INSTALLATION AND BOLTING PRACTICES

In the mission to eliminate leaks and control fugitive emissions in piping and pressure vessel systems, it is important to fully understand the mechanisms that impact reliable bolted joint performance. Proper inspection of all components and the utilization of proper installation techniques is a critical step in controlling bolted joint integrity. The following is a list of practices and recommendations that will help ensure maximum joint integrity. Some more difficult or critical joints will need additional steps and guidance from plant reliability to assemble correctly. As with any work, always follow all plant safety rules and guidelines.

There are two important facts you should keep in mind when dealing with tension joints.

- The bolt is a mechanism for creating and maintaining a force, the clamping force between joint members.
- The behavior and life of the bolted joint depend very much on the magnitude and stability of that clamping force.

The following procedures are of fundamental importance regardless of the style of gasket or material used in the bolted joint.

SUPPORT EQUIPMENT

- Ensure the stability of the equipment before loosening the fasteners.
- Loosen fasteners - Loosen fasteners systematically, loosening all fasteners slightly first, using a second step to completely loosen all fasteners.

  NOTE: This avoids overloading one or two fasteners by releasing the load of the adjacent fasteners.
- Open flanges - Spread the flanges apart a distance that is ample to remove the old gasket, clean and inspect the seating surfaces, and install the new gasket.
- Do not allow tools to come into contact with the flange face.

REMOVE THE FASTENERS, HARDENED WASHERS, FLANGES, AND OLD GASKET

Fasteners - Hex head bolt and nut or threaded stud with one nut on each end.

- If the fasteners are to be reused, it is important to store them properly by replacing the nut onto the same fastener that it was removed from, replacing the nut onto the same end of the fastener that it was removed from, and stacking the fasteners so as not to damage the threads.

HARDENED WASHERS

- The washer should not be stored on the fastener as it may create a problem stacking the fasteners. Secure the washers in a dry container or area if possible.

FLANGES

- Extreme caution should be exercised in removing any detachable flanges. Care should be taken to protect the seating surface or flange face from hitting, bumping, or dragging against anything that would damage it.
- When storing these detachable flanges, do not lay the flange face against a rough surface such as concrete, pavement, or steel grating. Store on strong wood or other strong but non-abrasive material.
- If the flanges are to be left exposed to the weather, light oil should be applied to the flange face and the nut-bearing surface for protection against corrosion. The

commercial lubricant spray is not suitable for this purpose, it is primarily a solvent. If the storage time is to be prolonged, heavy grease is preferred.

Old Gasket

- The old gasket should be removed using a scraper or other tools that will not damage the seating surfaces of the flanges. Brass brushes or abrasive wheel that is softer than the flange material is recommended so as not to alter the flange surface finish.
- If the joint has failed and a failure analysis is to be done, take special care in removing the gasket. Keep the gasket intact if possible, mark its orientation to the flanges, mark the problem areas, and store properly.

Clean Equipment

Flanges

- Remove all foreign materials from the flange seating surfaces. Use tools or approved solvents that will not damage the surfaces.

  Note: In some situations, there may not be ample space to clean the flanges in the usual manner nor an approved solvent. Rough sanding, sandblasting, and rough filing are not recommended. Always scrape flange faces in a path or direction that corresponds with the serration path and not across them.

- Remove old paint and lubricant from the nut-bearing surface of the flanges. [This is the backside of the flange where the nut or the head of the bolt contacts it.]

Fasteners

- Use solvent, wire brush, buffing wheel, etc. to remove old lubricant, paint and rust from the fastener threads.
- Clean the fastener heads and nuts in a similar manner, being sure to clean the load bearing surfaces of both the head and the nut.

Inspect Equipment

- Visually inspect the seating surfaces for any pitting, corrosion, cracks, dings, or cuts. Cracks, excessive pitting or corrosion may warrant the use of inspection by dye penetrate, x-ray, or ultrasound.
- Where possible, use a straight edge across the flange faces to check for warping, metal draw, and flange rotation. Any indication of problems at this point should be followed with a run-out check using a dial indicator.
- Physically run the nut or nuts onto the bolt or stud. The nuts should run freely past the point on the fastener where it will come to rest after it is installed and tightened. This is done on both new and old fasteners.
- Check to see if your plant has a policy on replacing used fasteners. As a general rule, it is always best to replace these expendable components that contribute to the success of the properly assembled joint.

Hardened Washers

- Visually check for correct size and hardness, pits, cracks, marring, and flatness.

Note: Hardened washers that exhibit cracking may indicate a misuse of the product.

Repair or Replace Equipment

Flanges

a. Light to medium pitting, corrosion, cracks, dings, or cuts on the seating surfaces may be repaired by machining. Heavy pitting, corrosion, cracks, dings, or cuts may require fill welding and machining or replacement of the flange.

b. Most warping, metal draw, and flange rotation can be removed by machining. Extensive out of tolerance conditions may require replacing the flanges.

c. Excessively worn or damaged nut bearing surfaces may be repaired by machining or filing until flat and installing hardened washers.

NOTE: Tolerances for statements a. and b. should be based on the engineering design of the flanges, flange rigidity, the minimum gasket compression in thousandths of an inch, and the available bolt load.

FASTENERS

- Light corrosion, wear, and damage may be repaired by running a die nut over the threads or filing with a thread, blade, or three corner file. Excessive damage, wear, corrosion, incorrect size or grade, or cracks indicate that the fastener should be replaced. If there is considerable time between the repair and installation of a fastener, you will want to apply light oil to the threads and the nut face or bearing surface.

  NOTE: The commercial lubricant spray is not suitable for this purpose, it is primarily a solvent. Do not apply heavy grease or anti-seize at this time, it may gather trash as the fastener is installed.
- Light wear and corrosion are tolerable on the fastener bearing surfaces. Medium to heavy wear and corrosion indicate that the fastener should be replaced. Damage, cracks, or incorrect size or grade indicate that the fastener should be replaced.
- The inability of the nut to run freely on the bolt or stud may be corrected by working the nut back and forth on the fastener or running a file or die nut over the threads. Many small imperfections can be worked out by running the nut down the fastener as far as it will go and then hit the nut against something solid. This flattens the burr or imperfection and allows the nut to travel on. If the nuts consistently stop traveling as soon as there is full engagement between the nut and the fastener, you have an improper thread pitch match. If problems persist with new bolts look for solutions through proper handling, shipping, storing, and purchasing. If your plant has a policy on replacing used fasteners, refer to it for assistance. If one does not exist or does not address your application, here are some solid guidelines.
- Yielded fasteners should be replaced because their performance is uncertain.
- Inexpensive fasteners that have been tightened by unmeasured methods should be replaced because their performance is uncertain.
- The stud and nuts fastener should be replaced where cost is not prohibitive because it is not likely that you can control friction or get repetitive results from this combination. Even loading of the gasket is dependent on even bolt loads across the joint. Even bolt loads are dependent on consistent friction from fastener to fastener. Consistent friction on used fasteners is dependent on the same thread areas from both the fastener and the engaging repetitively. This is highly improbable given the obstacles that we would have to overcome.

  NOTE: The bolt and nut fastener is more likely to achieve repetitive loads as long as the same nut is properly installed on the bolt because of the fixed head of the bolt insures to some degree that the same threads are consistently used.
- Fasteners in high fatigue service should be replaced periodically
- Fasteners in critical service should be replaced because a failed joint becomes more costly than the fastener
- Fasteners subjected to extreme thermal cycles should be replaced.
- It is best to change all of the fasteners in a critical joint if you change one. If this is not feasible, attempt to install the new fasteners at evenly spaced intervals around the joint

HARDENED WASHERS

- Hardened washers should be replaced if they are damaged in any way.

  NOTE: Hardened washers are the big equalizer in the joint. They reduce friction due to flange misalignment, nut embedment, and poor bearing surfaces. They also stiffen the flange and lengthen the effective length of the fastener. While accomplishing all of this, they should not be installed in services that attack hard steels. The failed washer is worse than the negative sum of all its benefits.

- Excessive spacing or gap [A condition where 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 minimal force.]
- The force necessary to pull the flanges together should not exceed 10% of the maximum torque prescribed to properly load the gasket when using all of the fasteners in the joint.

Alignment of all Components

Rules for aligning flanges:

- Out of tolerance conditions should be corrected before the gasket is installed to avoid damaging it.
- The rule of thumb for aligning piping flanges is, "There shall not be any detrimental strain introduced into the piping system." Since it is very difficult for the craftsman to determine this point, a second rule usually will suffice in the field. "When aligning requires more force than can be exerted by hand or spud/pin wrenches consult your piping engineer."
- Before using jacks or wrench devices, you may want to do a pipe stress analysis, especially if the pipe is old or it is suspected that the walls have thinned from use.
- If the flanges that are in need of aligning are connected to pumps or rotating equipment, great care must be taken to prevent introducing a strain into the equipment housing or bearings. Measuring the movement in the equipment to insure that you do not disturb its aligned condition is a common and necessary practice.
- The best aligning is to repair the misaligned component by replacing it correctly, removing and reinstalling in the properly aligned position, or using uniform heat to relieve the stresses.
- In joints where one or more of the flanges are not attached to piping or vessels, such as cover plates and tube bundles, use ample force to accomplish the best aligned condition.
- Once the flanges are aligned, install the gasket and tighten the fasteners completely, and then release the aligning devices. Follow this rule as closely as possible. External forces have less effect on properly loaded joints.

  NOTE: Proper alignment of all joint members is the very core of flange joint assembly. It results in maximum seating surface contact, maximum opportunity for even gasket loading, and reduced friction between the nut and the flange.

Prepare Fasteners, Washers, and Gasket for Installation

Fasteners

- Fasteners should be checked for the proper diameter, length, threads per inch, grade, and condition.
- The nut should run freely on the stud or bolt past the point where the nut will come to rest after it is installed and tightened.
- The fasteners should be transported to the job site with the nut or nuts on them. The nuts should remain on the fasteners until you are ready to install them in the joint.

Washers

- The washers should be checked for proper outside diameter. A quick field test when using a heavy hex nut is to lay the washer on a flat surface and center the nut on top of it. The washer should extend from under the points of the nut about one sixteenth of an inch.
- The proper inside diameter of the washer should be one eighth of an inch larger than the fastener.

- The thickness of the washer will usually be one eighth or one forth of an inch. All washers should have the same thickness. The washer would also have a uniform thickness.
- Most hardened washers will fit the above description. There should be, however, a grade marking stamped into the washer to indicate its hardness. In selecting a particular hardness of washer, you may want to consult your metallurgist. In order to improve the performance of the joint, the washer must be harder than the flange material.

Gaskets

- The gasket should be transported to the job site at the time that it is to be installed. The gasket should be kept in its protective packaging until it is time to install it. If there is no protective packaging or it is to be stored at the job site, secure the gasket so that it will not be bent, broken, scratched, exposed to adverse chemicals or elements, knocked around, stepped on, or receive damage of any kind.
- Some gaskets require the application of additional sealing materials at the time of installation, such as graphite of PTFE. This should be done in accordance with the manufacturer's recommendations [either the gasket or sealant manufacturer]. Care should be taken to keep any unwanted materials out of the application process.

Install Fasteners, Washers, and Gasket

Fasteners

- Fasteners should be placed into the bolt holes carefully as to protect the threads from damage. Driving the fasteners in with a hammer can cause damage that will impact performance. Proper aligning of flanges will permit easy installation of fasteners.
- If the fastener is a stud and is being installed into a tapped hole, you may or may not want to perform this task before the flanges are brought together. In choosing between methods, care to protect the threads and ease of installation should be considered. Special care should be taken not to cross-thread the fastener in the tapped hole. Exercise caution not to damage the threads on the other end while attempting to screw the fastener in the hole.
- The nut should be installed with the flat bearing surface or washer side toward the flange or against the washer, if one is used. The other side of the nut should bear a raised grade and manufacturer's marking.
- The fastener should provide ample length for the installation of any washers, the installation of the gasket, full engagement of the nut. When the fasteners are completely tight and the gasket fully loaded, the fastener should be, at the least, flush with the outside of the nut.
- In the case of studs being installed with additional length, the additional length may be shared between both ends or moved to the end that is least likely to be tightened or removed. This statement concerns good engineering and field practices, not the aesthetics of the joint.
- The fastener must pass through the flanges at right angles. Any degree of angle will cause the fastener to bend during tightening and the nut to embed into the bearing surface. This results in higher more unpredictable friction on the fastener system which in turn results in less control in joint load.

Washers

- Washers should rest parallel to the flange surface. Remove any high points on the flange before installing washer.
- Washers may be installed on both ends of the fasteners if the fastener length is ample, this will increase the rigidity of the joint. When installing only one washer , it must be installed under the nut that is being turned. This will reduce the friction

and protect the bearing surface on the flange.

Gasket

- Always be sure that the gap between the flanges is at least 1/16" wider than the thickness of the gasket, and 1/8" is preferred when possible.
- Check to be certain that the gasket seating surface remains free of obstructions or trash.
- Do not force the gasket into place. When moving the gasket about, use a flat tool to gently slide it. Do not put your fingers between the flanges.
- Center the gasket on the seats. Some gaskets have full-face contact with bolt holes through the gasket to insure proper fit. Full-face gaskets without bolt holes, of the proper dimension, usually are not a problem to center. A problem does occur on flanges smaller than one inch where the standard tolerance leaves a reduced seating contact when the gasket is positioned completely against the fasteners on one side. The same situation does occur in certain size flanges when using spiral wound gaskets.
- Some very large gaskets may require an adhesive to hold them in place while they are being installed. The adhesive should be one that is approved by the gasket manufacturer, process engineers, and your metallurgist. The ideal adhesive will adhere well, dissipate completely with time and temperature, and not react with equipment materials or the process chemicals.

  NOTE: Grease, tape, or petroleum gels are not recommended for this purpose. Also, the application of anti-seize to a gasket to cause it to be removed easily is not recommended.
- Once the gasket is installed, allow the flanges to come into contact with it slowly, squarely, and gently. Do not pull the flanges into alignment with the gasket in place.

LUBRICATE FASTENERS AND WASHERS

Fasteners

- Use an approved lubricant suited to the fastener material, process medium, temperature range, and friction requirements.
- Lubricant should be applied generously and evenly to all contacting surfaces of the fastener system.
- Except when installing bolts or studs into tapped holes, apply the lubricant after the fastener is installed in the flanges. If the lubricant is applied to the fastener beforehand, it may collect trash as it passes through the flanges.
- When the fastener system is a bolt and a tapped hole, apply the lubricant to the: bolt threads, under side of the head or the flange bearing surface, and the shank of the bolt where it may contact the flanges.
- When the fastener system is a bolt and nut, where the nut will be turned in the tightening process, apply lubricant to the bolt threads and the nut or flange-bearing surface.

  NOTE: If the bolt is to be turned and not the nut, treat it as though it were a bolt and a tapped hole.
- When the fastener system is a stud, a nut, and tapped hole; lubricate the stud threads on the end to be installed into the tapped hole. After the stud is installed and the flanges assembled, lubricate the threads on the other end of the stud where the nut is to be installed and the nut or flange bearing surface.
- When the fastener system is a stud and two nuts, lubricant may be applied to the threads on both ends of the stud and to the bearing surface of both nuts and flanges. If you want one end to be difficult to loosen later, you may leave off the

lubricant.

NOTE: You must always lubricate the end where the nut is to be turned and always apply the lubricate to ample threads so that the nut does not run dry before it is tight.

Washers

- Apply the lubricant to the side of the washer that is against the nut that is to be turned or the head of the bolt.
- If you are using a washer on both ends of a stud and want one end to be difficult to loosen, you may leave off the lubricant.
- There is no advantage to applying lubricant to both sides of the washer, except that you are now certain that you lubricated the correct side.

TIGHTEN EVENLY

Squaring and Stabilizing

- Bring the flanges to contact the gasket slowly and squarely using minimal but sufficient force to lightly tighten the fasteners and stabilize the joint. Tighten the fasteners in a star or crisscross pattern, checking to be sure that the gap between the flanges remains even at ninety-degree intervals around the flanges. The use of all the bolts is preferred on flanges with up to eight bolts. Above eight fasteners, the use of eight fasteners for the initial squaring and stabilizing is usually considered to be sufficient. You should not initiate any significant gasket compression at this time.

  NOTE: Very heavy flanges with stiff gaskets may require the use of additional fasteners. If the joint is considered critical for any reason, use all of the fasteners in the joint for this initial pass.

Compression Pass #I

Once the joint is stabilized, apply a medium or half strength tightening force. Use the same guidelines for this pass as you did for the stabilizing pass.

Compression Pass #II

After completing the medium pass, tighten the fasteners with ample but restrained force. Remember that there is a limit below which a joint will fail and an upper limit above which a joint component will fail. Use the same guidelines for this pass as for the first two passes.

Circular Compression Pass

Once the second compression pass is completed, you will apply the same tightening force in a circular pattern. Starting at the most convenient or practical point, tighten the fasteners, moving in one direction from one to the next in a circular fashion around the flanges. You will continue this, circling the flanges as many times as necessary until the nuts no longer turn. Do not increase the tightening force during this pass!

APPLICATION OF TORQUE

The most accurate method for obtaining the correct seating stress is to apply the bolt load by direct measuring its tension or stud elongation. However, in practice, this procedure is cumbersome and of difficult execution. As a consequence the trend in industry today is the use of torque wrenches, tensioning devices, hydraulic wrenches. The use of manpower to tighten the bolts, by sledgehammers, striking wrenches and pieces of pipe on the end of the wrench is not recommended since this offers no degree of accuracy.

Special thank you to Edward Hayman for his contribution of information for this chapter.

Bolt Torque Sequence

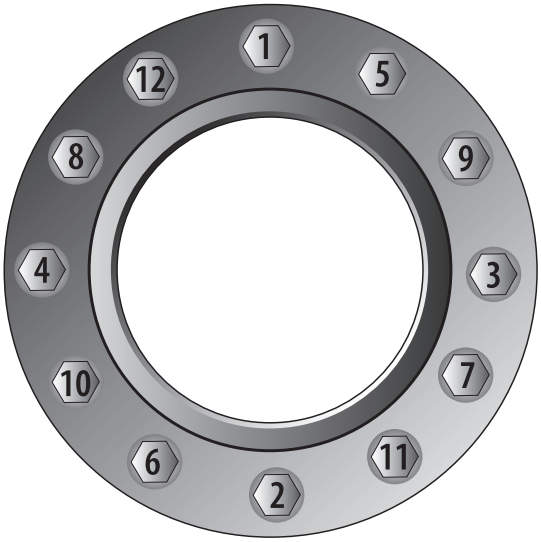
4-Bolts

Sequential Order	Rotational Order
1-2	1
3-4	3
	2
	4

8-Bolts

Sequential Order	Rotational Order
1-2	1
3-4	5
5-6	3
7-8	7
	2
	6
	4
	8

12-BOLTS

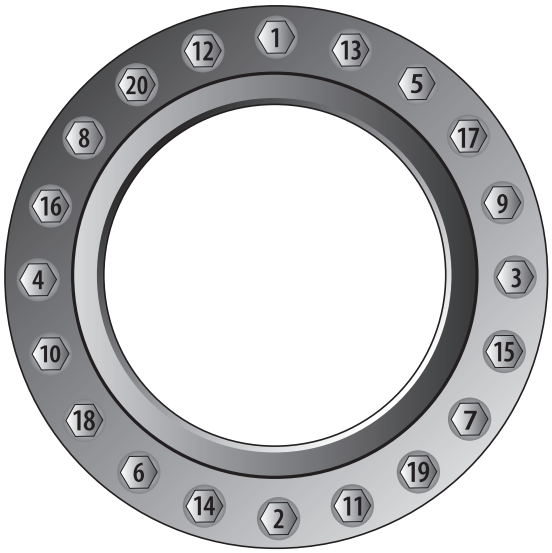


Sequential Order	Rotational Order
1-2	1
3-4	5
5-6	9
7-8	3
9-10	7
11-12	11
	2
	6
	10
	4
	8
	12

16-BOLTS

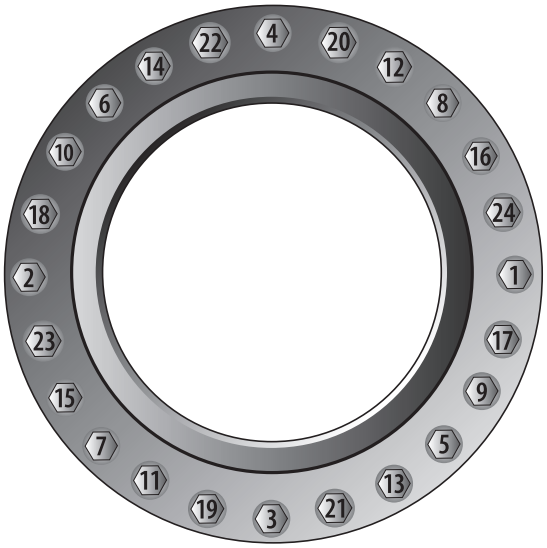
Sequential Order	Rotational Order
1-2	1
3-4	9
5-6	5
7-8	13
9-10	3
11-12	11
13-14	7
15-16	15
	2
	10
	6
	14
	4
	12
	8
	16

20-BOLTS



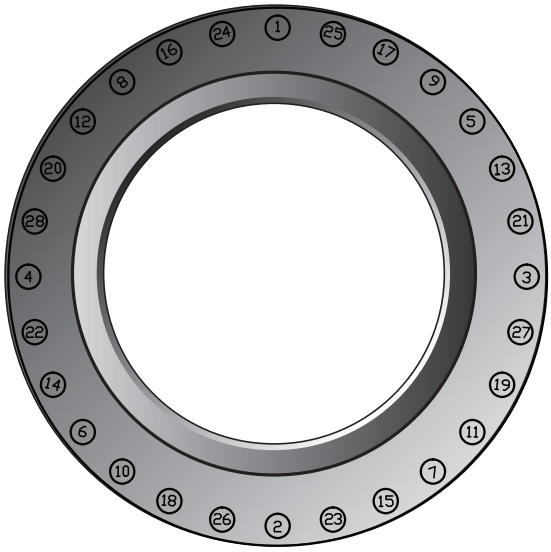
Sequential Order	Rotational Order
1-2	1
3-4	13
5-6	5
7-8	17
9-10	9
11-12	3
13-14	15
15-16	7
17-18	19
19-20	11
	2
	14
	6
	18
	10
	4
	16
	8
	20
	12

24-BOLTS



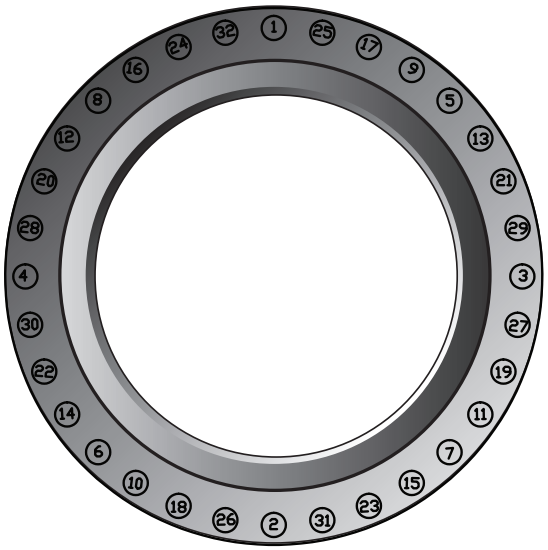
Sequential Order	Rotational Order
1-2	1
3-4	19
5-6	17
7-8	5
9-10	13
11-12	21
13-14	3
15-16	11
17-18	19
19-20	7
21-22	15
23-24	23
	2
	10
	10
	18
	6
	14
	22
	4
	12
	20
	8
	16
	24

28-BOLTS



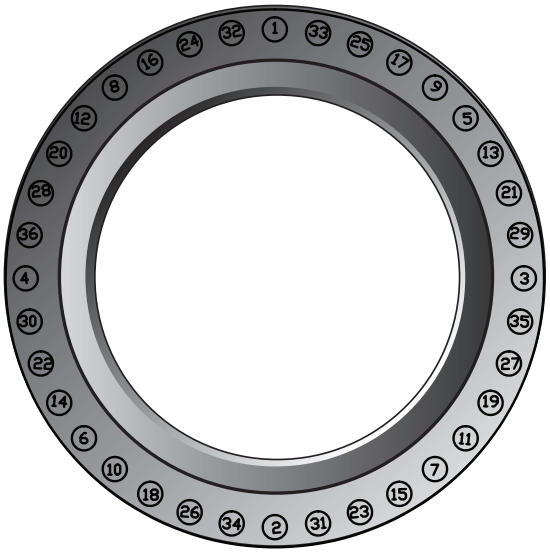
Sequential Order	Rotational Order
1-2	1
3-4	25
5-6	17
7-8	9
9-10	5
11-12	13
13-14	21
15-16	3
17-18	27
19-20	19
21-22	11
23-24	7
25-26	15
27-28	23
	2
	26
	18
	10
	6
	14
	22
	4
	28
	20
	12
	8
	16
	24

32-BOLTS



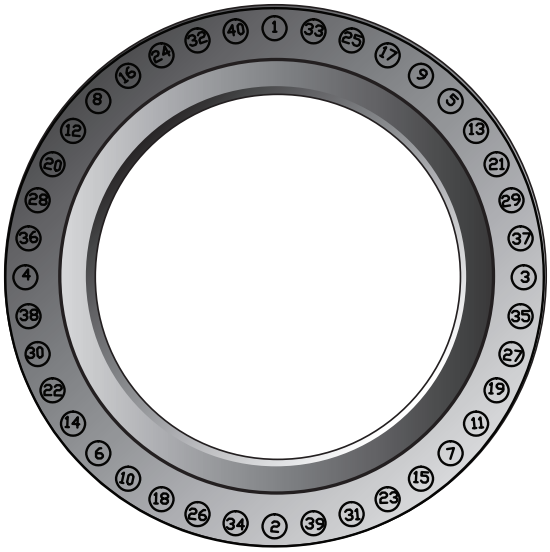
Sequential Order	Rotational Order
1-2	1
3-4	25
5-6	17
7-8	9
9-10	5
11-12	13
13-14	21
15-16	29
17-18	3
19-20	27
21-22	19
23-24	11
25-26	7
27-28	15
29-30	23
31-32	31
	2
	26
	18
	10
	6
	14
	22
	30
	4
	28
	20
	12
	8
	16
	24
	32

36-BOLTS



Sequential Order	Rotational Order
1-2	1
3-4	33
5-6	25
7-8	17
9-10	9
11-12	5
13-14	13
15-16	21
17-18	29
19-20	3
11-12	35
13-14	27
15-16	19
17-18	11
19-20	7
21-22	15
23-24	23
25-26	21
27-28	2
29-30	34
31-32	26
33-34	18
35-36	10
	6
	14
	22
	30
	4
	36
	28
	20
	12
	8
	16
	24
	32

40-BOLTS



Sequential Order	Rotational Order
1-2	1
3-4	33
5-6	25
7-8	17
9-10	9
11-12	5
13-14	13
15-16	21
17-18	29
19-20	37
21-22	3
23-24	35
25-26	27
27-28	19
29-30	11
31-32	7
33-34	15
35-36	23
37-38	31
39-40	39
	2
	34
	26
	18
	10
	6
	14
	22
	30
	38
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	16
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	32
	40

Trouble Shooting Leaking Joints

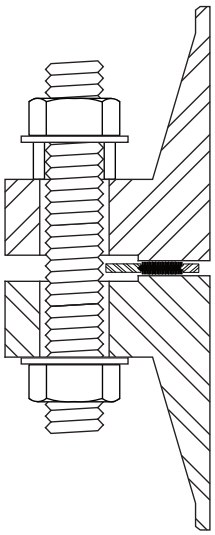
One of the best available tools to aid in determining the cause of leakage is a careful examination of the gasket in use when leakage occurred.

Observation	Possible Remedies
Gasket badly corroded	Select replacement material with improved corrosion resistance.
Gasket extruded excessively	Select replacement material with better cold flow properties, select replacement material with better load bearing capability - i.e., more dense.
Gasket grossly crushed	Select replacement material with better load bearing capability, provide means to prevent crushing the gasket by use of a stop ring or re-design of flanges.
Gasket mechanically damaged due to overhang of raised face or flange bore	Review gasket dimensions to ensure gaskets are proper size. Make certain gaskets are properly centered in joint.
No apparent gasket compression achieved	Select softer gasket material. Select thicker gasket material. Reduce gasket area to allow higher unit seating load.
Gasket substatially thinner on OD than ID	Indicative of excessive “flange rotation” or bending. Alter gasket dimensions to move gasket reaction closer to bolts to minimize bending moment. Provide stiffness to flange by means of back-up rings. Select softer gasket material to lower required seating stresses. Reduce gasket area to lower seating stresses.
Gasket unevenly compressed around circumference	Improper bolting up procedures followed. Make certain proper sequential bolt up procedures are followed.
Gasket thickness varies periodically around circumference	Indicative of “flange bridging” beween bolts or warped flanges. Provide reinforcing rings for flanges to better distribute bolt load. Select gasket material with lower seating stress. Provide additional bolts if possible to obtain better load distribution. If flanges are warped, re-machine or use softer gasket material.

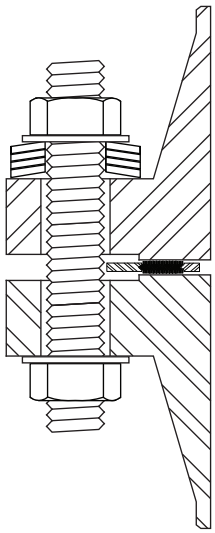
Other Bolted Connection Problem Areas

Joint Must Compensate for Wide Temperature Variations:

Solution: Consider use of sleeve around bolts to increase effective bolt length:



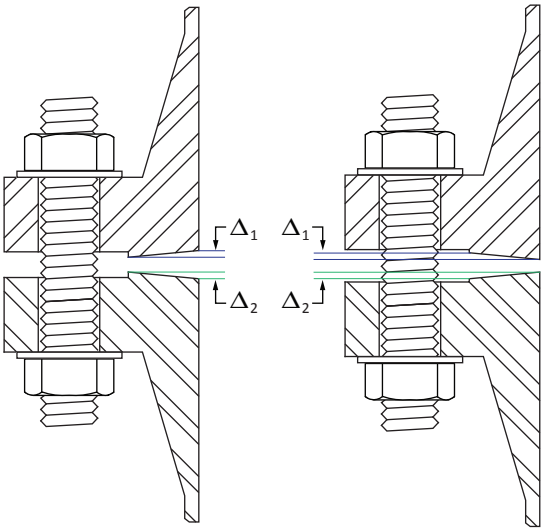
Or consider use of conical spring washers in place of sleeve to eliminate torque losses over wide temperature ranges.



Flanges Out Of Parallel:

Total allowable out of parallel: $\Delta_1 + \Delta_2 = 0.015$" (0.4 mm)

Note:
Deviation on right is less critical than deviation on left since bolt tightening will tend to bring flanges parallel due to flange bending.



Wavy Surface Finish:

Note:

1. If using jacketed or spiral wound gaskets - deviation should not exceed 0.015" (0.4 mm).
2. If using solid metal gaskets - deviation should not exceed 0.005" (0.13 mm).
3. If using rubber, more leeway is possible - suggested grade line total of 0.030" (0.8 mm).