VM-VFWSP2/WP

White Paper

Valve Flanges for Waterworks Service
Part 2: Construction and Installation

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Introduction

Flanges play an important role in piping systems because they allow the assembly and maintenance of system components without the need for cutting and welding pipe. The structural integrity and leak tightness of waterworks piping systems are only as strong as the weakest element, which is often the flange connection between various valves and fittings. The selection of different sealing mechanisms such as gaskets, O-rings, and mechanical seals can significantly affect the performance of the connection. Part One of this article provided a thorough explanation of the variables and ratings that affect flange ratings. Part Two will describe how flanges are produced and the accepted methods for their use and installation.

Flange Tolerances

Since it is important that flanges mate together in the field, both the dimensions and flatness of flanges are important. Most flange standards (AWWA C110) provide a list of tolerances that the manufacturer must meet including:

- Bolt circle diameter: +/- 0.06 in.
- Bolt hole to hole: +/- 0.03 in.
- Flange thickness: + .13 in., - 0.0 in.
- Slope of back face of flange: 3 deg. maximum

Of note is the fact that the flange OD is not considered important and does not typically get a tolerance. Also, the flange thickness is typically considered a “minimum” dimension. Fabricated flanges (i.e. AWWA C207) have special requirements for flatness and layback. Finally, cast valves and fittings will have a slope on the back of the flange which is necessary for the casting process. If the slope exceeds the tolerance, the nut may not sit flat or the flange bolt may be bent during tightening. The back of the flange can be back-faced (machined) or back spot-faced so that the nut and washer have a flat surface to rest against. Some utilities specify back spot-facing as a regular practice because of previous bad experiences with sloped flanges. The diameter of the spot face should be sufficient to accept a heavy hex nut and washer.

Flange Faces and Surface Finish

Waterworks valves, flanges, and fittings have historically been constructed of gray iron for operation up to about 250 psig. Because gray iron is brittle, waterworks flanges have traditionally been flat faced to reduce the bending loads on the flange. That is, they mate to each other on the same plane radially from the inside diameter (ID) to the outside diameter (OD) as shown in Figure 1. When bolting a cast iron flange to a raised face steel or ductile iron flange, low grade carbon steel bolts (ASTM A307 Grade B) should be used to avoid breaking the cast iron flange when tightening the bolts.

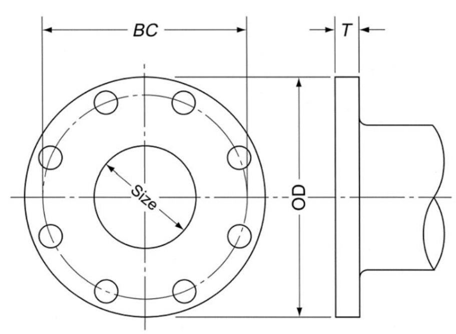

FIGURE 1. Typical Waterworks Flange Connection

The performance of the gasket seal is related to the surface finish of the flanges. Surfaces can vary from rough cast surfaces to lapped glass-like surfaces. Historically, waterworks flange faces are machined flat with shallow grooves to help the gasket seal and prevent gasket blowout. The AWWA C207 flange standard specifies a serrated finish having a surface finish of 250 to 500 micro-inch roughness. The micro-inch roughness is basically the vertical distance between the peaks and the valleys of the machined surface. 500 micro-inches is about one fourth the thickness of a piece of paper so it needs to be measured with an electronic quality instrument called a profilometer, which pulls a stylus or diamond needle across the surface to detect the peaks and valleys of the surface. Some inspectors also carry a metal inspection comparator plate which they use to compare the flange face to the surface plate visually or by touch.

It is customary that flange faces be free of lining and coating materials except for rust preventive compound. On the other hand, AWWA C110 iron fittings can be serrated or smooth and may be coated. Many waterworks fittings and gate valves are coated with fusion bonded epoxy (FBE) which because of the manufacturing process requires the flange faces to be coated. The flanges are smooth providing little friction for the gasket risking gasket blowout. Fabric reinforced gaskets, high tensile strength fiber gaskets, or special engineered gaskets may be needed for high pressure systems when the flanges are coated.

Flange Gaskets

It would be simple if all that was necessary would be to bolt two flanges together and a tight seal were obtained every time. Unfortunately, flanges are not perfectly flat so gaps, irregularities, and waviness between the mating surfaces allow fluid leakage. The purpose of the gasket is to fill those voids and withstand the pressure forces of the internal fluid. Gaskets need to be compressible to conform to the surfaces of the flanges yet have sufficient strength to prevent yielding from the bolt loads and pressure forces (ESA, 1998). Poor gaskets tend to relax or extrude causing gasket compression to be lost over time resulting in a leaky joint. In order for a gasket to maintain a seal, the compression force on the gasket from the bolts must be maintained even after the bolts are stretched from the hydrostatic end force tending to separate the mating flanges.

Gaskets therefore require certain properties that are needed for their performance in various applications. First, the material of the gasket must be compatible with the fluid media. In water systems, most gasket materials work well in cold water service. But the gasket material must still resist over-compression and extrusion, so its tensile strength is important. The tensile strength is related to the hardness of the gasket expressed in Shore A durometer. The durometer rubber hardness scale ranges between 0 and 100 where a rubber band is about 20 durometer and a hockey puck is 90 durometer. Rubber gaskets for flanges typically have a specified hardness of 70 or 80 durometer. The resilience of the gasket is measured by a compression set test where a load is applied and the recovery of the material is measured. Rubber is a unique material in that it does not compress, it displaces or cold flows. So if a rubber gasket is over compressed, it will flow into the ID or OD of the flange connection. The compression of rubber gaskets should be limited to 25% to avoid overflow. The rubber gasket will continue to bounce back and fill the voids and gaps in the flanges over time.

The AWWA C207 flange standard specifies the gasket to be 1/16 or 1/8 in. thick 80 durometer red rubber for pressures up to 175 psig and fiber type ring gaskets for 275 psig. Red rubber is typically a blend of styrene butadiene rubber (SBR). AWWA also specifies that fiber gaskets with rubber binder material shall be suitable for a seating stress of 3000 psi to 15,000 psi. The dimensions of standard "ring" type and "full face" type gaskets for waterworks service are shown in Figure 2. The ID of these gaskets differs from those of steel pipeline gaskets (ASME B16.21) because steel fittings and pipe have different ID's than AWWA fittings. For example, an NPS 12 ASME gasket has an ID of 12.75 in. to match the OD of steel pipe (ASME B16.21). AWWA fittings have ID's that match the nominal size, 12.00 in. (AWWA C111).

In general, the gasket should be as thin as possible (Czernik, 1996). When it is too thick, its diameter will change excessively when compressed. Also, a thicker gasket will be subject to deterioration from the fluid media due to the greater exposed area. Finally, gaskets can blow out of the flange from the internal pressure. The blowout forces are directly proportional to the thickness. So when a thick gasket is used on flanges faces with low friction, blowout or outward extrusion may occur over time.

DIMENSIONS OF CLASS 125 WATERWORKS GASKETS, IN. (AWWA C110)

Nom. Size In.	RING TYPE		FULL FACE TYPE				
	ID	OD	ID	OD	BC	Hole Dia.	No. Holes
3	3	5.38	3	7.50	6.00	.75	4
4	4	6.88	4	9.00	7.50	.75	8
6	6	8.75	6	11.00	9.50	.88	8
8	8	11.00	8	13.50	11.75	.88	8
10	10	13.38	10	16.00	14.25	1.00	12
12	12	16.13	12	19.00	17.00	1.00	12
14	14	17.75	14	21.00	18.75	1.13	12
16	16	20.25	16	23.50	21.25	1.13	16
18	18	21.63	18	25.00	22.75	1.25	16
20	20	23.88	20	27.50	25.00	1.25	20
24	24	28.25	24	32.00	29.50	1.38	20
30	30	34.75	30	38.75	36.00	1.38	28
36	36	41.25	36	46.00	42.75	1.63	32
42	42	48.00	42	53.00	49.50	1.63	36
48	48	54.50	48	59.50	56.00	1.63	44

FIGURE 2. Waterworks Gasket Dimensions

If the valve or fitting will be used in a corrosive application such as desalinization systems, the valve or fitting may need to be protected from galvanic corrosion. Galvanic corrosion occurs in aggressive fluids between dissimilar metals such as iron and stainless steel wherein a battery-like

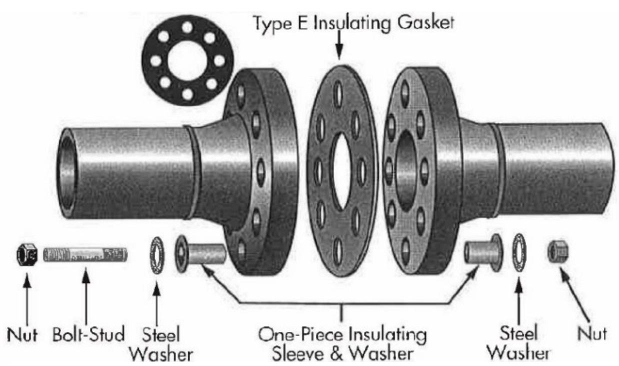

FIGURE 3. Insulating Gasket Assembly for Corrosive Service

electrical process occurs and the least corrosion resistant material (iron valve) is attacked. To prevent galvanic corrosion, special insulating gasket designs are used as shown in Figure 3. Insulating gaskets consist of full face gaskets, and insulating sleeves around the bolts and washers. The goal of an insulated joint is to break the metal-to-metal contact between the two flanges. When insulating gasket assemblies are specified, it is sometimes necessary to drill the flange holes oversize.

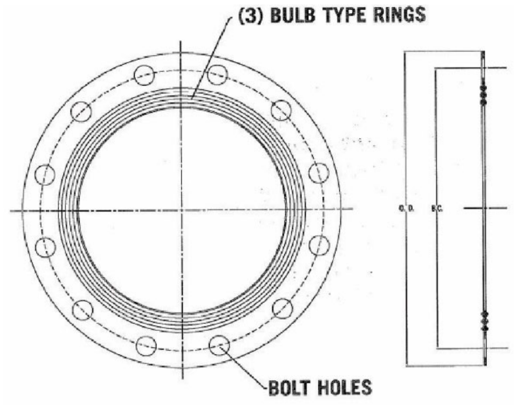

FIGURE 4. Special Engineered Gasket Resilient Rings

Finally, there are specially engineered gaskets designed for waterworks fittings that have the advantage of raised resilient beads or lips that seal with low gasket loads, see Figure 4. The body of the gasket is constructed of a hard plastic such as phenolic. The resilient portion is typically made of SBR rubber, which is common in the water industry. With this gasket, the bolts loads are low and the flange seal is therefore forgiving and reliable.

Flange Bolt Torque

The bolts are an integral component of the flange assembly. The bolts must withstand the pressure load inside the pipe while maintaining a minimum load on the gasket. The pressure load is calculated by multiplying the area of the pipe and gasket times the maximum expected pressure. The calculated bolt load on an NPS 12 CLASS 125 flange at 250 psi can be as high as 50,000 pounds or 25 tons. The bolts clearly have an important structural role. The load is divided by the number of bolts, 12 in this example. So each bolt must be tightened such that a preload of at least 50,000/12 or 4190 pounds is developed. The target bolt torque to produce a given load can be calculated using the following formula:

$$T = K\,D\,F / 12$$

Where:

- T = target torque, ft-lbs.
- K = nut factor, dimensionless
- D = nominal bolt diameter, in.
- F = target bolt load, lbs.

For lubricated bolts, the nut factor is typically 0.20. Hence, for the subject example, the NPS 12 flange has 7/8 inch bolts whose torque can be calculated as follows:

$$T = 0.20 * 0.875 * 4190 / 12$$
$$= 61 \text{ ft-lbs}$$

This torque would be considered the minimum required to maintain a seal with a resilient gasket at 250 psig. A higher torque can be used, but at the risk of crushing the gasket. Most resilient gaskets are limited to a maximum load of 2000 psi, unless they are fabric reinforced, then 4000 psi. Based on the area of the

NPS 12 ring type gasket, a 2000 psi gasket load corresponds to an individual bolt load of 14,500 lbs and a resultant bolt torque of about 210 ft-lbs. Therefore, the NPS 12 flange bolts for a rubber gasket should be tightened in the range of 60 to 210 ft-lbs. As the bolts are tightened the gasket compression should be monitored so that the gasket is not compressed more than 25% of its original thickness. Rubber is incompressible, so when the gasket is loaded, the rubber flows to the ID and OD of the joint.

If a fiber-type gasket were used, the gasket compression can be much higher that the resilient gasket, typically 4000 psi. Therefore the bolt torques in the previous example could be double the resilient gasket torque or 420 ft-lbs.

There is an additional upper limit to the maximum bolt torque based on the strength of the bolt. Flange bolts for waterworks flanges are typically heavy hex carbon steel fasteners made in accordance with ASTM A307, Grade B, which specifies a tensile strength of 60,000 psi. A safe load for this bolt is 40,000 psi. Each bolt size has a specific tensile stress area; the 7/8 inch bolt in the example has a tensile stress area of 0.462 square inches. The corresponding maximum bolt torque based on the strength of the bolt can be found by:

$$
\begin{aligned}
T &= 0.20 * 0.875 * 40{,}000 * 0.462 \ / \ 12 \\
&= 270 \text{ ft-lbs}
\end{aligned}
$$

Hence, the ASTM A307, Grade B bolts are suitable for the resilient gasket target torque range of 60-210 ft-lbs. However, the bolts may not be sufficient for the load needed for the fiber gasket, 420 ft-lbs. The next higher grade of bolt commonly used is ASTM A193 Grade B7, which is a chromium-molybdenum alloy steel with a tensile strength of 125,000 psi. The B7 grade is common for 275 psi applications and cases where high gasket loads are needed. ASME B16.1 recommends only B7 grade (low strength) bolts for gray iron flanges to prevent damage to the flange. ASME B16.5 also discusses bolting to gray cast iron flanges and recommends control of the bolt torque and piping loads, the use of elastomeric or fiber gaskets, and the use of low strength bolting.

Specially engineered gaskets are often used for waterworks fittings, see Figure 4. Engineered gaskets seal under low gasket loads because of their raised resilient beads or lips. The recommended bolt load for the NPS 12 engineered gasket is only 90 ft-lbs for 250 psi service and 110 ft-lbs for 350 psi service. With this gasket, the bolts really only need to support the pressure load and very little gasket load; hence the lower bolt torques. Also, since they have a hard shell, they cannot be over compressed.

The target bolt torque is the most common question asked of valve and fitting manufacturers but it is now clear that the target bolt torque is more a function of the gasket than the fitting or valve. The gasket manufacturer should provide a gasket load for the intended service. The gasket load can then be used to calculate the target bolt torque as described above.

Installation of Flanged Fittings and Valves

Care should be taken in the installation of flanged fittings and valves to prevent damage to equipment and to obtain a tight flanged connection. There are many obstacles to this endeavor including field conditions, misaligned pipe, valve weight, tolerances, etc. Unfortunately, few of the ASME or AWWA flange standards provide guidance on installation. The following guidelines are based on information provided in AWWA C110, ASME PCC-1, and general industry practices.

1. BOLTING: Standards such as AWWA C110 provide information on the material, size, length, and number of bolts. Certain valves have some threaded holes which may require shorter bolts or studs in these holes. An engagement of at least one bolt diameter is typically used for the flange bolts used in the tapped flange holes. When ring gaskets are used with gray iron flanges or when mating to raised face flanges, the bolt material should be low strength steel such as ASTM A307 Grade B or SAE Grade 2 Carbon Steel. Higher strength bolts such as ASTM A193 Grade B7 may only be used with full-face gaskets or when high pressure service is needed.

2. GASKETS: Gaskets for waterworks service are typically ring or full-face synthetic SBR rubber and are 1/16 in or 1/8 in thick. Ring gaskets are recommended for NPS 14 and larger to improve the sealing. Also available are special engineered gaskets with annular sealing rings, which greatly improve the gasket performance and reduce the bolt torque needed.

3. VERIFY DRILLING: Inspect the mating flanges with a tape measure to verify that the bolt circle diameters of the two mating flanges match and the bolt set is appropriate for the through and tapped holes in the flanges with consideration to the washer thickness. Hard steel washers should be used to provide a solid surface for the nut to seat against. Flange outside diameters and thicknesses often vary but should not affect fit up.

4. FLANGE FACES: Make sure flange faces are clean and not damaged. A scrape or mark across the flange face can cause a leaky joint. Do not use the flange to jack a fitting or pipe into place. Use large equipment anchored to the ground for positioning the pipe or fitting.

5. LUBRICATE: Lubricate the flange bolts or studs and insert them around the flange. Lubricate the internal nut threads and contact face. Lightly turn bolts until gaps are eliminated. Do not use the bolts to jack the flanges into alignment.

6. TORQUING: Starting with the bolt to the right of the vertical centerline, number the bolts in sequential order in a clockwise direction (i.e. 1, 2, 3, 4, etc.). The torquing of the bolts should then be done in three graduated steps (i.e. approximately 30%, 60%, and 100% of the target torque) using the cross-over tightening method. Cross-over tightening sequences for different number of bolts are shown in Figure 5.

Cross Over Tightening Sequences for Flange Bolts	
No. Bolts	**Sequence**
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

FIGURE 5. Typical Flange Bolt Tightening Sequences (ASME PCC-1)

7. CHECK TORQUE: When complete, check the torque on a rotational clockwise pattern until no further nut rotation occurs. If time permits, check the torque after 4-8 hours and repeat the clockwise pattern to restore the short-term relaxation of the gasket. Typical bolt torques for flanges with resilient gaskets are given in Figure 6. If leakage occurs, allow gaskets to absorb fluid and check torque and leakage after 24 hours. Do not exceed bolt rating or crush gasket more than 25 percent of its thickness.

125# FLANGE DATA Resilient Gasket 150 psig			250# FLANGE DATA Resilient Gasket 250 psi		
Size NPS	**Bolt Dia. (in)**	**Bolt Torque (ft-lbs)**	**Size NPS**	**Bolt Dia. (in)**	**Bolt Torque (ft-lbs)**
4	5/8	30-60	4	3/4	30-80
6	3/4	30-90	6	3/4	40-100
8	3/4	40-150	8	7/8	60-150
10	7/8	45-150	10	1	80-160
12	7/8	60-210	12	1 1/8	100-250
14	1	80-250	14	1 1/8	120-250
16	1	80-250	16	1 1/4	150-300
18	1 1/8	100-250	18	1 1/4	180-300
20	1 1/8	100-250	20	1 1/4	200-350
24	1 1/4	150-300	24	1 1/2	300-600
30	1 1/4	250-500	30	1 3/4	450-800
36	1 1/2	250-500	36	2	600-1000
42	1 1/2	300-600	42	2	750-1100
48	1 1/2	300-600	48	2	900-1500

FIGURE 6. Typical Flange Bolt Torques

8. RECORDS: Make a record of the flange connection for future reference including:

   a. Equipment identification
   b. Flange Size and Class
   c. Date of assembly
   d. Gasket material
   e. Bolt material
   f. Flange surface quality comments
   g. Target bolt torque and tools used
   h. Name of pipe fitter

By recording the flange installation information, future troubleshooting and repair of the joint will be facilitated. When complete, stand back and admire your work. You can see by the number of flanges shown in Figure 7, that flange design and installation plays an important role in piping systems.

FIGURE 7. Pipe Gallery in Treatment Plant in Morris, IL

Conclusion

The installation of valves and flanges can literally make or break a piping system. To avoid serious construction problems and costs, follow published guidelines on the installation of bolts, gaskets for your piping system.

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