Piping Flange Fundamentals

An Online Continuing Education Course for Engineers

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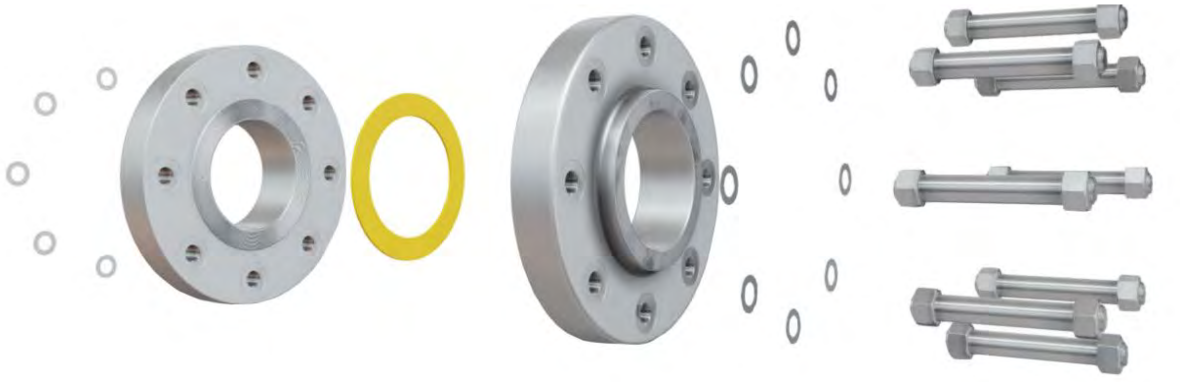
Introduction

Flanges offer a **mechanical** means of joining **pipes**, **fittings** (elbows, tees etc.), and **valves**. Compared to **welds**, flanges are a **non-permanent** type of joint that can be **easily assembled and disassembled** (ideal for systems that require **maintenance**). Flanges are installed via **welding**, **screwing,** or **lapping**, and they are the second most popular joining method after welding.

A flange assembly consists of:

- **Flange** (blade, hub).
- **Gasket** (metallic, composite, or non-metallic).
- **Fasteners** (nuts, bolts, or studs).



Flange Assembly

Flange Terminology

Flange **terminology** and **nomenclature** can be confusing due to the similar terms, definitions, and phrases that are used. To make the learning process easier, readers should clearly understand the following terms:

- **Flange types** – refers to the flange design. Examples of flange types include the **welding neck** (weld neck), **slip-on**, **socket weld**, **threaded**, **blind flange** and **lap joint** type flanges. Flange types are selected based on the temperature and pressure requirements, and are identifiable by their geometry.
- **Flange faces** – refers to the area used for sealing of the flange; a gasket is usually installed between the two opposing flange faces. Examples of flange faces include the **flat**, **raised**, **ring-type joint (RTJ)**, **lap joint**, **tongue and groove**, and **male and female** designs.
- **Flange surfaces** – refers to the condition of the flange face sealing surface. A flange face surface may be **smooth**, or **serrated**[1]. The smoothness of a flange face surface is defined by its **Roughness Average (Ra)** or **Arithmetic Average Roughness Height (AARH)**.

All of the afore mentioned topics will be further discussed. It is important to realise that there are many aspects that influence not only what flange type is chosen for a particular application, but also what face and what surface. For example:

- Certain systems may require welded joints that can be easily inspected (this is not always possible with certain flange types).
- Certain flange faces may not be suitable for higher pressure systems because the maximum sealing pressure is too low (flat face designs).
- Certain materials will tend to have poor finishes that yield a correspondingly rough sealing surface; these rough surfaces require a gasket if a leak tight seal is to be achieved e.g. cast-iron flanges.

When selecting a flange, the material is chosen to meet process requirements first, whilst the temperature and pressure requirements are then met based on the material chosen.

[1] *'Serrations' are machined grooves cut into the surface of a flange's face. Gasket material flows into the grooves, which results in a more reliable seal being obtained; the grooves also help hold the gasket stationary.*

Bolted, Threaded and Welded Joints

Flanges are a type of **bolted joint**. Other common types of **joint** include **threaded joints** and **welded joints**.

- A **bolted joint** requires a **flange** and **fasteners** (nuts, bolts, or studs).
- A **threaded joint** requires a **male and female screw thread**, the male thread screws into the female thread.
- A **welded joint** is made using a **weld** (the process of melting/fusing metal by applying heat).

Bolted Joint

The type of joint used depends on many factors, including **pressure**, **temperature, type of process fluid**, **operating characteristics of the system**, and the surrounding **environment**. A bolted joint may be used if:

- Other types of joint are **not suitable** e.g. welding may not be possible within areas that pose a fire or explosion risk (Ex areas); this is mostly a concern for an already operational piping system, not one that is under construction.
- A machinery item must be disconnected from the service line in order that maintenance or replacement of the machine can occur.
- Quick field assembly is required using only basic hand tools.
- The item (e.g. tank, pipe, machine) to which the flange is connected must be frequently maintained; it is quick and easy to disassemble and assemble a flange, but not a weld.

Some of the main **disadvantages** associated with a **bolted joint** include:

- Insulating a bolted joint (thermal insulation) **costs more** than insulating a threaded or welded joint.
- Bolted joints require **more physical space** than threaded or welded joints.
- Each bolted joint represents an **additional leakage point** (even if assembled correctly).

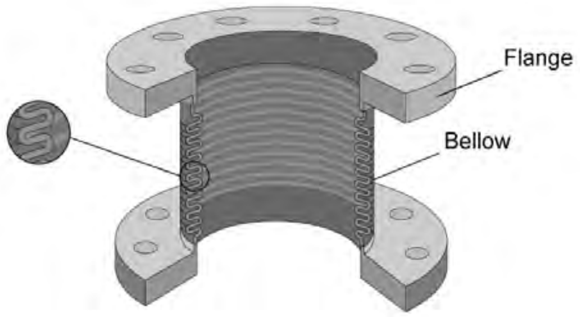
As a **general rule**, threaded joints are suitable for lower pressure and temperature applications only, whilst bolted and welded joints are suitable for higher pressure and higher temperature applications. If a threaded joint must be leak tight, and leakage cannot be tolerated, it can be **seal welded**. The seal welding technique is only used for higher service pressure conditions and is not an ideal solution because it creates a stress concentration point which will be prone to fatigue failure.

The advantage with **welded joints** is that the weld can be proved using **non-destructive testing (NDT) techniques** e.g. penetrant testing, ultrasonic testing, magnetic particle testing, hydrostatic pressure testing etc.; proving a flange -and flange gasket- is more difficult.

Expansion Joints

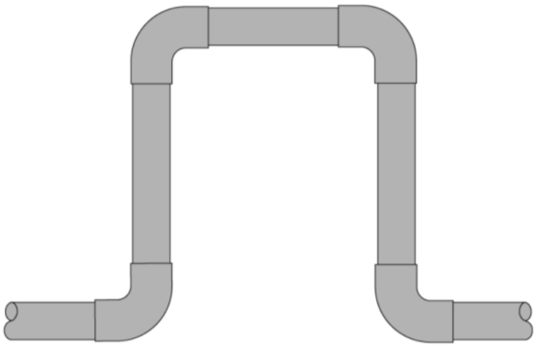
A less common type of joint is the **expansion joint**. Expansion joints cater for **thermal expansion** of a piping system as its temperature increases. Although expansion joints are usually considered only to cater for expansion, it is important to realise that they need to cater for the entire temperature range the piping system operates at, during both **contraction** (**lower temperatures**) and **expansion** (**higher temperatures**). To do this, they should not be overloaded during **compression** ('squeezing') or **tensile** ('stretching') loading. There are **four** main types of expansion joint:

- **Rubber bellow**
- **Metal bellow**
- **Slip**
- **Ball**



Metal Bellow Expansion Joint

Expansion joints are used if the installation of **expansion loops** (piping laid in a **semi-circular** shape) is not practical.



Pipe Expansion Loop

If thermal expansion of the piping system is not catered for, loads will be transferred to stationary supports and equipment, which may lead them to failing. The problems arising from thermal expansion must be dealt with at the design stage. Systems that have wide ranging temperature changes e.g. power plant steam systems, are particularly susceptible to damage arising due to thermal expansion.

> ***Tip*** *- within the piping industry,* ***expansion joints are being phased-out*** *for new piping system designs and many companies now prohibit their usage. The reason for this phase-out is because environmental factors often cause expansion joints to malfunction, and they require constant inspection and maintenance (at additional financial cost).*

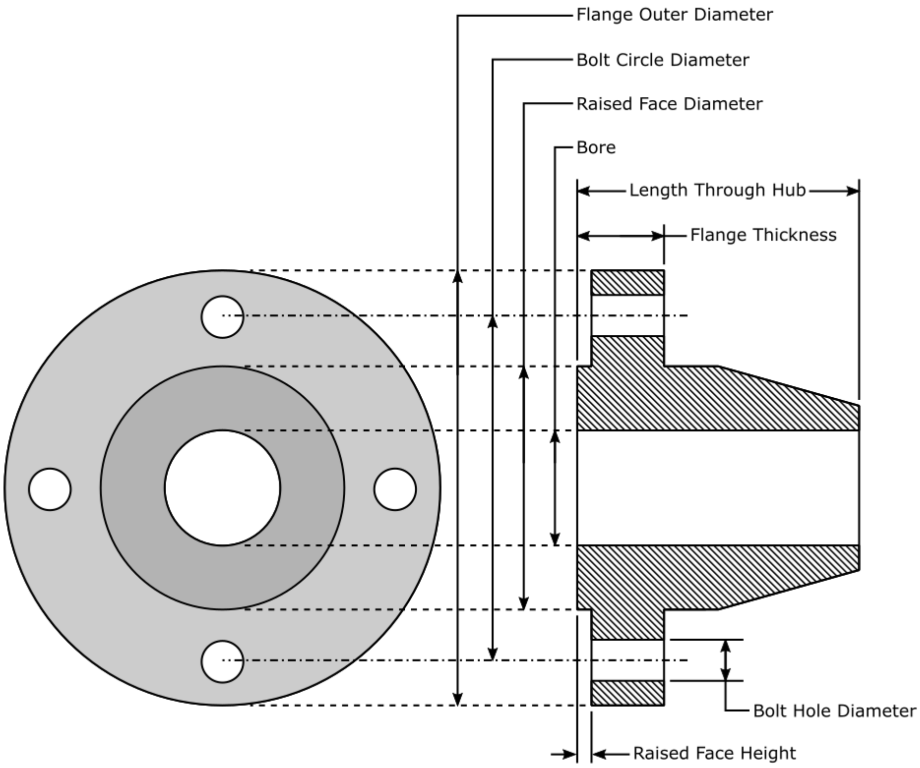
Flange Construction

Flanges are split into **two** main areas, the '**blade**', and the '**hub**'.

- The **flange blade** encompasses the area where the bolts penetrate through the flange and the flange face.
- The **flange hub** is the area that accommodates the pipe which attaches to the flange.

To ensure **no leaking** between the mating[2] flanges occurs, **gaskets** are used. It is possible to mate two metal flanges together without the use of gaskets, but sealing is difficult and can only be achieved with specially designed flanges.

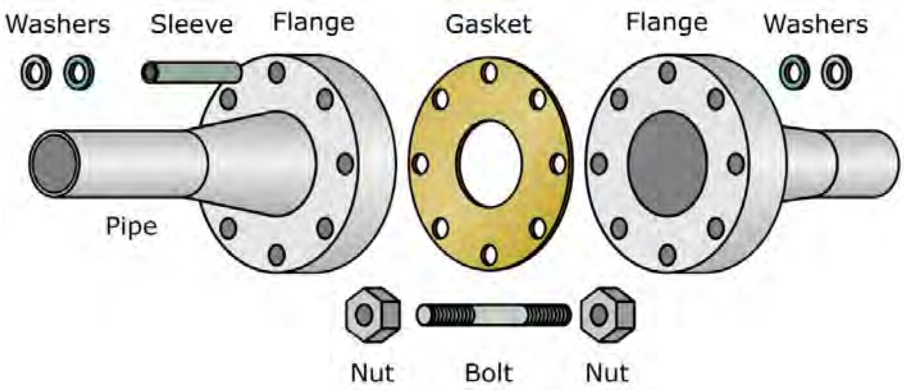
The **end connection** specifies **how the flange is connected** to its accompanying pipe (threaded connection or welded).



Flange Design

How Flanges Work

A flange is created when **two opposing surfaces** are intentionally pressed together in order to create a leak tight seal. To obtain a seal, force must be applied and maintained to each of the opposing flange faces. As many flange faces have manufacturing imperfections (scratches, dents, pits etc.), it is necessary to put a softer material between the two mating sealing surfaces to obtain the seal; this softer material is the **gasket**.



Flange Assembly

[2] *Mating – refers to the pressing together of two opposing flange face sealing surfaces.*

Basic Flange Math

To understand how flanges work, we must first understand the concept of pressure. Pressure is defined as:

Pressure = Force / Area

P = F / A

Flanges seal because pressure is applied to the mating sealing surfaces; this pressure is known as the '**gasket compression**' or '**sealing pressure**'. The applied pressure causes the two faces to either:

- Crush a gasket between the two mating faces.
- Press the two mating faces against each other.

In the gasket example, the gasket is deformed due to the pressure applied; this **deformation** causes the gasket to '**flow**' into any surface imperfections that may be present on either sealing face. Because the surface imperfections have been filled by the gasket material, leakage is no longer possible.

The second example assumes **no gasket** is present and that two flange faces are pressed together. It is hard to create a **leak tight seal** using this method, although it is possible if the surfaces are **well machined** and **very clean**. The sealing pressure applied will often need to be significant, as the flange surface may be manufactured from **metal**, which does not easily deform under pressure (material and flange class dependent). **Metal to metal** flange face sealing is **expensive** and thus **not common**.

To create the necessary sealing pressure, the variables of force and area can be adjusted.

- **Force** refers to the **tightening torque** (**bolting load**) applied to the mating flange faces when the nuts on a flange assembly are tightened. **Force (F)** depends upon the **torque (T)** applied, **torque friction (K)** and **nominal bolt diameter (D)**. The force described is classed as '**bolt pretension**' or '**bolt preload**', or '**bolt prestress**', and is represented by the equation **F = T/(KD)**
- **Area** refers to the size of the sealing face area.

The amount of pressure on the flange sealing faces corresponds t... applied when tightening the flange assembly. Thus it is possible to regulate t... effort that is exerted when tightening the bolts during fl...

The sealing area of a flange ... bly. A larger sealing face requires more force to obtai... aller sealing face. The below example highlights this point, ...

Example

A given flange assembly requi... a lot of force onto a small sealing face:

Or, it is possible to decrease the ... force required to create the same amount of pressure[3]:

[3] *Standards such as ASME B16.5 and B16.47 dictate the size of the sealing face required.*