Primary flange forces – Part 1

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Primary flange forces and gasket stress

The article is the first in a two-part series that takes a somewhat global perspective on the subject of flange forces, and the role they play in creating and maintaining the successful sealing of bolted flange connections (BFC).

Successful sealing of gaskets in a bolted flange assembly requires the gasket to remain within a particular range of stress. Its upper bound ensures the mechanical integrity of the gasket is not exceeded. The lower bound ensures sufficient sealing stress to provide the intended level of tightness. Because the forces that create the gasket stress must pass through the flanges, successful sealing is equally dependent on the balance of forces on the flanges. If the force on the flanges is too low, not enough compression on the gasket results. If it's too high, damage to the flanges, excessive rotation (bending) of the flange, or both can result, often resulting in leakage. Part 1 reveals how gasket stress is typically distributed between mating flanges, and identifies some of the most common flange forces to be considered in deriving a suitable bolt load for the connection. Part 2 will discuss the role these forces play and what can be done to control them.

Gasket stress distribution

Ultimately the leak-free reliability of a BFC depends on the state of stress in the gasket. It's often convenient to simply divide the total bolt load at bolt-up by the area of the gasket to judge the state of stress on the gasket. This simple ratio provides an average value. In actuality, the state of stress at any particular location in a gasket is different than this value, sometimes by a large margin.

Fundamental to understanding how flange forces affect gasket stress is to understand how gasket stress is distributed over the sealing surface of the flange. To help visualize how the flange and gasket face interact with one another, see Figure 1. The graphic is the result of a finite element analysis. The abscissa is the value of gasket stress, and the ordinate is the circumferential location in a 90° quadrant of the gasket face, of a four bolt flange. The dashed line represents the radial line through the center of a bolt. The plot shows the value of gasket stress at the outer diameter, middle and inner diameter of the gasket face. In this particular

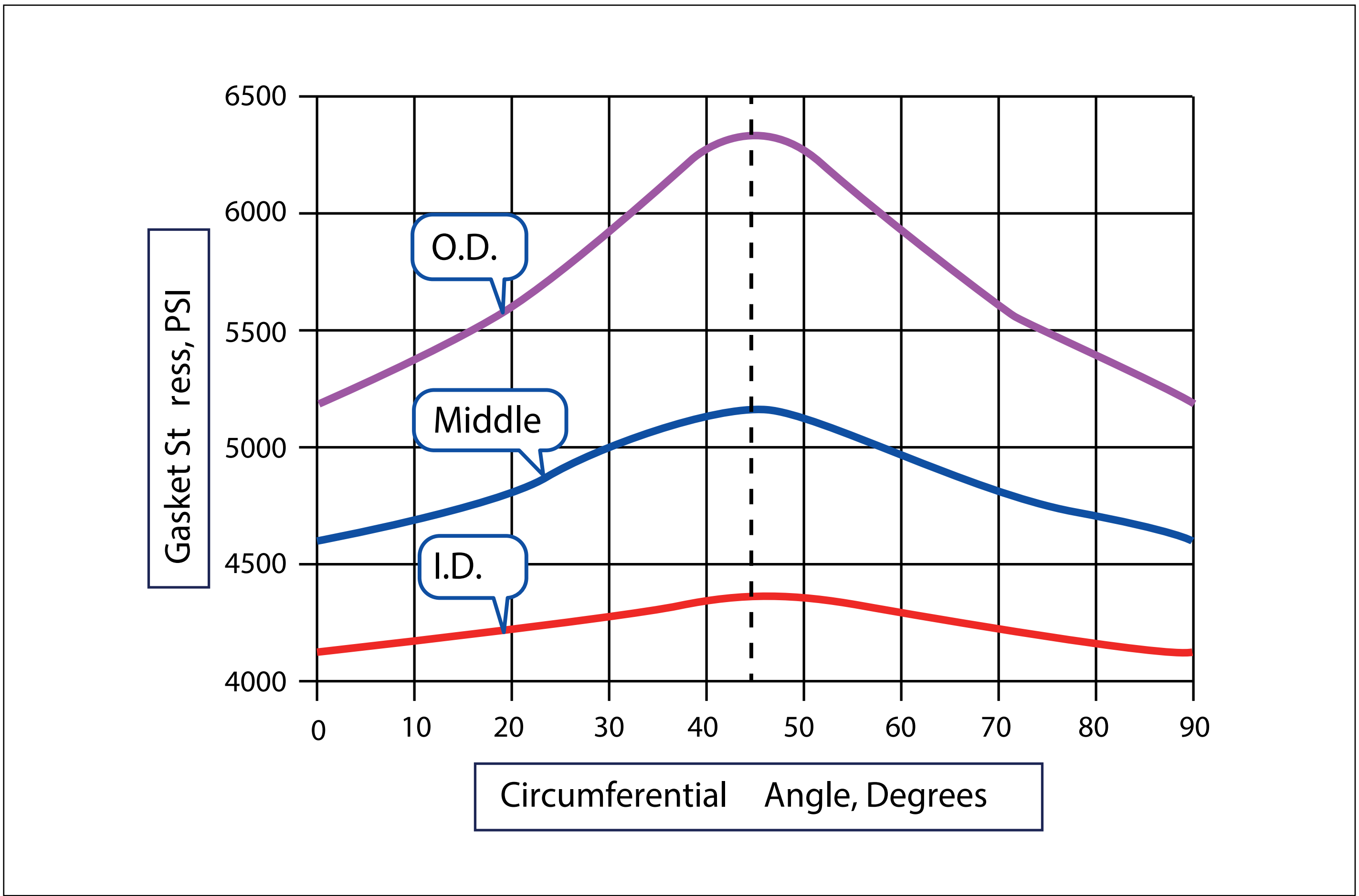

Figure 1

instance the flange is an ASME, A 182 Gr 316L, 3" diameter, Class 150 welding neck flange. Results though, will be similar for other BFC with 'floating' gaskets.
The bolt load is based on an average gasket stress of 5,000 psi, and is evenly distributed on all bolts. Note that even under these ideal conditions, the gasket stress varies both circumferentially and radially. This is due to the rotation of the flanges and the near juxtaposition of gasket material to the bolt. As the outer edges of the flanges are pinched together the gasket stress at its outer diameter is increased. The opposite effect is seen at the inner diameter of the gasket.
Controlling flange stresses is clearly important to controlling gasket stresses. Following are typical flange forces to consider in determining a gasket solution.

Bolt-up force

This is the force intended when the BFC is initially tightening. Most commonly the value of force for a given bolt is given by this simple, empirical equality.

$$F_{bu} = T \times 1000/(k\, d_{nom}) \quad \text{SI Units} \qquad \text{(Equation1)}$$

Where, F_{bu} = Bolt force from torque, N
T = Torque, Nm
k = Nut factor, dimensionless
d_{nom} = Nominal bolt diameter, mm

$$F_{bu} = T \times 12/(k\, d_{nom}) \quad \text{U.S. Customary Units} \qquad \text{(Equation 2)}$$

Where, F_{bu} = Bolt force from torque, lbf.
T = Torque, ft.lb.
k = Nut factor, dimensionless
d_{nom} = Nominal bolt diameter, in.

The total force on the flange from bolt-up becomes the force of a given bolt times the number of bolts. Note that this presumes that other forces are not resisting the bolt-up force.

$$F_{Tbu} = F_b \times B_{no.} \qquad \text{(Equation3)}$$

Where, F_{Tbu} = Total force from bolt-up, N (lbf.)
$B_{no.}$ = Number of bolts in flange

This is the primary flange force to which all other forces are either added or subtracted. It must be sufficient in value to withstand the effects of all conditions that will change it, while still being able to maintain a leak-tight value of stress on the gasket. The importance of ensuring that the intended bolt-up load is imparted to the flanges cannot be over stated. Engineering solution can provide a value for successful sealing of the flanges, but this success can only be realized when this load is accurately and evenly developed at the time of the installation.

Hydraulic force

After the initial bolt-up, the flanges are subjected to operating pressure and temperature. The pressure, if internal will create a force opposite to that of bolt-up. If external, the force is additive to the bolt load. In either case, its value is approximated by multiplying the pressure by the internal area defined by the inner diameter of the gasket.

$$F_{hyd} = P \times A_{hyd} \qquad \text{(Equation 4)}$$

Where, F_{hyd} = Hydraulic force on flange N (lbf)
P = Pressure contained. (+) if internal, (–) if external, MPa (lbf./in.^{2})
A_{hyd} = Pressure area contained by gasket, mm^2 (in.^{2})

In the simplest of approximations the average operating gasket stress would be the result of the difference, or sum of the bolt-up force and the hydraulic load. This seldom occurs because other flange forces are usually in action.

Piping induced forces - alignment

Piping induced forces are often introduced into a flange pair by less than idea fit-up of flanges. Fit-up problems occur as a result of misalignment of flanges. In the case of good flange alignment, bolts can easily be inserted by hand. Excessive misalignment of flange pairs though, requires the connected piping to be pulled or pushed into place so the bolts can be installed. The force(s) required to align the pipe are resisted by the bolts during fit-up. These forces may create axial, shear, torsional or bending loads on the flanges, individually, or all four simultaneously. When these forces are not excessive, they can be compensated for by additional bolt load.

Piping induced forces – expansion and contraction

Expansion or contraction of attached pipe and equipment will also introduce forces on the flanges. They're created after the initial installation and when the temperature of the attached piping and equipment changes to its operating temperature. Determining the extent of these forces requires a piping flexibility analysis which essentially reviews the piping layout of a system, and determines the resulting forces from restrained piping movement. Specific guidance on identifying limits is beyond the scope of this article. It's important to realize though, that the need for such an analysis and the respective limits of the effects on piping are called out in applicable engineering Codes. Typically a limiting value of force is allowed during the design of the attached piping system and the robustness of the flange design is sufficient to successfully withstand it. Troubles can arise though, if there's a change to the piping design and its effect is not taken into consideration.

Piping induced forces – environmental effects

Last in the consideration of flange forces are those created from environmental effects. These include such things as wind, earthquake and snow. Again, like expansion and contraction forces, these forces are normally included in the design of the piping system if necessary, and are rarely included in specifying the value of bolt load to successfully seal a gasket.

Part 1 conclusion

Gasket stresses are the direct result of flange forces. Successful BFC sealing requires these forces to remain with a range of predictable and controlled values. Both excessive values, and insufficiently low values can lead to connection leakage. In Part 2 we discuss how to target the correct value of flange force, and two of the most important safe guards to controlling these forces.

Part 2 will be published in the May issue of Valve World.

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