the number of bolts in the flange. Designate that as bolt number "4."

Step 6. Repeat Step 2 until the last bolt number is designated (the designation of the last bolt will equal the number of bolts in the flange unless a numbering error has occurred).

Step 7. When the bolts have been properly numbered, the tightening sequence will be in numerical order (i.e., 1 → 2, 3 → 4, etc.), resulting in a cross-pattern bolt tightening sequence.

The result of how the bolts would be numbered after Steps 1 through 7 is illustrated in Fig. F1.



GENERAL NOTE: Tightening the bolts in numerical order will, in most cases, provide a different cross-pattern tightening sequence than that required by Table 4 and illustrated in Figs. 3 and 4 of this Guideline. However, the resulting cross-pattern tightening sequence provided by the "324" method has proven to be equally effective.

FIG. F1 16-BOLT FLANGE EXAMPLE

[1] The key to remember is the number "324." The first time the bolt designation exceeds the number of bolts in the flange (Step 3), designate that bolt as "3." The second time the bolt designation exceeds the number of bolts in the flange (Step 4), designate that bolt as number "2." The final time the bolt designation exceeds the number of bolts in the flange (Step 5), designate that bolt as number "4."

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APPENDIX G
USE OF CONTRACTORS SPECIALIZING IN BOLTING SERVICES

G1 HIRING OF CONTRACTORS

Contractors providing bolting services should preferably be hired directly by the Owner. If bolting contractors are not hired by the Owner, the Owner's approval of the subcontractor is required.

G2 CONTRACTOR'S AUTHORITY AND FUNCTIONS

Contractors providing bolting services should be given authority to execute and verify all aspects of the assembly process, with the understanding that the contractor should provide the Owner with a daily report containing sufficient detail, the review of which will allow the Owner to verify that the joint assembly activities have been performed as specified. Contractors' functions may include but are not limited to the following:

(a) Prepare written joint assembly procedure(s) (or accept those provided by others) that comply with the essential elements of this guideline.

(b) Coordinate with Owner's Inspector (or other Owner-designated agent) for approval of deviations from agreed-upon procedures.

(c) Provide tools needed for bolt-up procedures (e.g., hydraulic torquing and tensioning equipment).

(d) Provide and supervise personnel to perform final assembly of flanged joints.

(e) Monitor and advise Owner's maintenance personnel used during joint assembly, if any.

(f) Provide and supervise bolt elongation (stretch control) as specified.

(g) Provide Owner with report covering each joint assembled, including, as a minimum, the record information listed in para. 14 of this Guideline.

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APPENDIX H
BOLT ROOT AND TENSILE STRESS AREAS

TABLE H1

SI Units			U.S. Customary Units			
Bolt Size, Basic Thread Designation [Notes (1), (2)]	Root Area, mm^2	Tensile Stress Area [Note (3)], mm^2	Bolt Size, in.	Threads per Inch	Root Area, $in.^2$	Tensile Stress Area [Note (3)], $in.^2$
M14-2	102.1	115.4	1/2	13	0.1257	0.1419
M16-2	141.0	156.7	5/8	11	0.2017	0.2260
M20-2.5	220.4	244.8	3/4	10	0.3019	0.3345
M24-3	317.3	352.5	7/8	9	0.4192	0.4617
M27-3	419.1	459.4	1	8	0.5509	0.6057
M30-3	535.0	580.4	1 1/8	8	0.7276	0.7905
M33-3	665.1	715.6	1 1/4	8	0.9289	0.9997
M36-3	809.3	864.9	1 3/8	8	1.155	1.234
M39-3	976.6	1 028	1 1/2	8	1.405	1.492
M42-3	1 140	1 206	1 5/8	8	1.680	1.775
M45-3	1 327	1 398	1 3/4	8	1.979	2.082
M48-3	1 527	1 604	1 7/8	8	2.303	2.414
M52-3	1 817	1 900	2	8	2.652	2.771
M56-3	2 132	2 222	2 1/4	8	3.422	3.557
M64-3	2 837	2 940	2 1/2	8	4.291	4.442
M70-3	3 432	3 545	2 3/4	8	5.258	5.425
M76-3	4 083	4 207	3	8	6.324	6.506
M82-3	4 791	4 925	3 1/4	8	7.487	7.686
M90-3	5 822	5 970	3 1/2	8	8.748	8.963
M95-3	6 518	6 674	3 3/4	8	10.11	10.34
M100-3	7 253	7 418	4	8	11.57	11.81

NOTES:
(1) Metric thread designations are given in bolt size (mm) and pitch (mm) (e.g., M14-2 refers to a 14 mm diameter bolt with a 2 mm pitch thread).
(2) The side-by-side placement of the two tables is not meant to infer direct conversion between the listed SI and U.S. Customary Units.
(3) The tensile stress areas are based on coarse-thread series for sizes M27 and smaller, and 3 mm pitch thread series for sizes M30 and larger (coarse-thread series for sizes 1 in. and smaller, and 8-pitch thread series for sizes 1 1/8 in. and larger).

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APPENDIX I
INTERACTION DURING TIGHTENING

I1 ELASTIC INTERACTION

Elastic interaction, sometimes called bolt cross-talk, can be explained as follows: As a joint is tightened, it compresses. Most of the compression occurs in the gasket, but additional compression also occurs in the flange. Local flange distortion under the bolt also is important. Subsequent tightening of individual bolts causes additional gasket compression and reduces the preload of previously tightened bolts.

I2 COUNTERING THE EFFECTS OF ELASTIC INTERACTION

The rotating cross pattern (sometimes called "four point" or "star" pattern) tightening sequence, as illustrated in Figs. 3 and 4 of this Guideline, used in conjunction with the torque increment rounds shown in Table 2 of this Guideline, is needed in order to apply load to the gasket reasonably uniformly during the tightening process,[1] and to counter the effects of elastic interactions caused by the tightening process. The first bolts tightened in a given torque increment round receive the most interaction (preload reduction); the last bolts tightened receive none and the in-between bolts receive an intermediate amount of interaction. The purpose of Rounds 4 and 5 (see Table 2 of this Guideline), during which the full torque is applied in rotational order, is to reduce the remaining interaction effects to a practical minimum.

[1] If the bolts are tightened in rotational order instead of as described herein, non-uniform compression of the gasket will occur and, as a result, the flanges are likely to become "cocked" (i.e., gap at outer perimeter of flanges will not be uniform), an indicator of non-uniform gasket loading and potential leakage. Additional tightening may not bring the flanges back parallel, and damage to the gasket can result.

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APPENDIX J
CALCULATION OF TARGET TORQUE

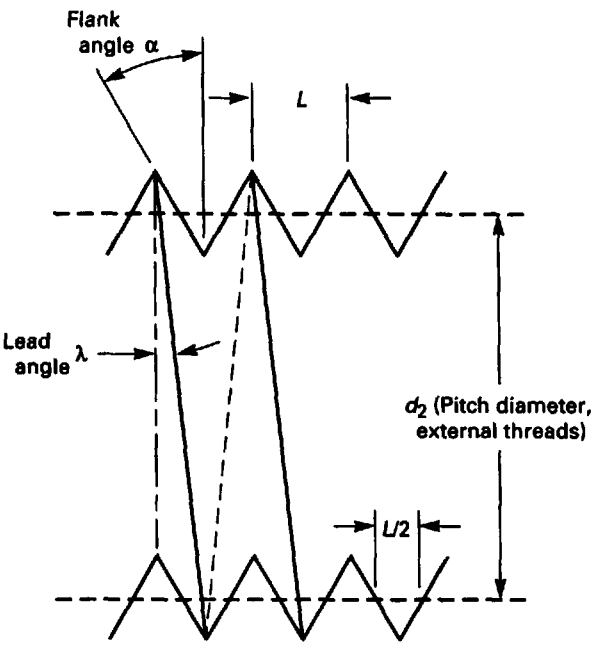
The Target Torque required to tighten bolting is computed as follows:

$$T = \frac{F}{2}\left[d_n F_n + d_2 \left(\frac{f_2 + \cos\alpha \tan\lambda}{\cos\alpha - f_2 \tan\lambda} \right) \right]$$

where

T = Target Torque, N·mm (in.-lb)
F = Target bolt tensile load, N (lb)
d_n = mean diameter of the nut (or bolt head) bearing face, mm (in.) (this diameter is equal to the simple average of the diameter of the nut washer face and the nominal bolt size)
f_n = coefficient of friction between the bolt nut (or bolt head) and the flange (or washer), (dimensionless)
d_2 = pitch diameter (or mean thread contact diameter), mm (in.) (see Fig. J1)
f_2 = coefficient of friction between bolt/nut threads, (dimensions)
α = thread flank angle, deg (see Fig. J1)
λ = lead angle, deg (see Fig. J1)

For UN and UNR screw threads, the flank angle (α) is equal to 30 deg, the lead angle (λ) is equal to $\tan^{-1}\left(\frac{L}{\pi d_2}\right)$, and the lead ($L$) is equal to the pitch of the threads (e.g., for 8-thread series, this will be $^1/_8$ in.).



L = axial movement of a threaded part when rotated one turn in its mating thread.

FIG. J1

NOTE: This Appendix uses ANSI/ASME B1.7M bolting terminology; see B1.7M for definitions of terminology. The formula used in this Appendix was obtained from Chapter 3 of the *Handbook of Bolts and Bolted Joints*, Bickford, John H. and Nassar, Sayed, eds. 1998. New York: Marcel Dekker, Inc.

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APPENDIX K
NUT FACTOR CALCULATION OF TARGET TORQUE

A common method for calculating Target Torque is to use the following simplified formula:

$$T = KDF$$

where

T = Target Torque, N·mm (in.-lb)
K = nut factor[1]
D = nominal bolt diameter, mm (in.)
F = Target bolt load, N (lb)

Based on the above, the friction coefficients of 0.16 and 0.12 (see Table 1M/Table 1 of this Guideline) correspond to nut factors of 0.20 and 0.15 for noncoated and coated bolts, respectively.

NOTE: The computed nut factor varies slightly with bolt diameter; thus the above formula introduces a slight error in the calculation of Target Torque. However, experience has proven this error to be negligible.

[1] The nut factor, K, is not a coefficient of friction but, instead, is an experimental constant that applies when either SI or U.S. Customary Units are used.

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