White Paper

Valve Flanges for Waterworks Service
Part 1: Flange Design and Standards

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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. Because piping systems are subject to many types of loads and are constructed of various materials, it is difficult to understand and predict the rating and performance of flange connections. Further, the use of different sealing mechanisms such as gaskets, O-rings, and mechanical seals can significantly affect the performance of the connection. Finally, ASME B16.1 lists pressure ratings for Class 125 flanges from 50 to 200 psig depending on size, material, and temperature. Part One of this article will provide 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 Geometry

Figure 1 illustrates a basic flange that can be found on most waterworks valves and fittings. The connection consists of a circular ring or "flange" that is welded to or cast integral with the valve body and pipe. The basic dimensions of a flange consist of the Outside Diameter (OD), Bolt Circle Diameter (BC), Thickness (T), and the number and size of the bolt holes. It is customary for the bolt pattern in valves and fittings to straddle the vertical centerline. The flanges of two fittings mate together and are sealed with a resilient gasket, which is tightly compressed by the bolts located in a circle, concentric with the pipe OD. To obtain a tight seal, the bolts must withstand the hydrostatic end force of the pipe and compress the gasket to a multiple of the maximum pressure of the system.

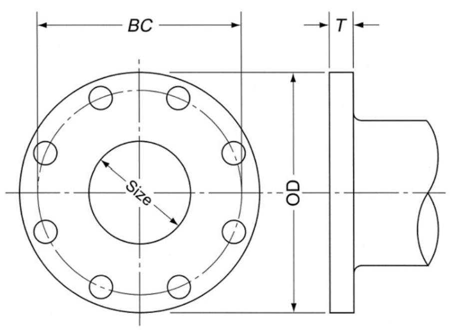

FIGURE 1. Typical Waterworks Flange Connection

Because of the body shape of some valves, valve flanges often contain tapped holes instead of through holes, which will affect the selection of bolting. The 24 NPS eccentric plug valve shown in Figure 2 requires four tapped holes on the top and four tapped holes on the bottom of the flange because the nuts behind the flange would interfere with the main part of the valve body.

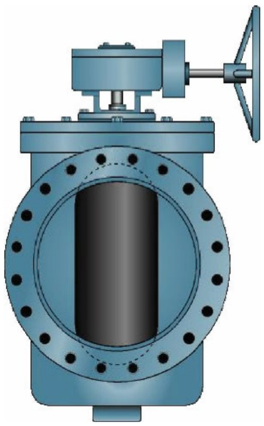

FIGURE 2. 24 NPS Plug Valve Flange with 8 Tapped Flange

A flange is a structural element of the piping system and must withstand the pressure and pipe loads related to the system since it is a rigid or restrained joint. The flange connection will not slip or pivot and must withstand the internal pressure forces without any external restraint. Certain push-on and mechanical joint connections, which are often used below ground, are not restrained. It is an important distinction that affects the supports, anchors, and thrust blocks needed in many systems. The flange must be of sufficient strength to transfer pipe loads, pressure forces, and gasket loads from the bolts to the connecting pipe, fitting, or valve. When a pipe is pressurized internally, the hydrostatic forces tend to stretch the pipe and pull the flanges apart. The bolts must maintain contact between the mating flanges and gaskets without excessive stretching.

To absorb these loads, there are several types of flange shapes available to the designer as shown in Figure 3. The simplest is the ring flange, which consists of a flat plate of uniform thickness. The hub flange is similar to the ring flange but has additional material at the base of the flange so that the loads are distributed more uniformly to the pipe or fitting. Ring and hub flanges can be attached to the pipe by welding or by threading (companion flange). High pressure steel flanges often have a raised face and sloped hub that optimizes the strength to weight ratio of the flange and are attached to the pipe with a butt weld. The raised portion of the flange focuses the bolt load over a smaller gasket area improving the performance of the gasket. Finally, when the purpose of the flange is to block off the end of the pipe, a blind flange is used which consists of a solid flat plate. A flat plate is an inefficient shape to withstand pressure (dished heads are better), so blind flanges tend to be thicker than pipe flanges.

Flange Materials

The pressure ratings of flanges are based on their material of construction. This makes sense because steel can be twice as strong as gray iron. But in order to understand how material strength affects flange ratings, it is important to understand some fundamental mechanical properties of metals. Gray iron and ductile iron are both alloys of iron but their mechanical properties differ greatly. To produce a cast flanged fitting, pig or scrap iron is melted down and combined with other elements such as carbon and silicon to produce its unique properties. As shown in Figure 4, when gray iron solidifies, its grain structure includes graphite (carbon) in the form of flakes, which appear as jagged lines in the figure. These flakes of graphite give gray iron its strength and hardness, but at the same time, make it brittle. Nevertheless, gray iron is used extensively in fittings and many other products including engine blocks because the graphite structure absorbs noise and exhibits good wear resistance.

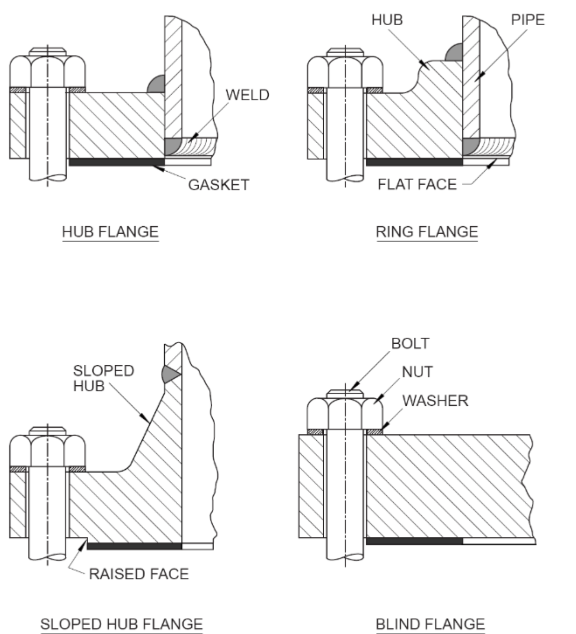

FIGURE 3. Examples of Flanges

Conversely, when ductile iron is cast, the molten metal is treated with magnesium, which causes the graphite to solidify into nodules, see Figure 5. The nodule shape gives ductile iron greater strength and less brittleness than gray iron. Materials like ductile iron tend to deflect significantly before fracturing. This tendency for a material to deflect before fracturing (like a rubber band) is called ductility. Granted, a rubber band may deflect 5 to 10 times its length before breaking, but by the same principle, ductile iron may deflect as much as 18% before breaking. Since ductile iron can bend like steel, it also has the ability to absorb shocks, which helps reduce line breaks in water main applications. This knowledge of materials and their mechanical properties allow engineers to establish safe and predictable flange designs for use in various industries.

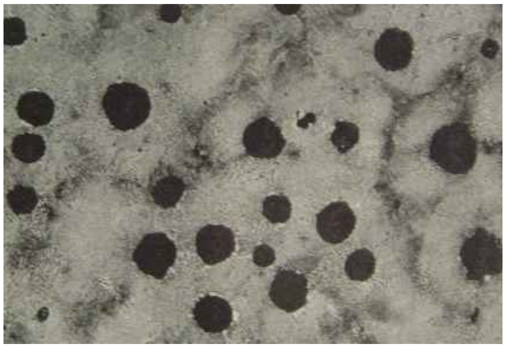

FIGURE 4. Gray Iron at 400X

FIGURE 5. Ductile Iron at 400X

Flange Standards

To allow interchangeability of components within an industry, engineers have developed standard dimensions over many decades for bolts and flanges for various pipe sizes and pressure ranges. The first such effort was undertaken by the American Society of Mechanical Engineers (ASME). The ASME is dedicated to ensuring the safety of the general public from the risks of pressurized systems like boiler piping. Beginning in 1920, the ASME "B16" committee assumed responsibility for developing codes and standards related to valves, pipe flanges and fittings. Their published body of work includes standard dimensions and pressure/temperature ratings for gray iron flanges and fittings given in ASME B16.1, ductile iron in ASME B16.42, and steel in ASME B16.5. They also recently produced a standard for large steel flanges, ASME B16.47, but its use is targeted for the petroleum industry. Compliance with these standards is voluntary but their application ensures safety at the stated pressures and temperatures and uniformity so that flanged valves and fittings from different manufacturers are interchangeable.

Similarly, the American Water Works Association (AWWA) A21 Committee publishes flange and fitting standards that mate with some of the ASME flanges, but are designed for cold water service. Most notably, AWWA C110 "Ductile-Iron and Gray-Iron Fittings" describes 3 in. to 48 in. fittings and flanged joints with Class 125 dimensions for waterworks service. These fittings and their ratings are based on extensive burst testing and provide a safety factor of at least three times the rated cold working pressure (AWWA C110). Because these products are intended for cold water, the ratings of AWWA fittings and flanges are higher that a similar ASME fitting. Keep in mind that the ASME fittings are also used for steam service which is far more hazardous than waterworks service. Finally, it is important to realize that while valves incorporate these flanges, their pressure ratings may differ based on different valve standards. For example, some butterfly valves with Class 125 flanges have flanges capable of 250 psig, but AWWA C504 "Rubber-Seated Butterfly Valves" limits the maximum working pressure of gray iron valves to 150 psig.

Flange Classes

ASME and AWWA standards provide sets of flange dimensions for various classes of flanges. Given these dimensions, the standards development organizations then establish pressure ratings for flanges and fittings based on the material from which they are made and the temperature at which they are used. Pressure classes such as 125, 250, 300 etc. cause considerable confusion in the industry because they are often interpreted as the rated pressure for the flange but there can be nothing further from the truth. These classes are "designations" that generally represent a pressure and temperature for saturated steam. For example, an ASME B16.1 Class 125 flange is rated for 125 psig at 353º F, which is the boiling temperature for water at that pressure. As temperature increases, the pressure rating of the flange decreases. For example, a Class 150 flange is rated about 270 psig at ambient conditions, 180 psig at 400°F, 150 psig at 600°F, and 75 psig at 800°F. At ambient temperatures (i.e. 100°F), it makes sense that the pressure ratings are higher than the saturated steam pressure. When the temperature rises, the rated pressure goes down, and vice versa. Pressure and temperature tables must be consulted in the applicable standards to apply them to a piping system.

A general summary of flange pressure ratings versus temperatures is shown in Figure 6. The ASME pressures represent nonshock pressure ratings, or in other words, steady pressures and not pressure spikes or cyclic water hammers. Conversely, AWWA fittings are adequate for the rated pressure plus a surge allowance of 100 psi or half the rated working pressure, whichever is less (AWWA C110). The table brings to light some important observations.

1. In all cases, as the maximum temperature increases, the pressure rating of the flange goes down. Metals are weaker at high temperatures.
2. Most of the time, the pressure ratings do not match the Class designation at 100°F.
3. As the Class designation increases, the pressure rating increases.
4. Ductile iron flanges are rated higher than gray iron flanges.
5. AWWA C110 only specifies Class 125 drilling.
6. The AWWA fittings are not rated for high temperatures.

Max Temp	ASME STANDARDS (ASME B16.1 and ASME B16.42)								AWWA STANDARDS (AWWA C110			
	Gray Iron ASTM A126 Class B				Ductile Iron ASTM A395 Gr 60-40-18				Gray Iron Class 25 or 30		Ductile Iron Gr 70-50-05	
	CLASS 125		CLASS 250		CLASS 150		CLASS 300		CLASS 125		CLASS 125	
	NPS 1-12	NPS 14-24	NPS 1-12	NPS 14-24	NPS 1-12	NPS 14-24	NPS 1-12	NPS 14-24	NPS 3-12	NPS 14-24	NPS 3-12	NPS 14-24
100°F	200	150	500	300	250	250	640	640	250	250	350*	350*
200°F	190	135	460	280	235	235	600	600				
300°F	165	110	375	240	215	215	565	565				

*With special gasket containing molded annular sealing elements.

FIGURE 6. Non shock Pressure Ratings of Gray and Ductile Iron Flanges, Psig

There are many other standard pressure classes in ASME standards. But in the waterworks industry, Class 125 and Class 250 apply to gray iron flanges while Class 150 and Class 300 apply to ductile iron, steel and stainless steel (ASME B16.1, ASME B16.42). The bolting patterns of Class 125 and Class 150 match, as do Class 250 and Class 300. It is important not to mix the rating of the fitting with the drilling of the flange. Most AWWA fittings have Class 125 drilling, but a 250 psi rating even when made of gray iron (AWWA C110).

In the water works industry, AWWA publishes standards for flanged fittings and valves that are related to the ASME standards. Because AWWA fittings and valves are used with water, which is considered a safer media, the general safety factor may be lower than with hazardous high temperature steam applications. AWWA also allows several alternate grades of gray iron and ductile iron.

Flange Sizes

Even though every flange size and pressure class has an exact OD, flange sizes are denoted by the size of the pipe, expressed as nominal pipe size (NPS). It is often assumed that NPS stands for the inch size of a pipe, technically the NPS value is a dimensionless number and is related to the reference nominal diameter (DN) used in international standards. Similarly, the DN sizes are dimensionless and not millimeters. The general relationship is shown in Figure 7 (ASME B16.5).

US Customary Sizes	International Sizes
NPS 1	DN 25
NPS 1-1/2	DN 40
NPS 2	DN 50
NPS 2-1/2	DN 65
NPS 3	DN 80
NPS 4	DN 100
For NPS > 4, the DN is NPS x 25	

FIGURE 7. Flange Size Relationship

Each flange standard has limited size ranges and pressure classes. Figure 8 presents the scopes of the various standards. In addition to those listed, there are flange standards for stainless steel, copper, and international (metric) drilling. But the standards listed below are the most common in this industry. There are some general facts that should be understood when using these standards.

First, Class 125, Class 150, and AWWA Classes B, D, & E flanges have the same bolt pattern and can be joined together (AWWA C207). The same goes for Class 250, 300, and AWWA Class F.

The steel flanges given in ASME B16.5 only go up to NPS 24, so that standard is of little use for large flanges. Hence, AWWA C207 is used for large steel flanges in the waterworks industry. C207 is a relatively new standard and only just released dimensions for sizes up to NPS 144 in 1978 (AWWA C207). Therefore, there are many valves and fittings in the field with “special” flange drilling. Caution should be observed when fabricating replacement equipment for existing piping systems.

Class 125/150 drilling is the most common flange in the waterworks industry. It is so common that some projects specify iron valves with 250/300 flanges drilled special to mate with a Class 125/150 bolt pattern. This is done so that the valve can carry the same pressure rating as the steel mating flange. But this is not practical because it adds unnecessary weight to the valve and is unsightly when the flange diameters do not match in the pipeline. A better practice is to simply specify a Class 125/150 valve flange in ductile iron which will carry a similar pressure rating as the steel mounting flange.

Finally, Class 250/300 drilling is common, but only available up to size NPS 48. Above that size, flanges will have the 125/150 drilling with the pressure rating dependent on the material (ASME B16.1).

FLANGE STANDARD	MATERIALS	CLASSES	SIZE RANGE
ASME B16.1	Gray and Ductile Iron	25, 125, 250	NPS 1 to 96
ASME B16.5	Steel, Stainless Steel	150, 300, 400, 600, 900, 1500, 2500	NPS ½ to 24
ASMEB16.42	Ductile Iron	150, 300	NPS 1 to 24
ASME B16.47*	Steel, Stainless steel	75A, 150A, 300A, 400A, 600A, 900A, 75B, 150B, 300B, 400B, 600B, 900B	NPS 26 to 60
AWWA C110	Gray and Ductile Iron	125	NPS 3 to 48
AWWA C207	Steel	B (86 psi), D (175 psi), E (275 psi), F (300 psi)	NPS 4 to 144
MSS SP-44*	Steel	150, 300, 400, 600, 900	NPS 12 to 60

*CAUTION, These standards apply to steel petroleum pipelines and do not match B16.1 drilling in large sizes. The “A” designation indicates MSS SP-44 compatibility; the “B” designation indicates API-605 compatibility (ASME B16.47).

FIGURE 8. Applicable Water Works Flange Standards

Conclusion

Flanges are an important component of piping system that are provided by both valve and pipe manufacturers in many configurations and a full knowledge of their design and applicable standards is essential for the success of the piping system. Valve and pipe flange are provided in many alternate materials and conflicting pressure class designations in the waterworks industry. To avoid serious construction problems and costs, know your flange ratings and specify flange systems that meet the required pressure and temperature requirements of your piping system.
severe applications, surge tanks can be employed.

References

1. American Society of Mechanical Engineers, ASME B16-1-2010. *Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250*.
2. American Society of Mechanical Engineers, ASME B16-5-2013. *Pipe Flanges and Flange Fittings: NPS ½ through NPS 24 Metric/Inch Standard*.
3. American Society of Mechanical Engineers, ASME B16-42-2011. *Ductile Iron Pipe Flanges and Flanged Fittings: Classes 150, and 300.*
4. American Society of Mechanical Engineers, ASME B16-47-2011. *Large Diameter Steel Flanges: NPS 26 Through NPS 60*.
5. American Water Works Association, ANSI/AWWA C110/A21.10-12 *Ductile-Iron and Gray-Iron Fittings.*
6. American Water Works Association, ANSI/AWWA C207-13 *Steel Pipe Flanges for Waterworks Service – Sizes 4 In. Through 144 In.*
7. American Water Works Association, ANSI/AWWA C504-10 *Rubber-Sealed Butterfly Valves, 3 in (74mm) through 72 in (1800mm)*.
8. Manufacturers Standardization Society, MSS SP-44-2010. *Steel Pipeline Flanges.*

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