Training Services

Flanges

Purpose

- **Introduce the common types and uses of flanges and outline the methods to select or design a flange for a given application**

Outline

- **Introduction**
- **Standards**
- **Materials**
- **Flange Selection**
- **Flange Facings**
- **Gaskets**
- **Finishes**
- **Flange Design**
- **Leakage Causes and Correction**

Flanged Joint

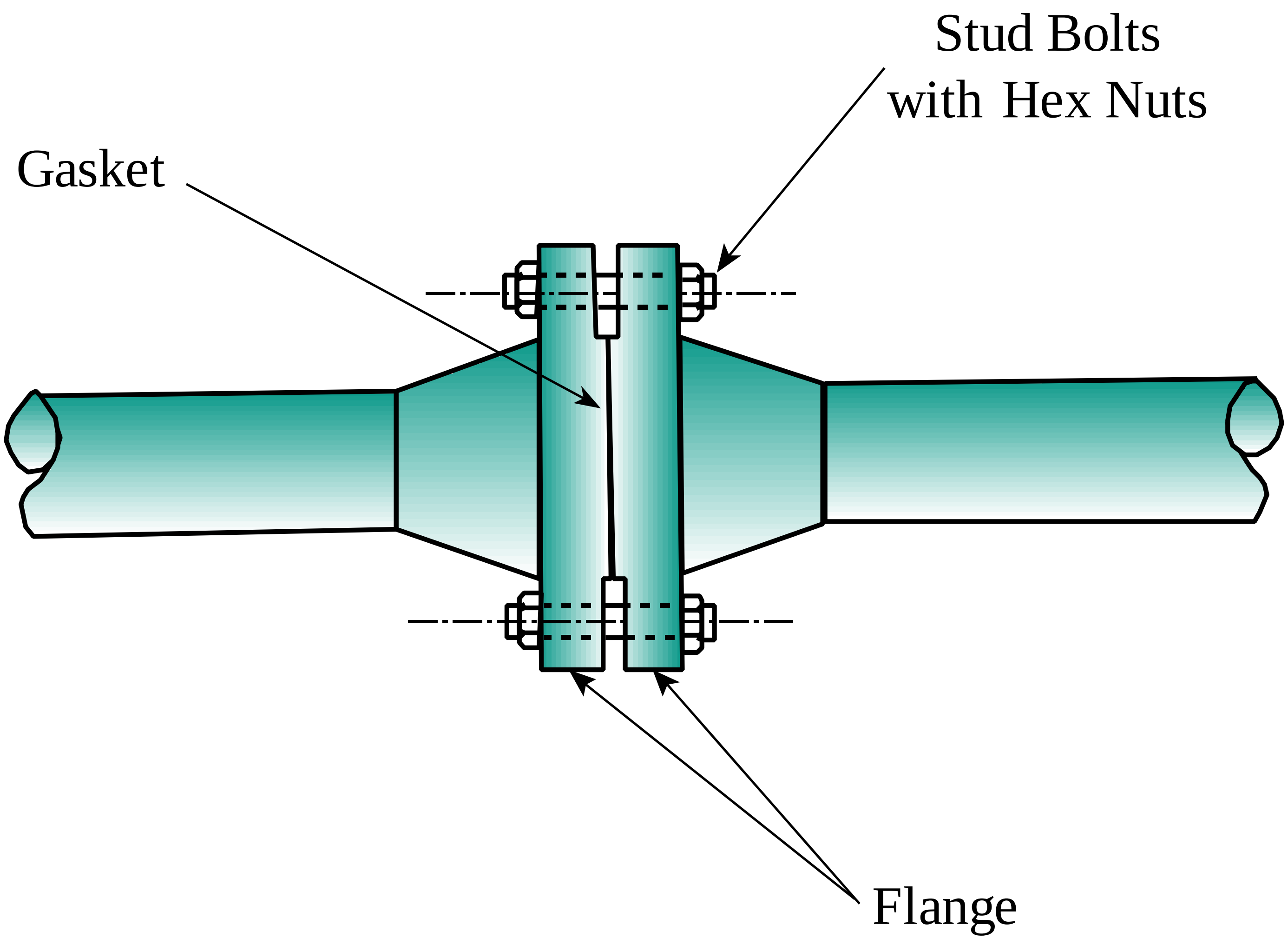
- **A flanged joint connects piping or equipment by means of bolting**
- **The joint provides a seal against the contained fluid at design conditions**
  - **Fluid molecule size plays a role (e.g., water is much bigger than hydrogen)**
- **A flanged joint is composed of three components -- flanges, gasket, and bolts**
- **Performance is influenced by another factor, assembly of the joint**

Flanged Joint
(continued)

- **The gasket provides the seal, bolts provide the forces necessary to seat the gasket and hold the joint together, flanges provide the surfaces for the gasket to seal against and carry the applied forces around the gasket**

- **The joint allows for "easy" disassembly and reassembly of piping or removal of components (e.g., valves and instruments)**

- **Because of their cost and the potential for leaks, use flanges only when absolutely necessary.**


Stud Bolts
with Hex Nuts
Gasket
Flange

Flanges

- **Flanges may be uniquely designed or selected from standardized designs in a recognized document**

- **Design methods or standards referenced must be in accordance with the governing code**

Standard Flanges

- **Flanges from accepted standards have a proven record of widespread safe, reliable use**
- **They are economical because standardized dimensions allow vendors to "tool up" for efficient production**
- **Everyone uses the same basis and benefits from economies of scale**
- **Users may obtain flanges easily and quickly, and need only stock a limited number of varieties**

Referenced Standards

The following standards are referenced by the Pressure Vessel Code (ASME Section VIII) and the Process Piping Code (ASME B31.3)

- **ASME B16.5, "Pipe Flanges and Flanged Fittings"**
  - **Covers flanges from nominal pipe size ½ to 24 inches (12 inches for Class 2500)**
  - **Most commonly used standard for refinery and petrochemical plant flanges**
- **ASME B16.42, "Ductile Iron Pipe Flanges and Flanged Fittings Classes 150 and 300"**
  - **Used for many ASME pumps**

Referenced Standards
(continued)

- **ASME B16.47, " Large Diameter Steel Flanges"**
  - **Covers flanges from 26 to 60 inches, in Classes 150 through 900**
  - **Range of included materials is more limited than in B16.5 (e.g., few nonferritic materials such as Inconel)**
- **ASME B16.20, "Metallic Gaskets for Pipe Flanges - Ring - Joint, Spiral - Wound, and Jacketed"**
  - **Unlike its predecessor, API 601, it does not specify default materials.**
- **ASME B46.1, "Surface Texture (Surface Roughness, Waviness, and Lay)"**

Obsolete Reference Standards

- **API 601, "Metallic Gaskets For Raised - Face Pipe Flanges and Flanged Connections (Double - Jacketed Corrugated and Spiral Wound)" – replaced by ASME B16.20.**

- **API 605, "Large Diameter Carbon Steel Flanges" – replaced by ASME B16.47.**

Scope of ASME B16.5

- **Materials**
- **Pressure - Temperature Ratings**
- **Dimensions**
- **Tolerances**
- **Marking**
- **Testing**

Materials for B16.5

- **Permissible flange materials are listed in Table 1A, bolting materials in Table 1B**

- **Flange materials are organized into groups of materials with similar compositions and mechanical properties**

- **Ratings are based upon the material in each group with the lowest allowable stress**

Materials for B16.5
(continued)

- **Bolt materials are divided into three groups based upon strength**
  - **High strength (e.g., A193 B7 or B16) may always be used**
  - **Intermediate strength (e.g., A193 B8 Class 2) may be used, provided it has the ability to maintain a sealed joint**
  - **Low strength (e.g., A307 and A193 B8 Class 1) is limited to Class 150 and Class 300 flanges and certain gaskets**
- **Stud bolts with 2 nuts are typically used**

Materials for B16.5
(continued)

- **Flanges may be either forged or cast**
- **Forged flanges are preferred due to a lower likelihood of flaws or brittle material**
- **Cast flanges are usually provided as an integral part of cast valves and other components**
- **In forged and cast construction, the grain tends to be non-directional or circumferential, limiting the potential for large cross grain stresses**

Materials for B16.5
(continued)

- **Only blind and certain reducing flanges (those without hubs) may be made from plate**
- **One reason is that a flat plate closely approximates a blind flange's shape (e.g., there is no raised hub)**
- **Another reason is that the directional nature of the grain in these flanges is not a serious additional concern because there will be cross grain bending stresses in blind flanges regardless of how the grain is oriented**

Flange Classes

- **Flanges are organized into classes for identification**
- **Classes used by B16.5 are:**

Class 150
Class 300
Class 400
Class 600
Class 900
Class 1500
Class 2500

Flange Classes
(continued)

- **Class 150 flanges are lightly built and are often avoided, especially when imposed loads (e.g., from piping) or cyclic loads are present**
- **Class 150 flanges are not used above a design temperature of 700°F because they may tend to deform or creep, possibly opening and leaking**
- **Class 400 (and sometimes Class 900) flanges are usually avoided because valves and fittings are not commonly available for them**

Flange Classes
(continued)

- **A rating table is provided for each material group**
- **For a given material group, temperature, and non-shock pressure, the table indicates the appropriate flange class**
- **Each size flange in each class is built to a standard set of dimensions**

B16.5 Rating Considerations

- **Ability to withstand stresses necessary to seat the gasket**
  - **Special attention is required for some Class 150 and Class 300 flanges with spiral wound gaskets**
- **Adequate thickness to sustain the stresses due to pressure and other loadings necessary to maintain a fluid seal**
- **Distortion due to loadings is transmitted through the piping or bolting**

Use of B16.5 Rating Tables

- **Determine the applicable group for the material used (Table 1A)**
- **Determine the design temperature and pressure (including hydrostatic head) that apply**

Use of B16.5 Rating Tables
(continued)

- **Enter Table 2 and determine a flange class with a pressure rating equal to or greater than the design pressure for the applicable material and temperature**

- **Check the flange for hydrotest conditions (including hydrostatic head) with a maximum permitted pressure of 1.5 times the 100ºF rating rounded up to next multiple of 25 psi**

Use of B16.5 Rating Tables (continued)

- **If the flanges are made of different materials, both must be checked**
  - **The highest resulting flange Class governs both flanges**

- **Interpolation is permitted between the listed temperatures**

Use of B16.5 Rating Tables
(continued)

- **Flanges used to be designated by "Pound" rather than "Class" (e.g., 600 Pound)**
- **Previously, this referred to the pressure capacity of a carbon steel flange at 850ºF (500ºF for 150 Pound)**
- **This is no longer true; therefore, the word Class is used and, except as noted below, the number is only an identifier.**

Use of B16.5 Rating Tables
(continued)

- **Rating table pressures for Class 300 and above are based upon the formula:**

$$P_T = P_R \text{ x } S_I / 8750 \text{ £ } P_C$$

where:

P_T	=	**rated pressure (psi)**
P_R	=	**Class (e.g., 300 for Class 300)**
S_I	=	**material allowable stress at temperature (psi), determined from the rules in Annex D of B16.5**
P_C	=	**ceiling pressure per Annex D of B16.5**

Use of B16.5 Rating Tables
(continued)

- **Rating table pressures for Class 150 comply with the formula on the previous slide, except use 115 for P_R and limit P_T to 320 - 0.3T (T = temperature in ^oF)**

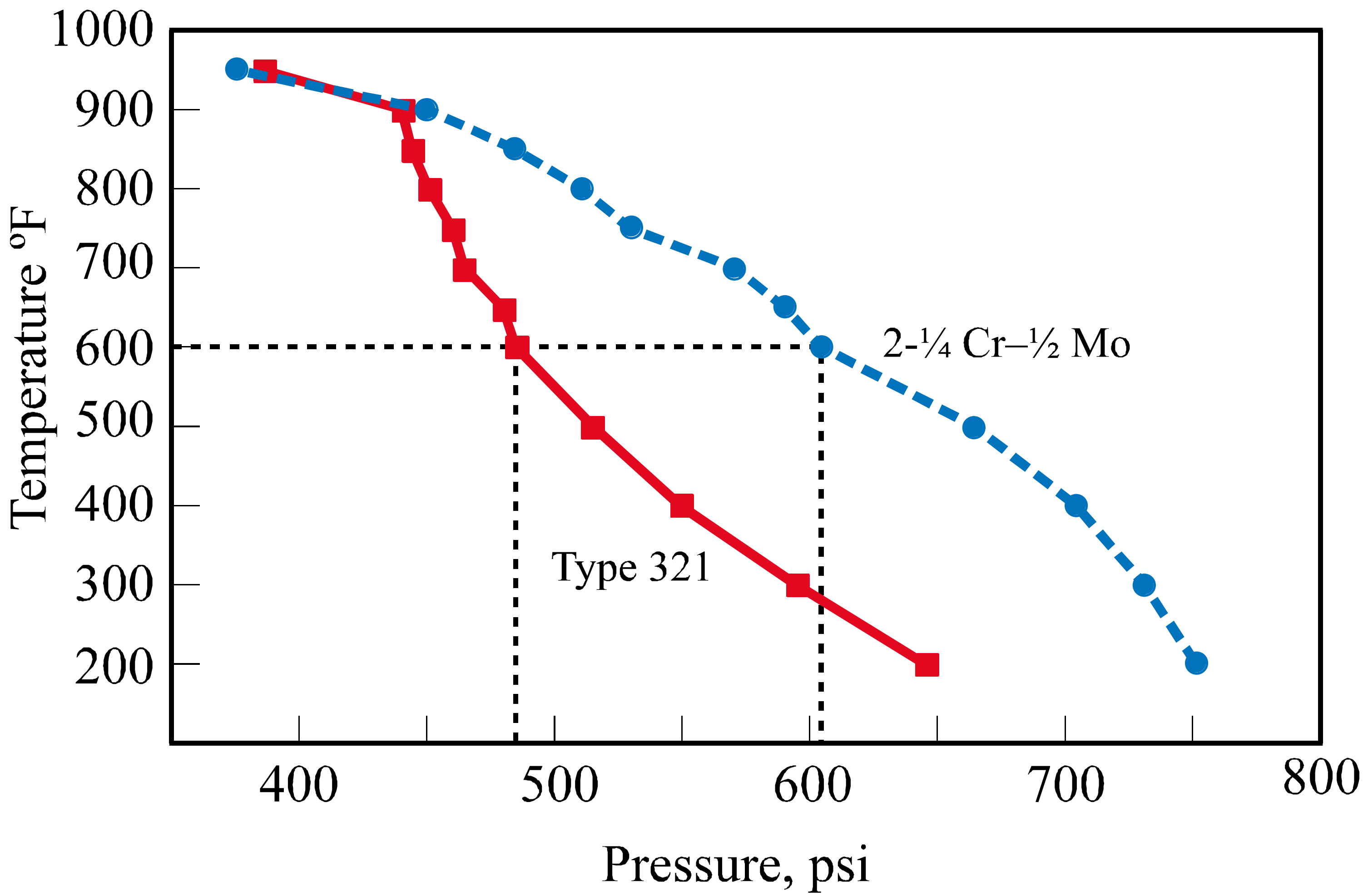
- **B16.5 ratings originated with experience and were essentially empirical**

- **Recently (1996), the ratings have been revised to agree more closely with the formulas**

Class 300
Temperature - Pressure Ratings

	Material	
Temp (ºF)	**2 ¼ Cr - 1 Mo (psi)**	**321 S.S. (psi)**
100	**750**	**720**
200	**750**	**645**
300	**730**	**595**
400	**705**	**550**
500	**665**	**515**
● ● ●	**● ● ●**	**● ● ●**

Class 300



1000
900
800
700
600
500
400
300
200
Temperature °F
2-¼ Cr–½ Mo
Type 321
400
500
600
700
800
Pressure, psi

Example

- **Material**
  SA182 - F11 class 2 (1¼ Cr - ½ Mo)
- **Design Pressure**
  P_D = 400 psig
- **Design Temperature**
  1000ºF
- **Allowable Stress (per the Pressure Vessel Code)**

@ 1000ºF	**S_H = 6,300 psi**
@ ATM.	**S_C = 20,000 psi**

Use Class 600 Flange

Check for Hydrostatic Test Pressure

$$P_T = (1.3)\, P_D \times \frac{S_C}{S_H}$$

$$P_T = (1.3)\, 400 \times \frac{20{,}000}{6{,}300}$$

$$\therefore\ P_T = 1{,}650\ psi < 2{,}250\ psi$$

1,500 * 1.5

Allowable Pressure @ Ambient

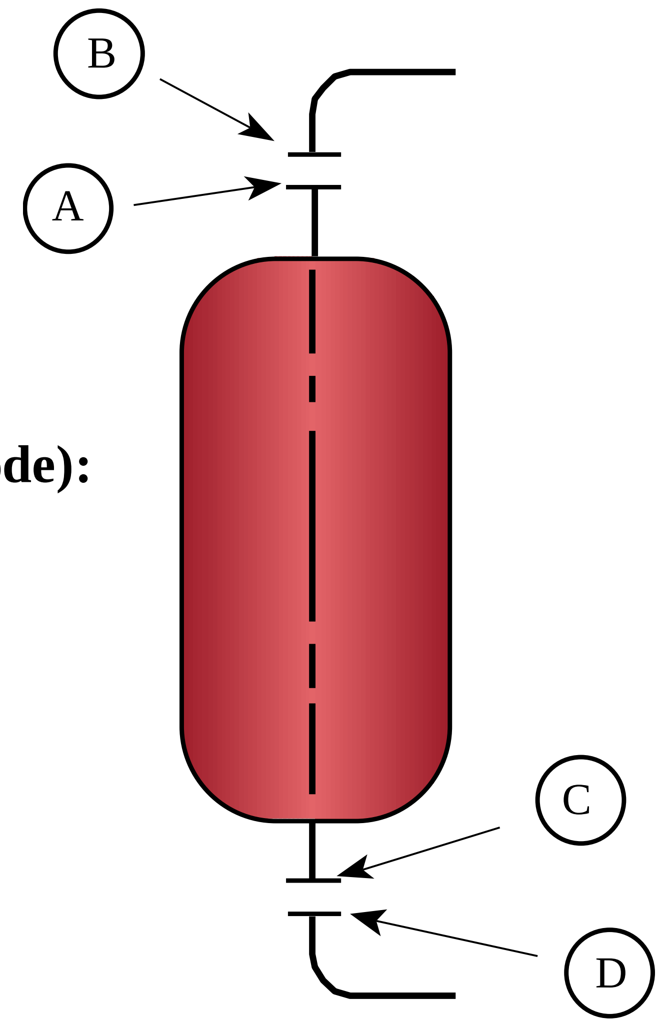
Flange Material:
A B C, SA182-F11 class 2 (1¼ Cr - ½ Mo)
D, SA182-F316 (16 Cr-12 Ni-2 Mo)

Design Pressure: P_D = 850 psi
Design Temperature: T = 850°F

Allowable Stress (per the Pressure Vessel Code):
A182-F11 @ 850°F : S_H = 18,700 psi
@ ATM. : S_C = 20,000 psi

A182-F316 @ 850°F : S_H = 11,600 psi
@ ATM. : S_C = 20,000 psi

For A & B, Use Class 600
For C & D, Use Class 900



Check for Hydrostatic Test Pressure

SA 182-F11

$$P_T = (1.3)\, P_D \times \frac{S_C}{S_H}$$

$$P_T = (1.3)\, 850\ x\ \frac{20{,}000}{18{,}700}$$

$$P_T = 1{,}182\ psi < 2{,}250\ psi$$

Check for Hydrostatic Test Pressure (continued)

SA 182 - F 316

$$P_T = (1.3)\,850 \times \frac{20{,}000}{11{,}600}$$

$$P_T = 1{,}905 \text{ psi} < 3{,}250 \text{ psi}$$

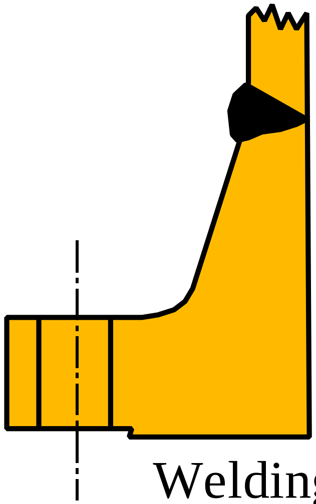
2,160 * 1.5

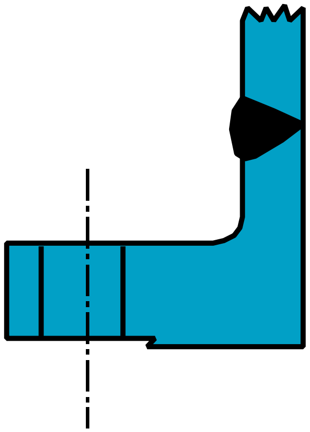
Allowable Pressure @ Ambient

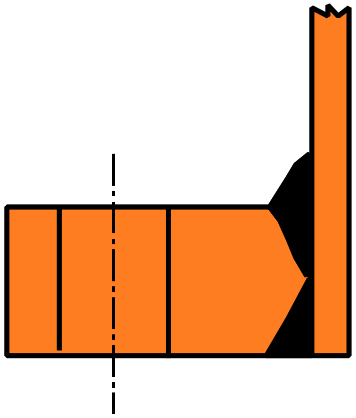
Flange Types

- **Integral Flanges (flange is part of or buttwelded to the piping or vessel so the system acts as an integral structure)**
  - **Welding neck**
  - **Long welding neck**
  - **Integrally reinforced**
  - **Ring**
  - **Studding**
  - **Specialty joints such as exchanger closures**

Integral Flanges







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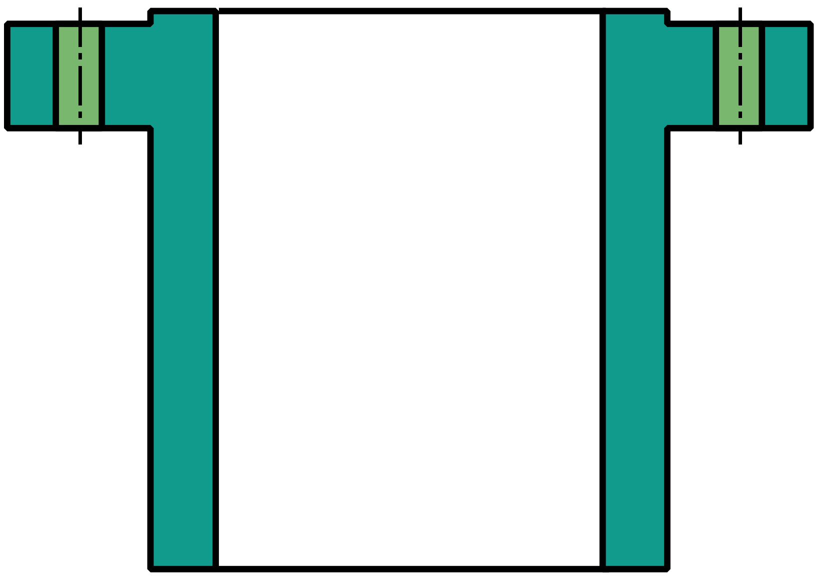
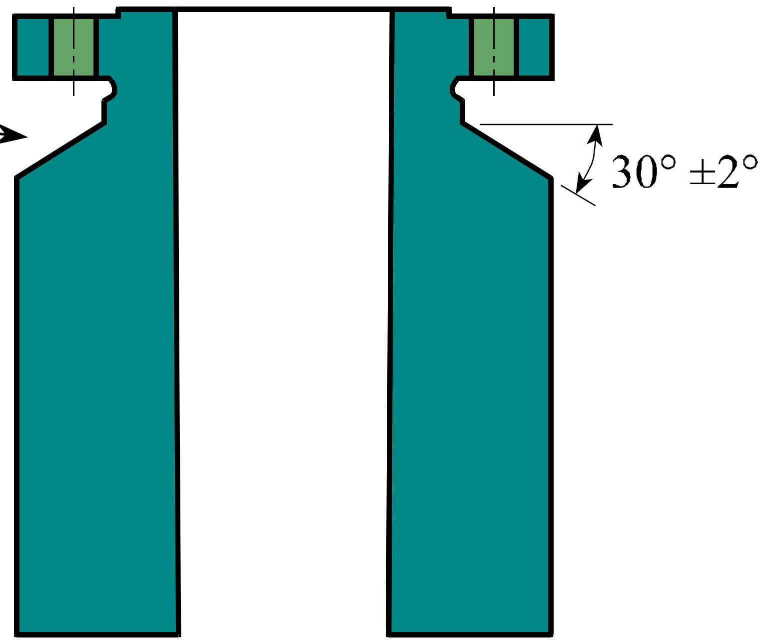
Integral Flanges
(continued)



Long Welding Neck

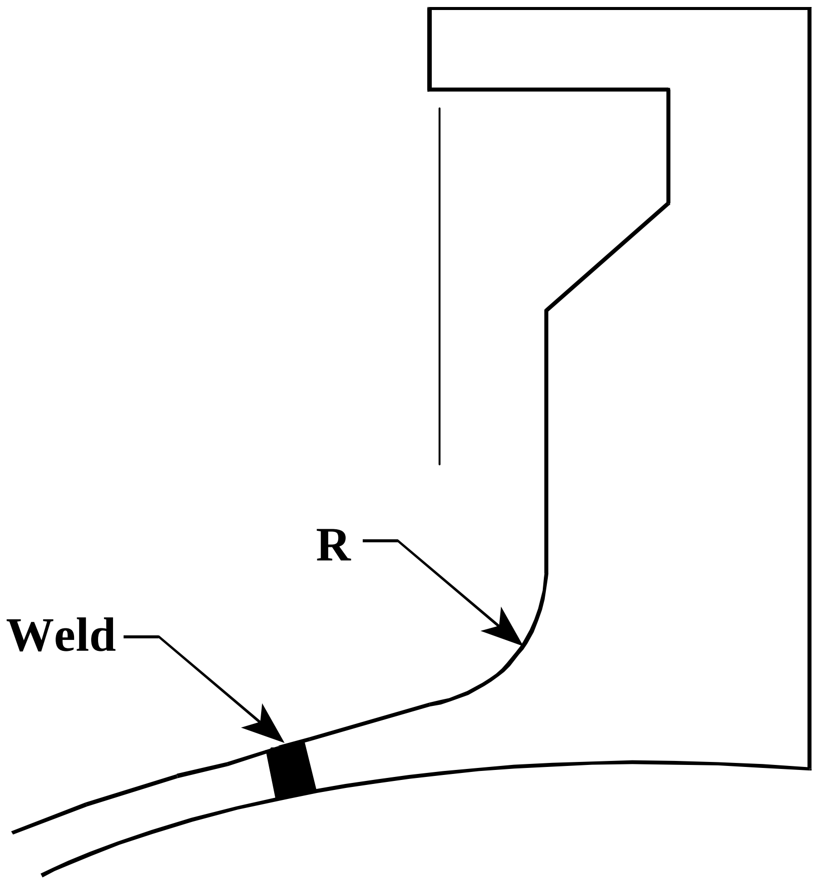
Integral Flanges
(continued)

Allow room for the nuts on the bolts (bolts are removed through the mating flange)

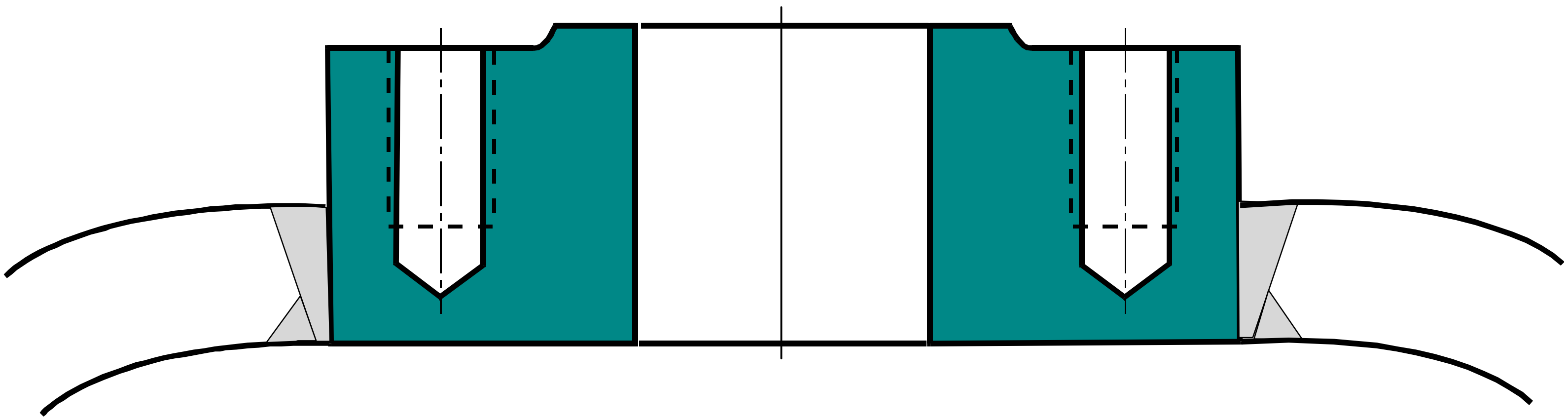


Integrally Reinforced

Flared Nozzle



Integral Flanges
(continued)



Studding

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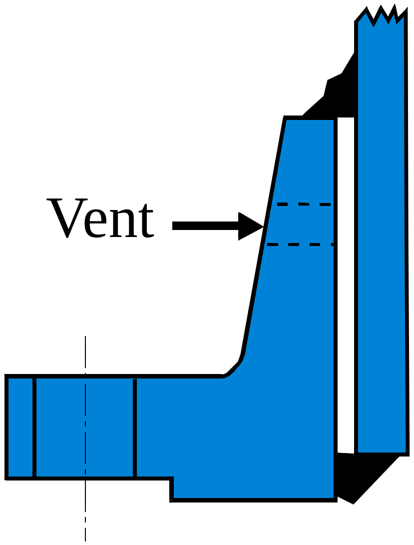
Flange Types

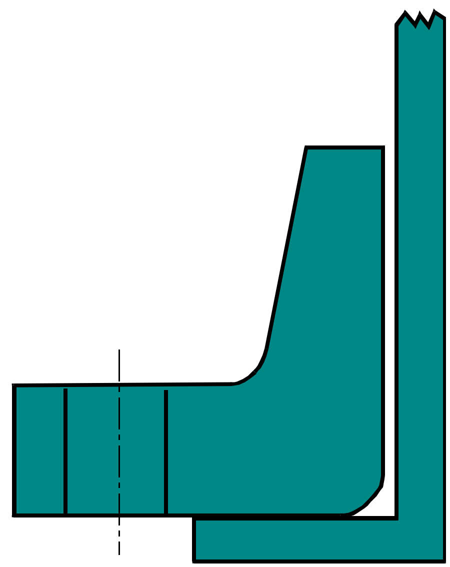
- **Loose Flanges (no direct attachment between the flange and piping or vessel, does not act as one integral structure)**
  - **Slip-on**
  - **Lap joint**

- **Blind Flanges (closures)**
  - **Generally thick because they are flat, spanning the opening like a beam, developing through thickness bending moments**

Loose Flanges

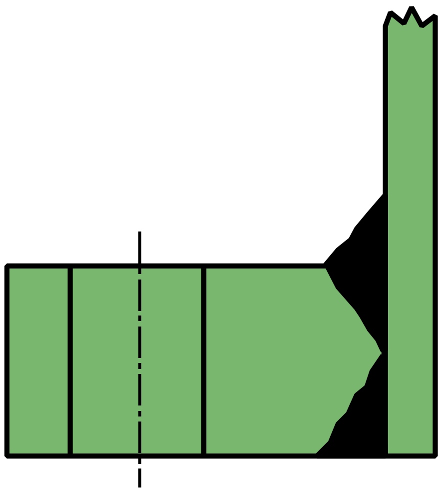


Slip-on



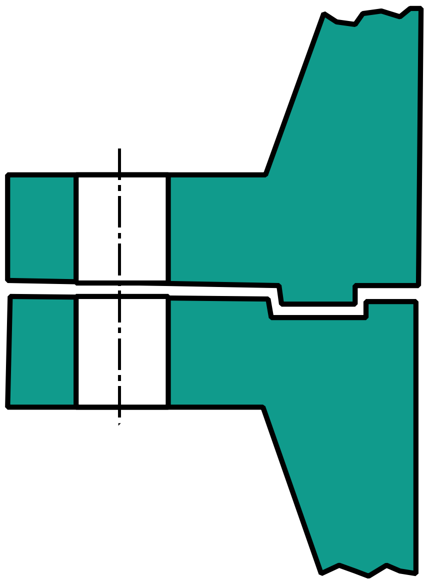
Lap Joint

Types of Flange Facing
Flat Face



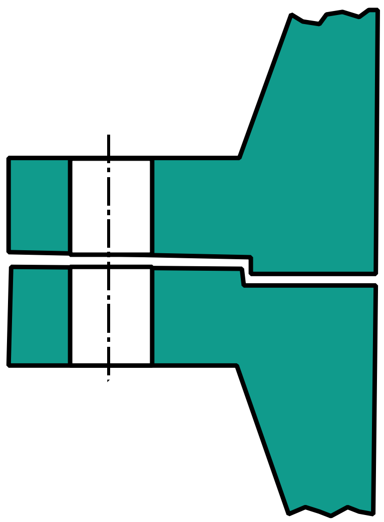
- **Inexpensive**
- **Used with a full face gasket in low temperature/pressure services**
- **Easily sealed (i.e., containment of large molecules), non-dangerous, non-cyclic services that require low bolt loads and sealing pressures**
- **ASME process pumps and utilities such as cooling water are examples**

Types of Flange Facing
Tongue and Groove



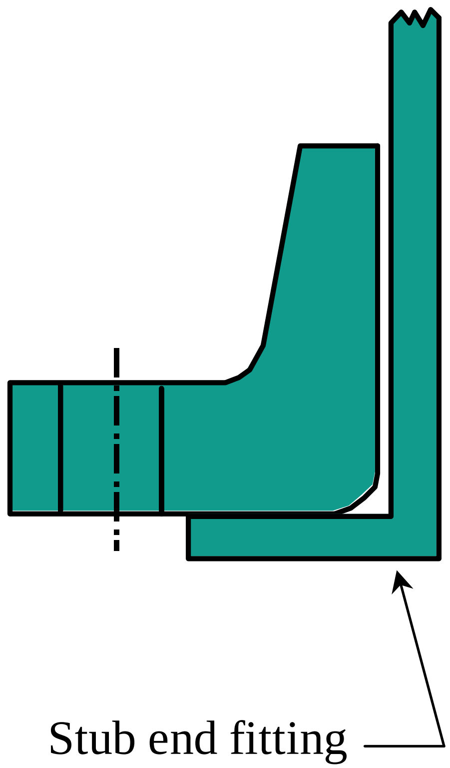
- **Mating flanges are different - one with a $^{3}/_{16}$ inch recess, the other with a ¼ inch raised portion**
- **The gasket is confined on both edges and partially protected from the internal environment**
- **The projecting sealing surface is subject to damage**
- **Reduced bolt load when compared to raised face, due to the smaller gasket area**

Types of Flange Facing
Male-Female



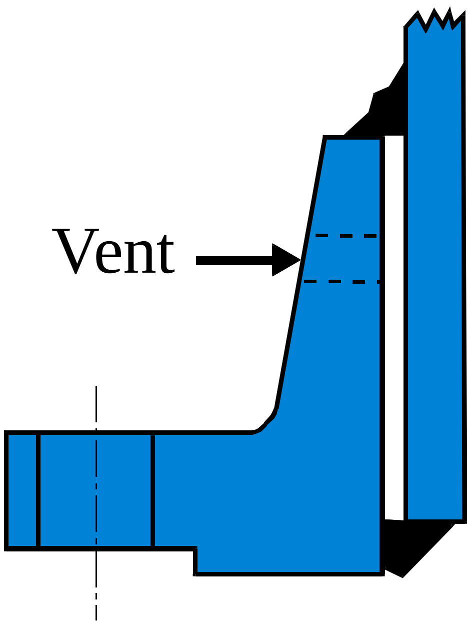
- **Similar to tongue and groove except the gasket is confined only against blowout**
- **The sealing surface is not protected from the internal environment**
- **Projecting portion is larger and less likely to be damaged than on the tongue and groove style**

Types of Flange Facing
Lap Joint



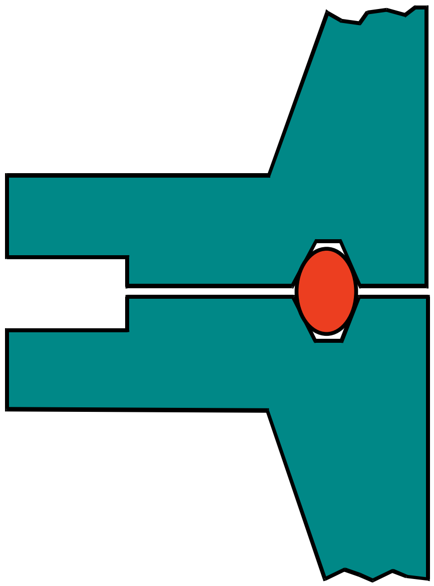
- **Allows use of a different metallurgy for the flange than for the piping**
- **Is not welded**
- **Avoid in cyclic or services other than low pressure**
- **Compensates for some misalignment**
- **Limit to low temperature services to avoid differential thermal expansion problems**
- **Sealing may be more difficult because the flange and sealing surface (stub) are independent**

Types of Flange Facing
Slip-On



- **Allows adjustment of the flange position(s) in situ**
- **Must be double welded and vented**
- **Not used above Class 150 (except for manways and some reducing flanges) or 500 °F**
- **Not used in hydrogen atmospheres and cyclic services**

Types of Flange Facing
Ring Joint



- **The gasket is confined within grooves provided in the mating flange faces**
- **Used for high pressure, high temperature services, or aggressive operating conditions**
- **Expensive**

Ring Joint Flanges

- **The seal is provided by pressure against the sides of the groove (the gasket does not contact the bottom of the groove)**
- **Two narrow sealing surfaces are formed, one on each side of the groove, with very high imposed stresses**
- **One sealing surface is protected from the internal atmosphere and possible corrosion**
- **The sealing surfaces are small and sheltered, protecting them from damage (e.g., when the flange is open(ed) during a turnaround)**

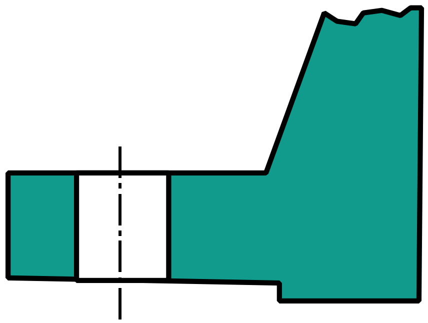
Ring Joint Flanges (continued)

- **Internal pressure tends to increase the sealing pressure on the outside of the gasket**
- **Due to flange distortion during operation, the groove, and the gasket contained in it, may become non circular**
  - **The gasket cannot then be (easily) replaced with a new one**
- **Grooves have flat bottoms**
  - **Flat is used to insure the gasket touches only where desired**
  - **Groove dimensions are standardized in B16.5 and identified by a groove number**

Ring Joint Flanges (continued)

- **A generous radius ($^1/_8$ inch or 3mm) is provided at the intersection of the flat bottom and the sloped sides to prevent initiation of a crack**
- **Where differential expansion occurs, do not use for flanges over 10 inch NPS**
- **Very sensitive to scratches in the sealing area of the grooves**
- **Grooves must be machined into the flange—an additional cost**
- **Grooves of mating flanges must match each other and the gasket**

Types of Flange Facing
Raised Face



- **The sealing surface is raised 0.06 inch (1mm) for Class 150 and Class 300 flanges and 0.25 inch (6 mm) for other flanges**
- **Raised faces help prevent contact of the flange edges due to rotation from high bolt loads**
- **The most common type of facing in refineries**
- **The sealing surface is exposed and susceptible to damage when opened during a turnaround**

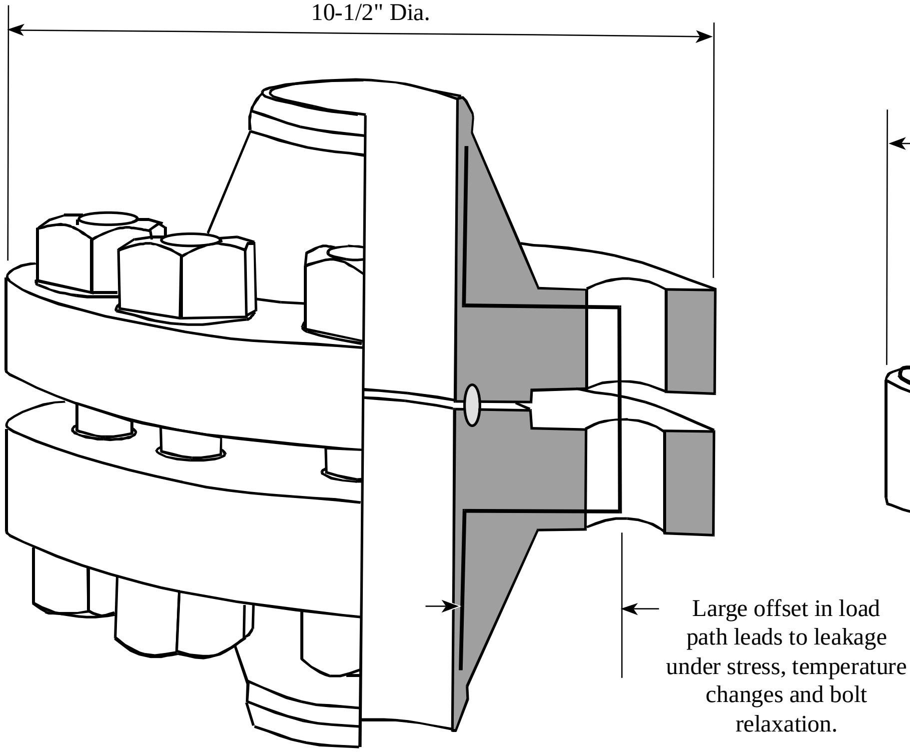
Specialty Types

- **Generally developed to make the joint smaller and lighter**
- **Normally proprietary and, therefore, more expensive**
- **May be less tolerant of mis-alignment and applied forces**
- **Components are matched and may not be interchangeable**

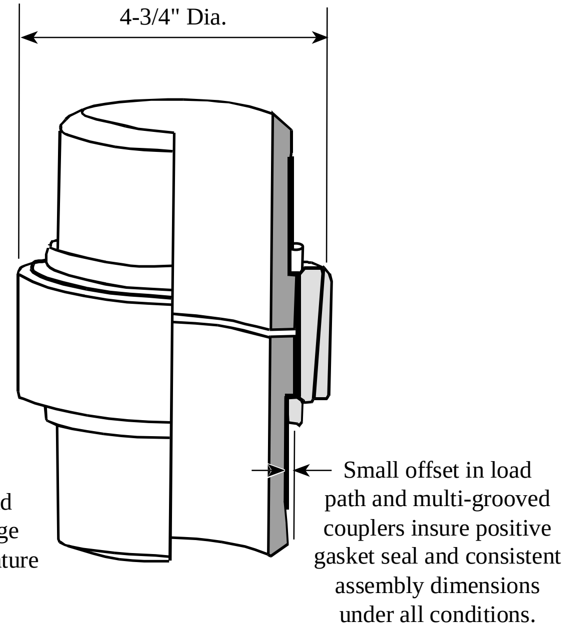
Specialty Types
(continued)

- **Examples are:**
  - **Dur O Lok**
    - **Uses a coupling style system with a self energized gasket**
  - **Graylock**
    - **Clamping style system using two clamps with the bolts oriented parallel to the piping diameter**

DUR O LOK® Couplings
Changing the Load Path Reduces Size and Eliminates Leaks



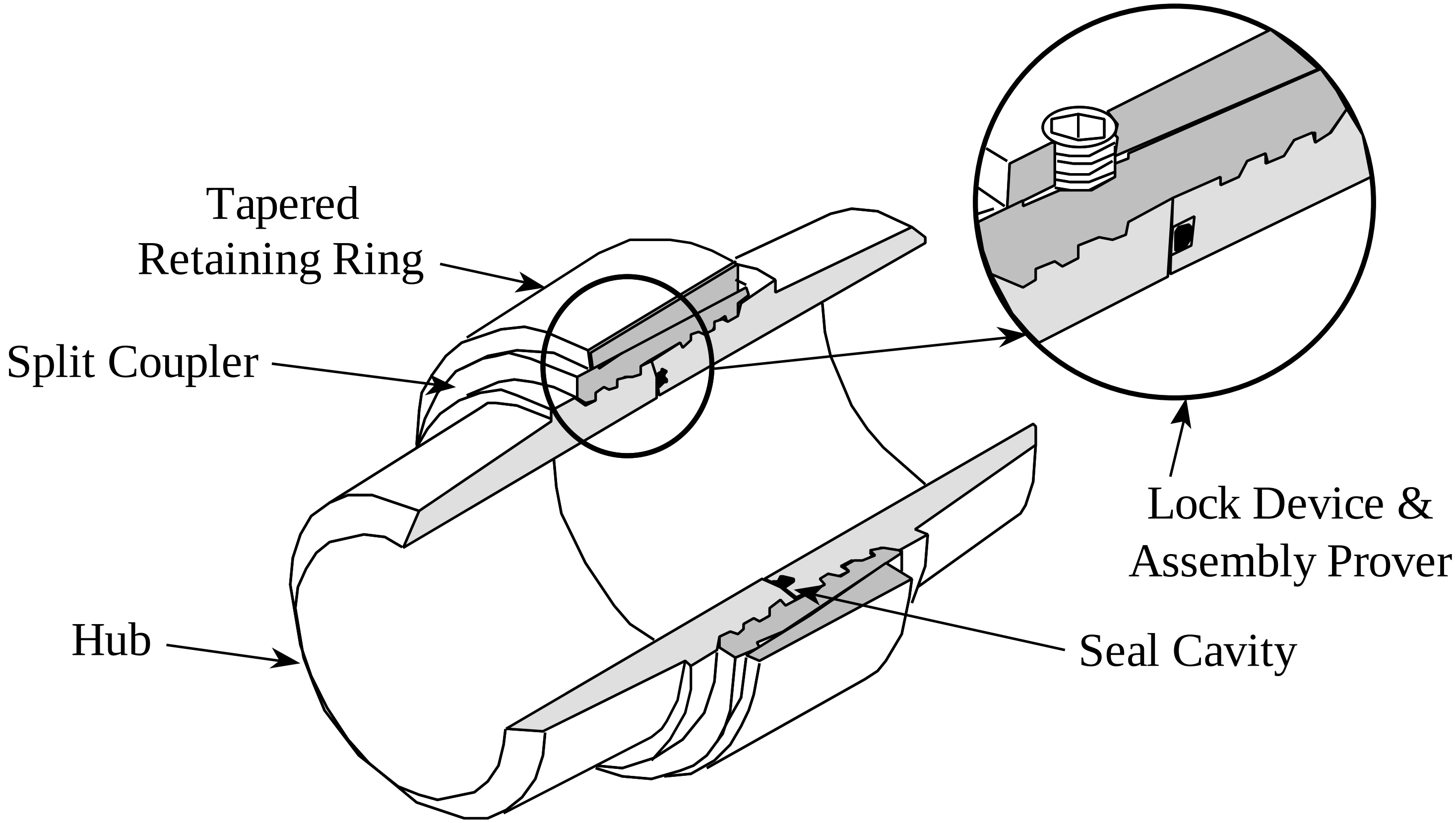
Load path through a bolted flange.



Load path through DUR O LOK coupling.

Three Inch Class 300 Joint

DUR O LOK® Couplings



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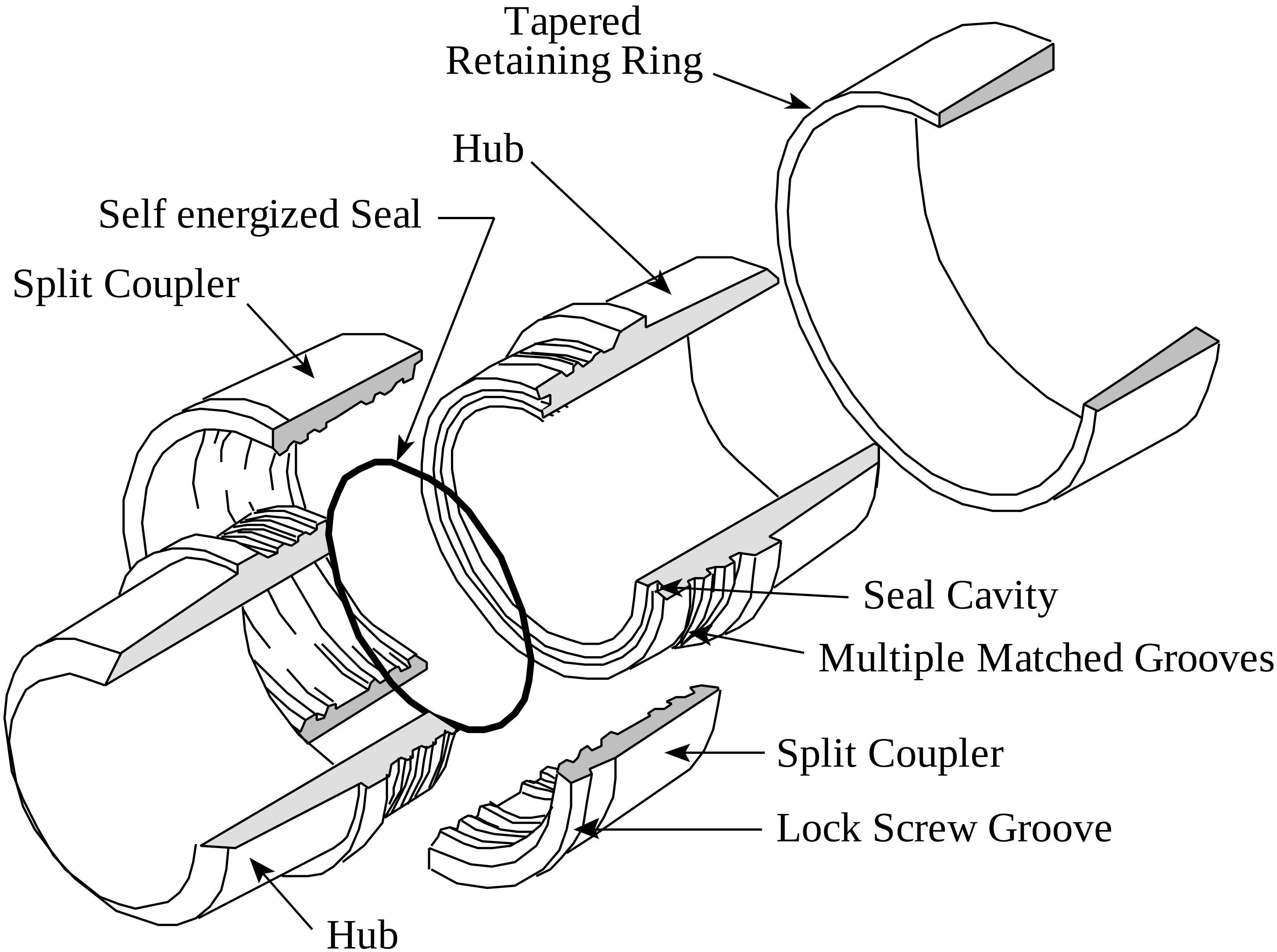
DUR O LOK® Couplings



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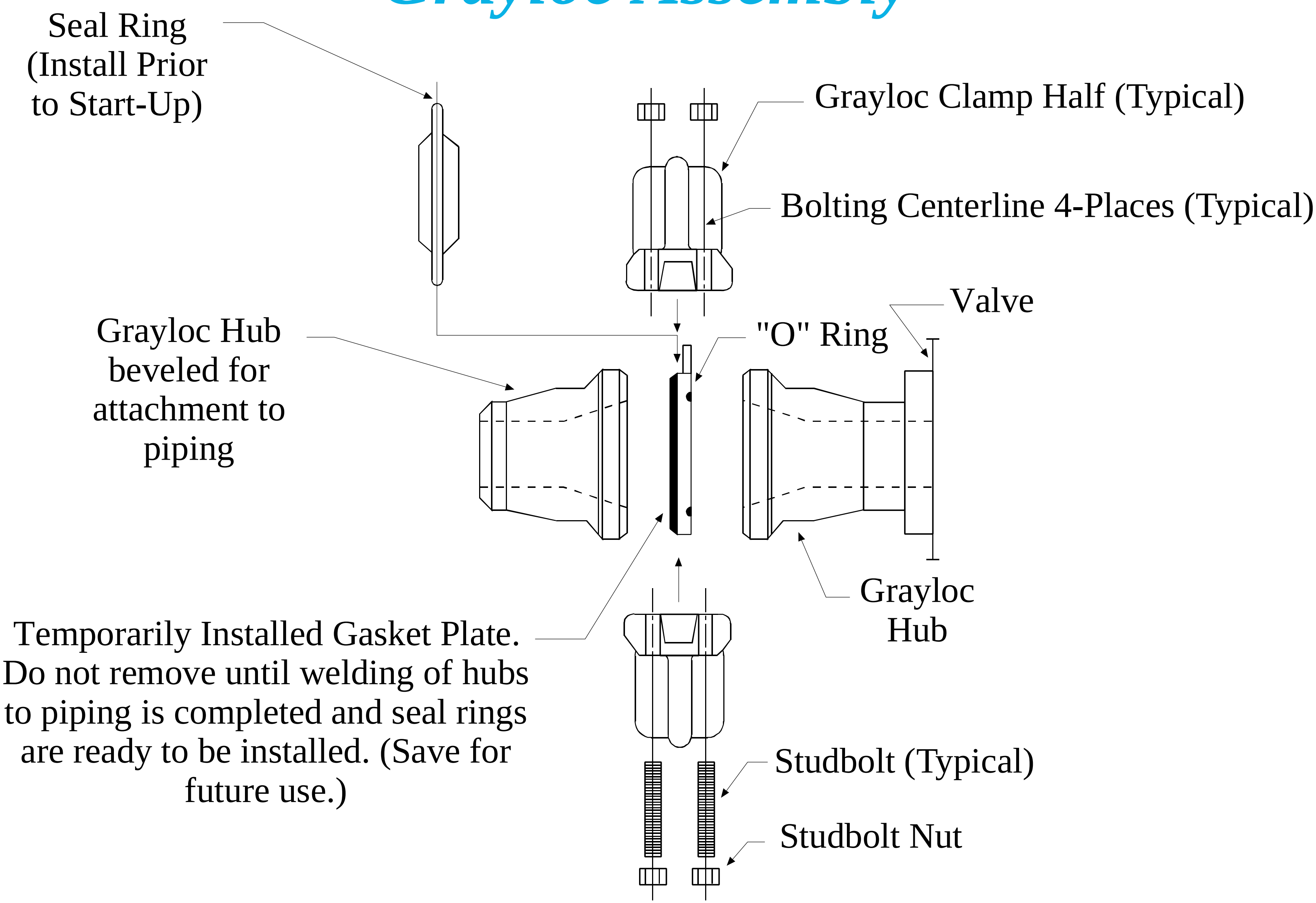
Grayloc Assembly



Gaskets

- **Gaskets create a static seal between two members of an assembly and maintain the seal during operating conditions that may fluctuate**
- **The seal is provided by gasket material flowing into imperfections in the mating surfaces**
- **The force to effect the seal is provided by the bolting compressing the gasket**

Gaskets
(continued)

- **Sufficient initial force is necessary to deform the gasket into the imperfections**
- **For gasket design, the necessary compressive stress depends upon the gasket style and materials and is called "Y"**
- **Sufficient force must be present during operation to maintain the seal against the internal pressure, preventing leakage**
- **For gasket design, the required ratio of gasket compressive stress to internal pressure depends upon the gasket style and materials and is called "M"**

Gaskets
(continued)

- **"Y" and "M" have no theoretical basis but are empirical, developed from experience**

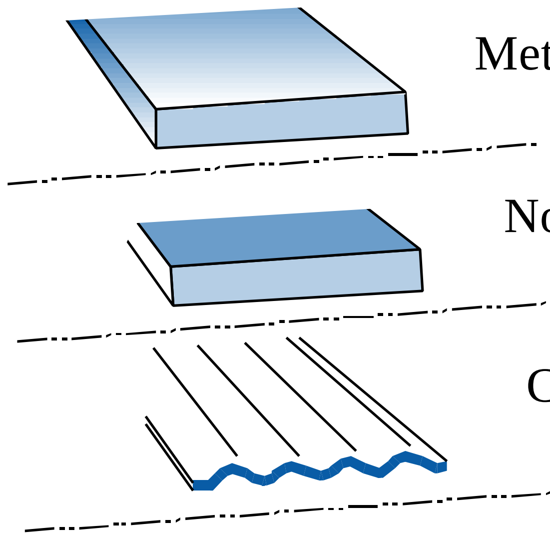
- **Gasket material must be suitable for the temperatures, pressures, and environment to which it is exposed**

- **Gasket filler material is generally graphite or, sometimes, Teflon or another non-asbestos, compressible material. Teflon is generally used in acid services below 400ºF.**

Representative "M" and "Y" Values

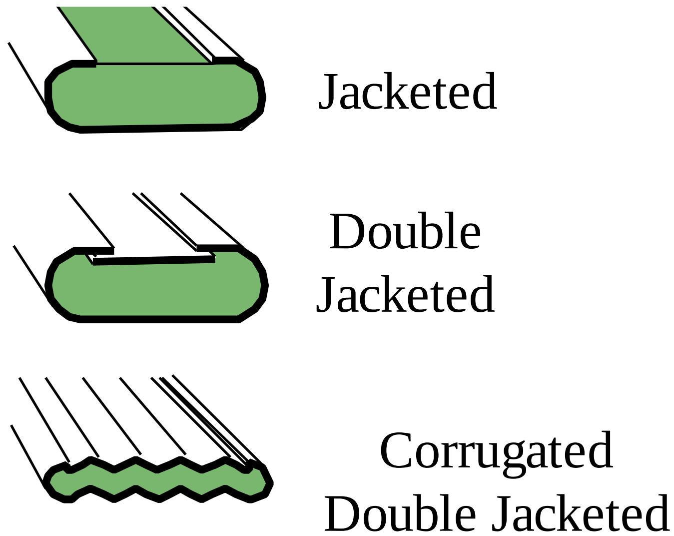
	"M"	**"Y" (psi)**
Spiral Wound	2.5 - 3	10,000
Corrugated & Jacketed	2.5 - 3.5	2900 - 6500
Flat & Jacketed	3.25 - 3.75	5500 - 9000
Ring Joint	5.5 - 6.5	18,000 - 26,000
Flat Face		
Asbestos	2 - 3.5	1600 - 6500
Elastomers	1 - 2.75	400 - 3700
Metal	4 - 6.5	8800 - 26,000

Types of Gaskets
Flat Face



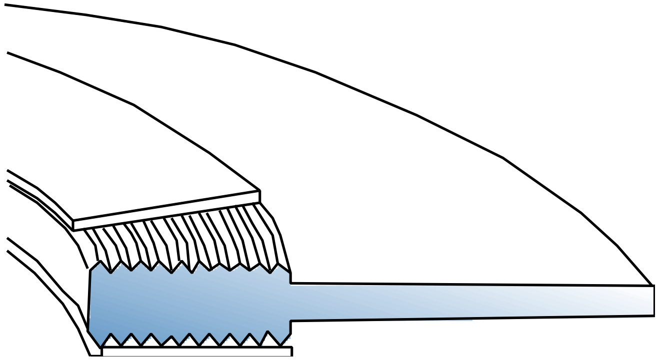
- **Covers most of the face to minimize flange rotation and possible contact.**
- **Used only in limited, non-hazardous or mild hydrocarbon services.**
- **Nonmetallic gaskets are made of a suitable, compressible material held together with a binder. Asbestos was common, most are now proprietary materials.**

Types of Gaskets
Jacketed and Filled



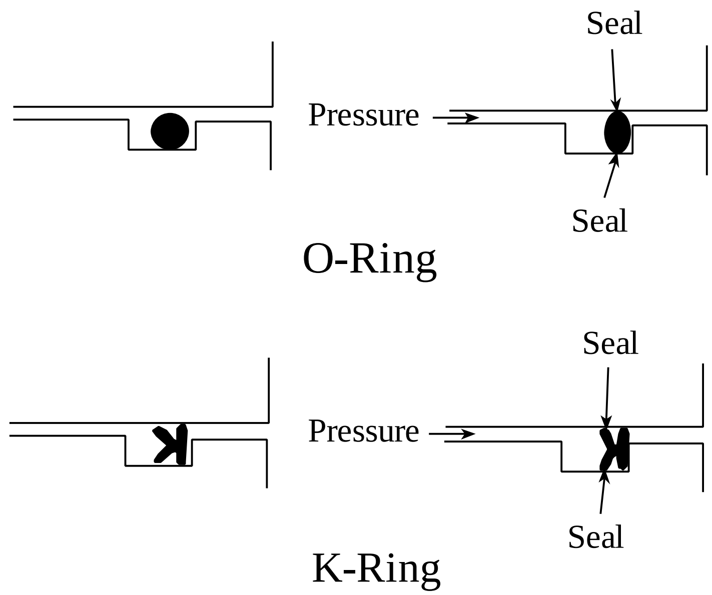
- **This was the standard refinery gasket**
- **Soft compressible filler material is contained within a thin "wrapper"**
- **Corrugations provide the seal, and a labyrinth leak path**

Types of Gaskets
Kammprofile



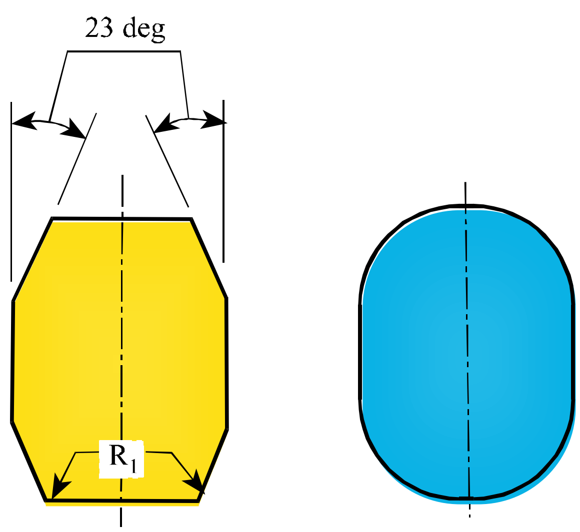
- A serrated metallic filler sandwiched between two layers of sealing material
- Upon bolt-up the sealing material deforms into and is held by the serrations
- Seal stress is concentrated at the peaks of the serrations, while the valleys prevent the sealing material from flowing
- Metallic filler can be reused
- Becoming more popular, especially in Europe

Types of Gaskets
Self Actuated



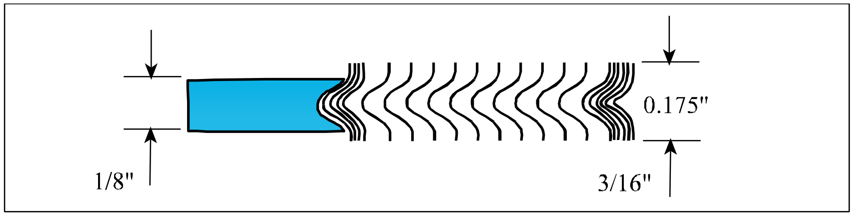
- **Gaskets for which an increase in the pressure to be contained increases the sealing pressure**
- **Examples are O-rings, K-rings, and to a lesser degree, gaskets for ring joint flanges**
- **Gasket material must be soft and deformable. Acceptable materials have low limiting temperatures (200-400 °F)**

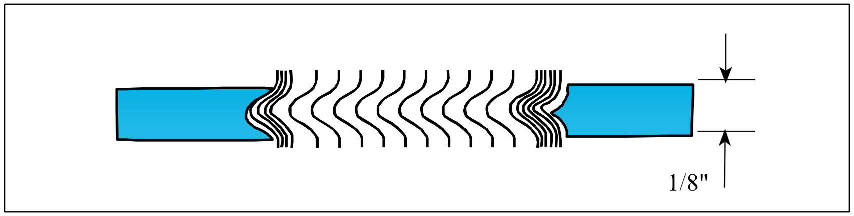
Types of Gaskets
Ring Joint



- Ring joint gaskets are either oval or octagonal (oval is preferred)
- Made of a variety of hard metallic materials to avoid distortion
- Must be compatible with the internal atmosphere and softer than the flange material
- Must be no rougher than 63Ra
- Hard to handle

Types of Gaskets
Spiral Wound





- **Composed of alternating layers of compressible filler material and metal rings wound in a spiral**
- **Most common type of gasket in refinery service**

Spiral Wound Gaskets

- **Commonly used in refineries due to excellent sealing performance through a wide range of temperatures, pressures, liquid or gaseous atmospheres (including hydrogen), and flange finishes**
- **Layers provide many sealing surfaces and a labyrinth path in the direction of leakage**
- **Forgiving to overstress and less prone to relax over time**

Spiral Wound Gaskets
(continued)

- **Asbestos used to be the "universal" filler material**
- **Filler materials are now commonly a non asbestos material**
  - **Graphite and sometimes Teflon (for low temperature applications) are the most common**
  - **Specialty materials are available for particular conditions**
- **Filler material must be specified for each gasket (there is no default)**
- **Windings are commonly 304 Stainless Steel**
  - **Must be compatible with the internal atmosphere**

Spiral Wound Gaskets
(continued)

- **Gaskets have an outer ring for stability**
- **By using the flange bolts as a guide, the outer ring is used to center the gasket**
- **The outer ring also helps resist blowout and acts as a limit stop, preventing crushing of the outer windings from overbolting**
- **The outer ring is normally carbon steel, protected against corrosion**

Spiral Wound Gaskets (continued)

- **An inner ring is provided for additional (handling) stability for large gaskets**
- **An inner ring is also used to protect the flange surface from corrosion due to the internal atmosphere**
- **Use the same material as for the windings**
- **An inner ring is frequently used for Class 900 and higher flanges to resist inner deflection and possible gasket buckling due to the high bolt loads present**
  - **The bolt load tends to squeeze the outer portion of the gasket and push the gasket inward**

Spiral Wound Gaskets
(continued)

- **Graphite (and Teflon) filler materials act as incompressible fluids as the flanges press upon the gasket**
- **As the gasket is squeezed, the filler material presses outward into the windings and ring**
- **This can cause bucking of the windings and a failure of any gasket**
- **Asbestos is a system of compressible fibers and does not create radial forces as it is compressed**
- **All winding and ring materials must be specified (is no default)**

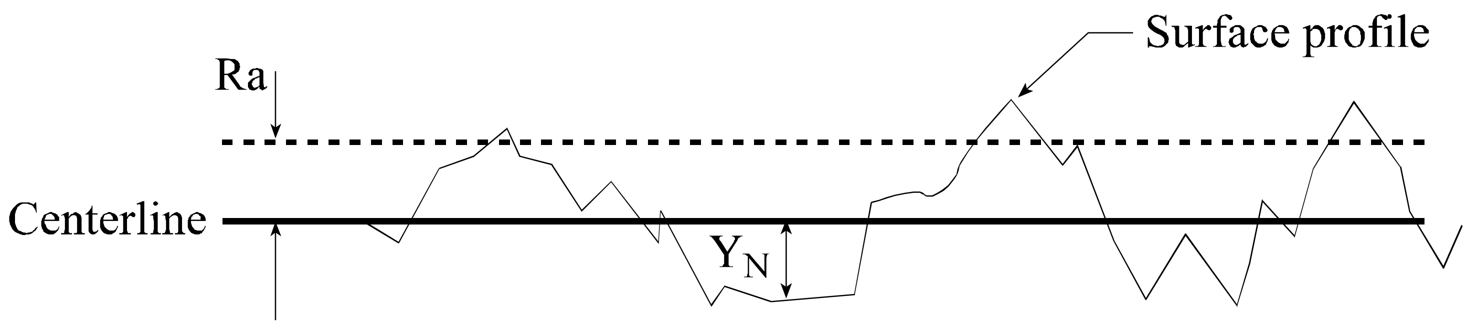
Spiral Wound Gaskets
(continued)

- **Durable**
- **Works with a wide range of fairly rough flange finishes**
- **Easily replaced because it rests upon a flat surface and is less affected by flange distortions**
- **Gaskets must be replaced each time the flange is opened**

Flange Surface Finish

- **Surface finish is critical to the proper performance of the flanged joint**
  - **Too rough or too smooth and the gasket will not seal**
- **Finish is provided by a cutting tool producing serrated concentric or spiral grooves**
  - **Provide 45 - 55 grooves per inch**
- **Surface finish is measured and designated by “Ra”, an arithmetic average of the surface roughness**

Determination of Ra



Centerline – The surface profile defines equal areas above and below this line.

Ra – Arithmetic average of the absolute values of the surface profile deviations from the centerline.

$$\mathbf{Ra} = \frac{1}{L}\int_0^L |y|\,dL$$

$$\mathbf{Ra\ (approx)} = \frac{Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + \ldots Y_N}{N}$$

Flange Surface Finish
(continued)

- **There is an optimal surface finish for use with each gasket type**
- **For spiral wound gaskets, the finish should be 125 - 250 Microinch Ra**
- **Other required finishes (in microinches) are 63 - 80 Ra for metal jacketed, 125 - 250 Ra for Kammprofile, 63 Ra for ring joint, and 500 - 750 Ra for flat non-metallic gaskets**

Flange Surface Finish
(continued)

- **Surface finish is evaluated by visual comparison and feel to a standard comparitor of finishes**
- **Mechanical means are not used because they may not distinguish between a uniformly rough surface and a smoother surface with a few large discrepancies. Both may have the same calculated Ra but perform differently**
- **Flanges may be refinished in the field**

Flange Markings Required by B16.5

- **Manufacturers name and/or trademark**
- **ASTM material identification (specification, grade, and melt identification for forged or cast flanges)**
- **Flange Class (e.g., Class 300)**
- **Designation of governing standard, e.g. ASME B16.5**

Flange Markings Required by B16.5
(continued)

- **Nominal pipe size (NPS) of flange (e.g., 6 inch)**
- **Ring joint flanges shall be marked with the letter "R" and the ring groove number per B16.5**
- **All markings are to be on the outer rim of the flange for visibility while in operation**

Gasket Markings Required by B16.20

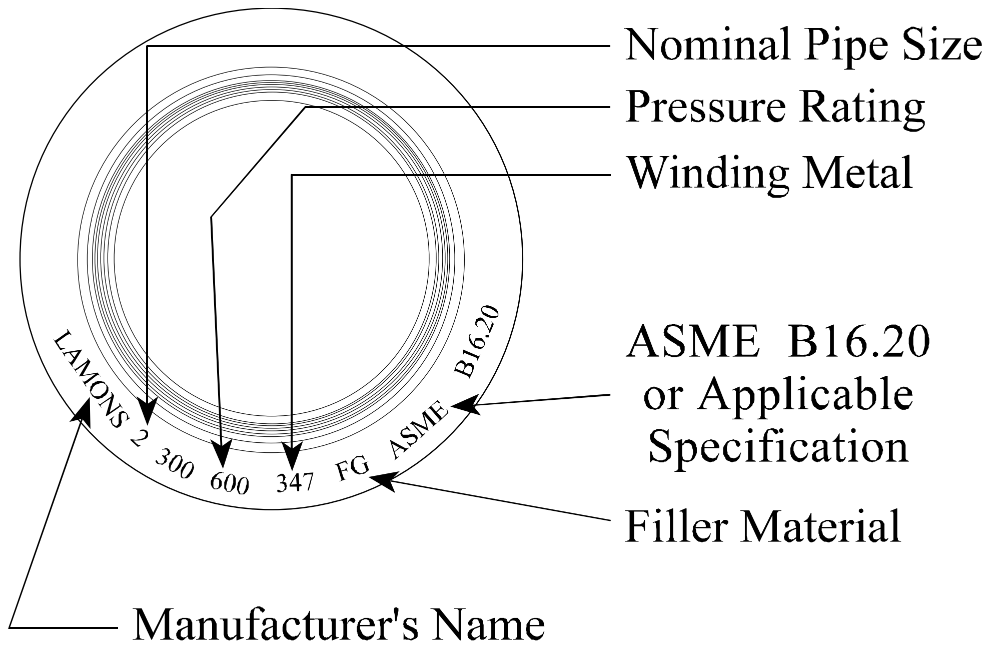
- **Ring Joint Gaskets**
  - **Manufacturer's name or trademark**
  - **Gasket number prefixed by R, Rx, or Bx**
  - **Gasket material identification**
  - **Designation of ASME B16.20**

Gasket Markings Required by B16.20 (continued)

- **Spiral Wound Gaskets**
  - **Manufacturer's name or trademark**
  - **Flange size (NPS)**
  - **Pressure Class**
  - **Winding material identification (may be omitted for 304 windings)**
  - **Filler material identification**

Gasket Markings Required by B16.20 (continued)

- **Spiral Wound Gaskets (continued)**
  - **Centering and inner ring material identification (may be omitted for carbon steel outer and 304 inner rings)**
  - **Flange identification if other than B16.5 (e.g., B16.47)**
  - **Designation of ASME B16.20**


LAMONS 2 300 600 347 FG ASME B16.20
Nominal Pipe Size
Pressure Rating
Winding Metal
ASME B16.20
or Applicable
Specification
Filler Material
Manufacturer's Name

Flange Design

- **Codes encourage use of standardized flanges**
- **Codes often recognize standards in addition to B16.5**
- **In situations where no suitable flange exists in an accepted standard, the flange may be designed**

Flange Design
(continued)

- **Design rules and methods are given in Appendix 2 of ASME Section VIII, Division 1**

- **Method is required by the Pressure Vessel and Process Piping Codes**

- **Design rules analyze two situations**
  - **Gasket seating**
  - **Maintenance of a seal against the internal design pressure**

Flange Design
(continued)

- **Design rules are actually evaluation methods**
- **Design begins by selecting a gasketing system and flange dimensions, then evaluating them by comparing stress levels to allowable stresses for the materials at temperature**
- **Flange dimensions may be from any available flange (e.g., Taylor Forge specialty classes) or may be uniquely developed**

Flange Design
(continued)

- **Flanges in most accepted standards have been designed in accordance with the ASME Code method**
  - **B16.5 flanges are an exception**

- **Other design methods which evaluate flanges for their tendency to leak based upon the design conditions and the contained fluid are available, but not yet incorporated into Codes**

Forces Acting on Flanges

- **Internal pressure acting across the inside diameter acts to open the joint**
- **This force is applied axially through the pipe or nozzle wall**
- **Internal pressure acts upon the exposed flange face inside of the gasket, tending to open the joint**

Forces Acting on Flanges
(continued)

- **The sealing force on the gasket acts over most of the gasket surface**

- **The reciprocal force tends to open the joint, but relaxes if the joint does tend to open**

- **Bolt forces act at the centerline of the bolt circle**
  - **This force tends to close the joint**

Forces Acting on Flanges
(continued)

- **Applied axial or bending loads**
  - **May tend to open or close the joint**

- **For gasket seating, consider only the seating force necessary (based upon "Y" for the gasket) and (to allow for overtightening) the average of the resulting bolt load and the bolt load using the allowable bolt stress**

- **Use ambient allowable stresses**

Forces Acting on Flanges
(continued)

- **For operation, consider all of the forces and allowable stresses of each component at their design temperature**

- **Sealing force on the gasket is based upon the internal pressure and “M” for the gasket**

Forces Experienced by a Flange in Operation

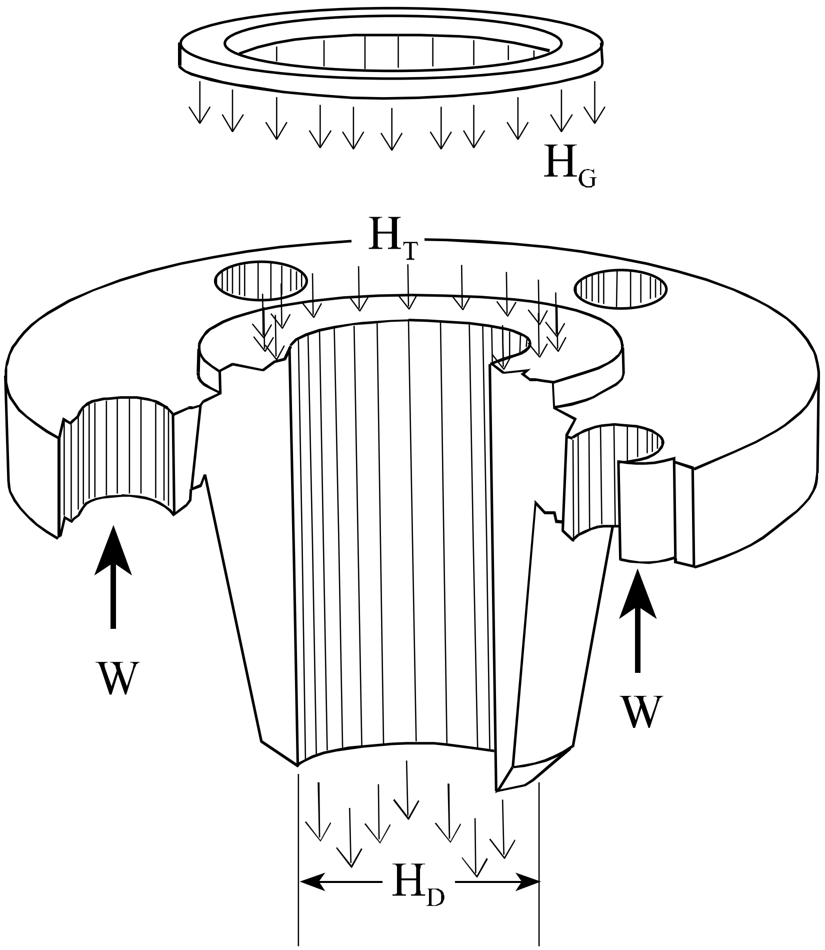
<u>Forces</u>

H_G = Compressive force on the gasket

H_T = Pressure force on the flange face

H_D = Hydrostatic end force

W = Tightening bolt force



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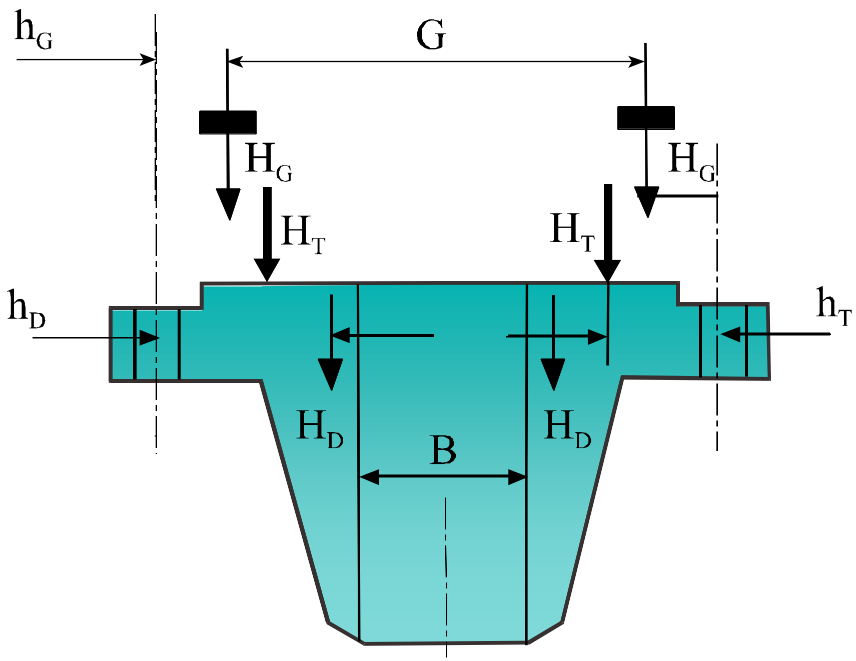
Design Procedure

- **Follow the procedure of ASME Section VIII, Division 1, Appendix 2**
- **For convenience some flange and gasket manufacturers (e.g., Taylor Forge) provide worksheets**
- **Check required bolt area (must be less than the available bolt cross sectional area at the root of the threads), bolt spacing (maximum per Code to prevent flange deflection and possible loss of seal between bolts), and stresses in the flange**

Design Procedure
(continued)

- **Most allowable stresses are as listed in the Code**
- **Longitudinal hub stress may reach 1.5 x Code allowable because it is a bending stress (maximum at a point, decreasing to 0 at the neutral axis)**
- **If slight yielding occurs, the load redistributes safely**

Critical Dimensions in a Flange



<u>Positions</u>

G = Average gasket diameter

B = Flange I.D. (bore)

h_G = Distance from bolt hole to the gasket force, H_G

h_T = Distance from bolt hole to the position of H_T

h_D = Distance from bolt hole to the position of H_D

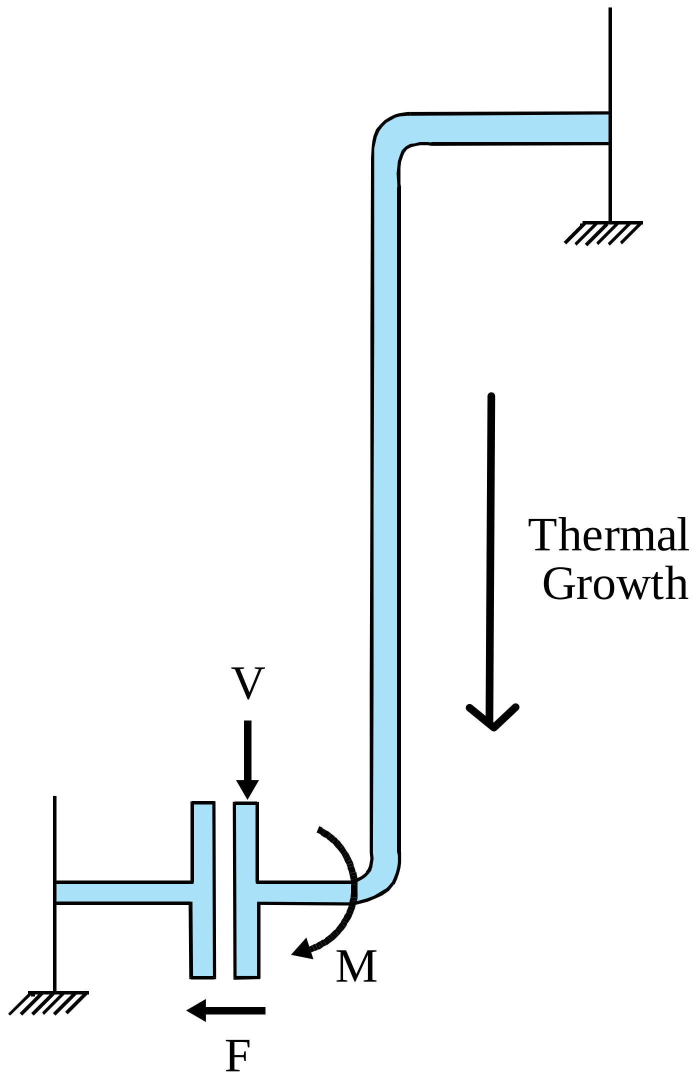
External Loadings
Equivalent Pressure Method

- **A conservative method of evaluating the suitability of a flanged joint for axial and bending loads imposed by the piping**

- **Loads are converted into an "equivalent" internal pressure, which is added to the actual internal pressure**

- **The flange is then evaluated for the total pressure (internal pressure + equivalent pressure)**

External Forces on a Flange



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External Loadings
Equivalent Pressure Method (continued)

- **Imposed loads are converted into an equivalent pressure via the following formula:**

$$P_{EQUIV} = 16\,M / \mathrm{p}\ G^3 + 4\,F / \mathrm{p}\,G^2$$

where: **M = Bending moment**

F = Axial force

G = Diameter at gasket reaction

External Loadings
Equivalent Pressure Method (continued)

- **Shear and torsion on the bolts must be considered separately**
- **The method is very conservative, especially for bending loads**

Flange Assembly

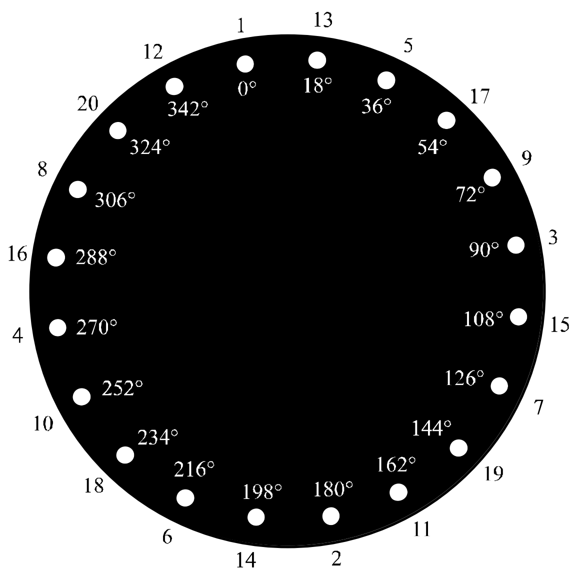
- **Insure flange faces are parallel**
- **Avoid pulling or pushing the flange into assembly position**
  - **The resulting piping forces will affect the joint's performance**
- **Be sure the gasket is properly placed and centered**
  - **The gasket must not be creased, twisted, bunched, etc.**

Flange Assembly
(continued)

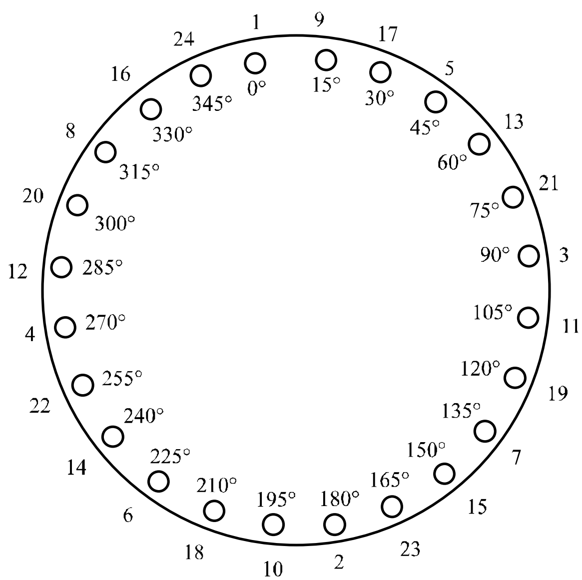
- **Do not overtighten the bolts**
  - **Bolts may yield, the gasket may be crushed, or the flange may be distorted (e.g., the outer portion squeezed together, causing a rotation tending to unload some of the gasket)**
- **Tighten the bolts uniformly**
  - **Bolt tensioning devices are the most reliable method**

Flange Assembly
(continued)

- **The order of bolt tightening is very important**
  - **Tightening in circumferential order will not achieve a uniform seal**
  - **Tighten bolts in a diametrically opposed pattern**
  - **Do not fully tighten the bolts in one step**
  - **Proceed through the tightening sequence several times (usually three) to achieve the desired bolt force**
  - **After each step, adjust to an even gap between the flanges**
- **Avoid use of flange "cements" on the gasket -they tend to damage the flange surface and are difficult to remove without causing further damage to the sealing surface**



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



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

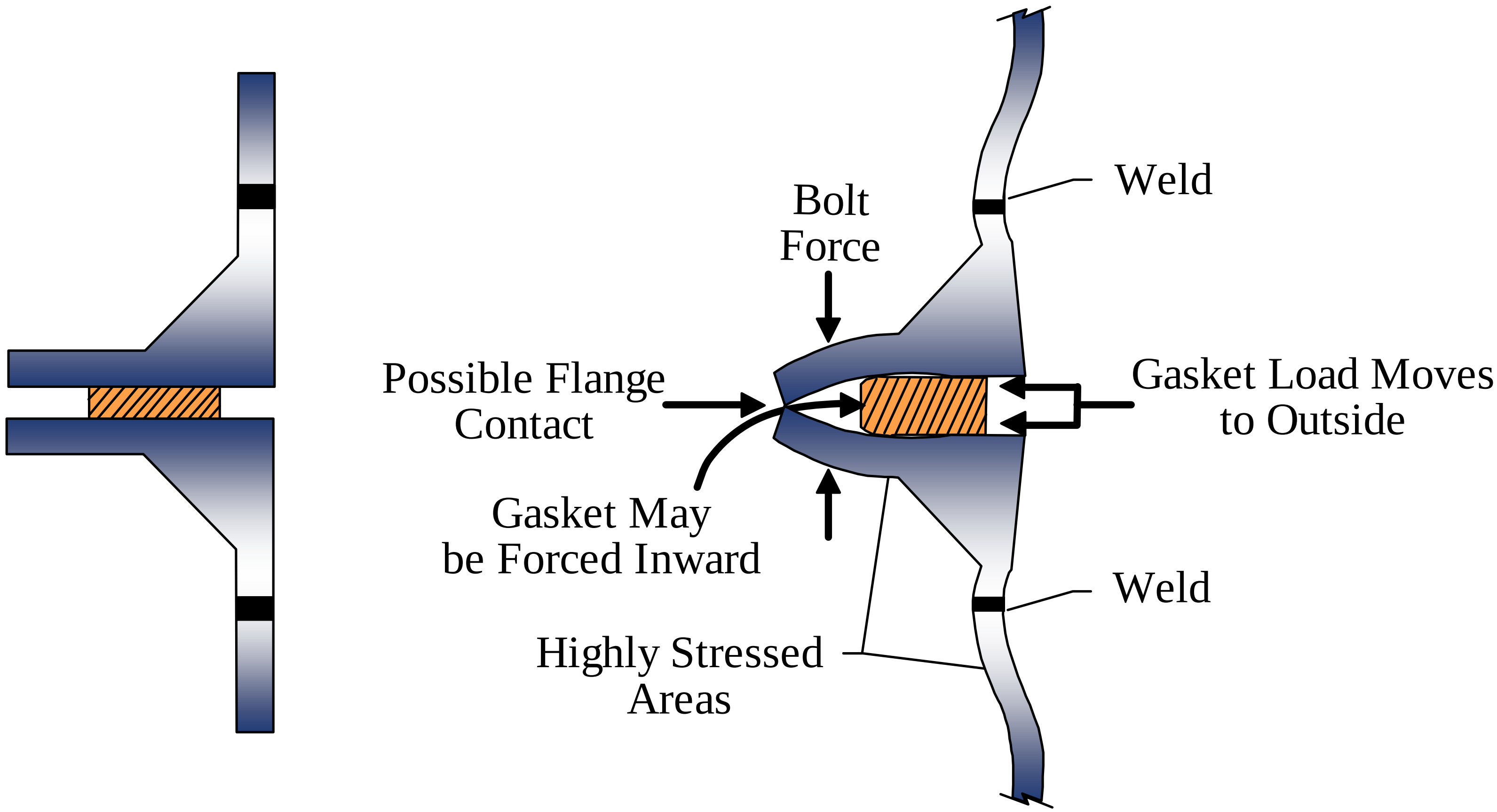
Leakage Causes

- **Damage to the flange surface (especially radial scratches or corrosion)**
- **Flange misalignment, i.e. mating flanges are not parallel**
- **Flange faces are not flat**
  - **Are distorted or contain raised or depressed areas**

Leakage Causes
(continued)

- **Flange "cupping" or rotation due to bolt loads**
- **Improper surface finish**
  - **Too rough and the gasket may not seal**
  - **Too smooth and the gasket may slide and/or not seal)**
- **Inadequate thread engagement between the bolts and nuts**
- **Vibration may cause the nuts to "back off" or loosen slightly, reducing the bolt force and, therefore, the sealing force on the gasket**

Flange Distortion Due to Boltup



Flange Prior to Boltup

Distorted Flange (Exaggerated) after Boltup

Leakage Causes
(continued)

- **Inadequate bolt tightness**
  - **May be due to:**
    - **An improper bolt tightening sequence**
    - **Inelastic relaxation (e.g., creep) or yielding of the bolt**
    - **Yielding the bolt or differential expansion between the bolt and flange (e.g., the flange expands more and yields the bolt or the bolt expands more and loosens)**

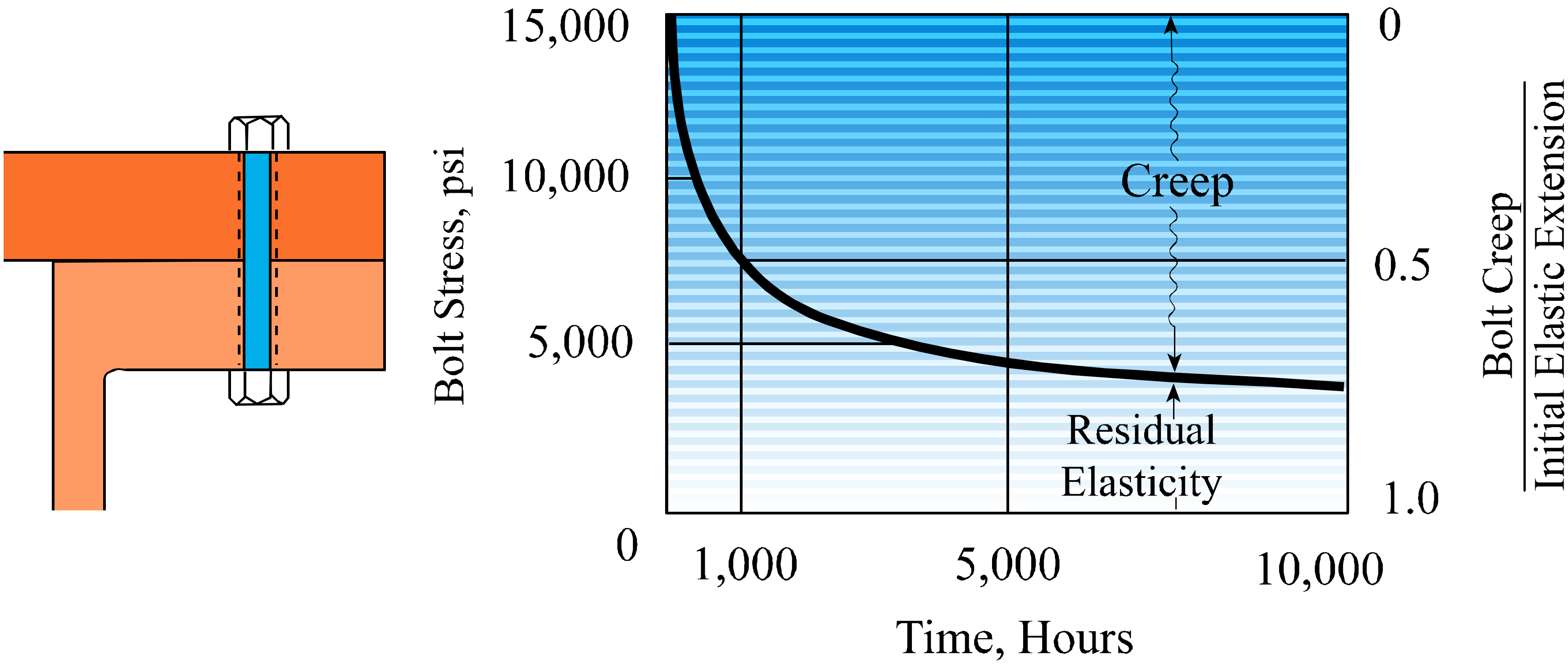
Leakage Causes
(continued)

- **Insulating an existing flange increases the bolt temperature and thermal expansion relative to the flange, possibly tending to loosen the bolt**
- **Insulating the assembly may increase the temperature to the point where the flange is no longer rated for the temperature (i.e. piping where credit was taken for the lower flange and bolt temperatures of uninsulated flanges).**
- **Uninsulated flanges are exposed to uneven cooling from weather conditions.**

Leakage Causes
(continued)

- **Rapid startup causing the flange to heat and expand before the bolts**
  - **May inelastically deform the bolts**
  - **When the bolts then heat and expand, they will, in effect, loosen**
- **Improper gasket type or material**
- **Damage to the gasket, e.g. crushed, extruded or buckled**
- **Use of a gasket intended for a different flange class**
- **Different temperatures around the flange circumference**

Behavior of Bolt in an Unyielding Flange



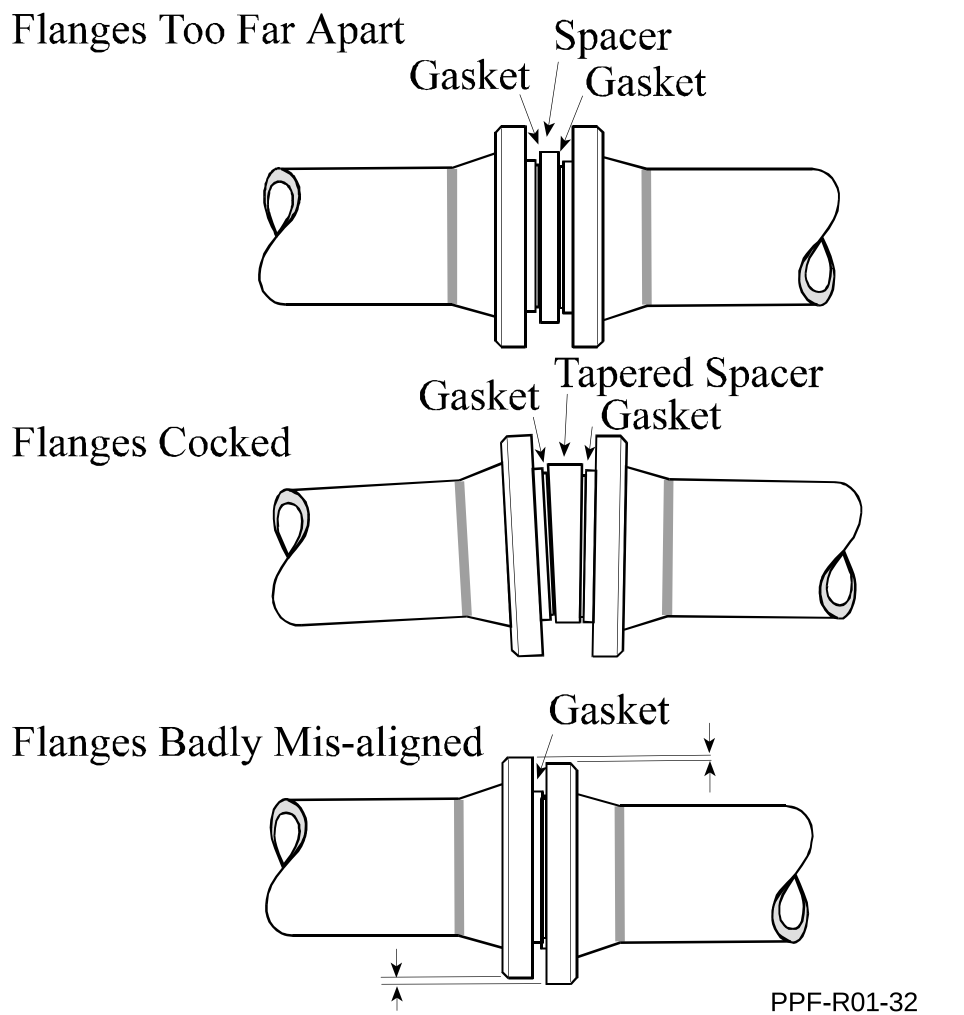
Leak Correction

- **If flanges are mis-aligned, separated, or rotated, consider a spacer between the flanges, with a gasket on each side**

- **If the surface finish is damaged or incorrect, consider refinishing the flange**
  - **Take care to retain the required flange dimensions after refinishing**
  - **In some cases, consider a different gasket that will perform with the existing finish**

Flanges Badly Cocked or Separated Too Far

- **Solution**
  - **Do not try to correct the problem with the flange bolts – they can be overstressed**
  - **Do use spacers with a gasket on each side to correct the problem**



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Leak Correction
(continued)

- **Tighten bolts while on stream (hot bolting)**
  - **Used if the flange leaks after a period of successful operation at elevated temperature without a shutdown, indicating the bolt has elongated due to creep**
  - **May be used if the bolt has been inelastically strained, i.e., elongated during startup**
  - **Bolt replacement will be required at shutdown**
- **If bolts loosen due to vibration, consider the use of double nutting**
  - **Will require longer bolts and more clearance to accommodate the two nuts**

Leakage Correction

- **Leakage only at shutdown may indicate the bolt was inelastically elongated during operation by greater thermal expansion of the flange, or possibly creep of the bolts**
  - **Bolts should be replaced**

- **Leakage, and the need for hot bolting, after achieving an elevated operating temperature may mean the bolts loosened due to greater thermal expansion than the flange**

Leakage Correction
(continued)

- **If the flange heated first and yielded the bolts, then the bolts expanded and loosened, hot bolting may correct a leak present at or near startup**

- **Hot bolting is not effective in other cases of bolt yielding because the additional strain (due to tightening) will not result in a significant bolt force increase**

Leakage Correction
(continued)

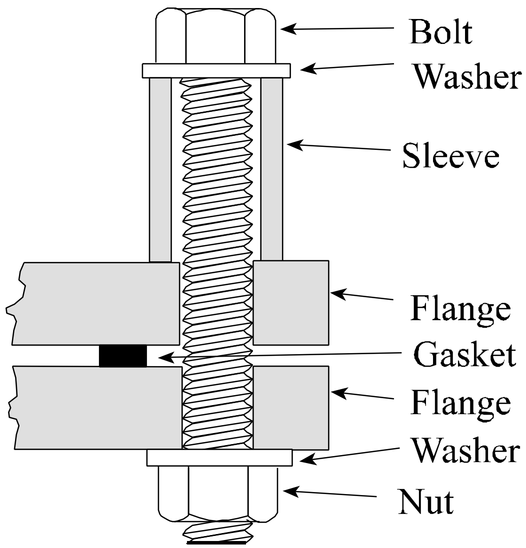
- **Hot bolting may be avoided by using proprietary products such as Belleville Washers, or spring washers, to provide a constant bolt stress over wide temperature ranges, elongation of the bolt relative to the flange from thermal expansion or creep, and vibration exposure**

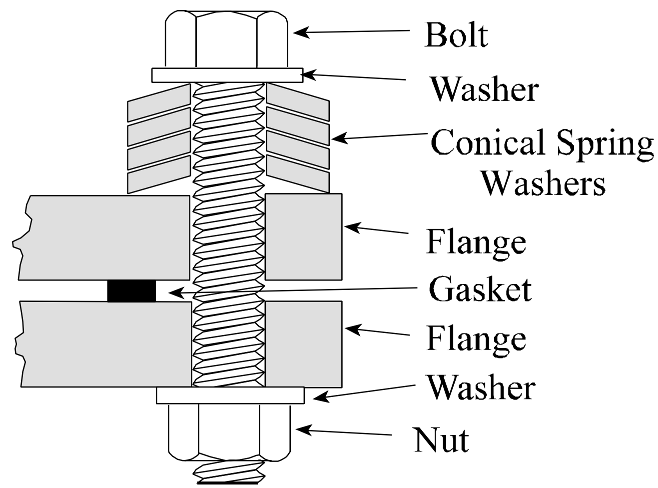
Leakage Correction
(continued)

- **Use of a sleeve and extra long bolts reduces the relative strain differential due to thermal expansion variances or creep**
  - **The bolt extension is cooler and elongates less than the portion between the flanges**
  - **The total strain change averaged over the entire bolt length is, therefore, less**
  - **A lower change in strain means a lower stress change**
    - **This reduces the chance of exceeding the bolt's yield strength and reduces the creep rate (if in the creep range)**

Joint Must Compensate for Wide Temperature Variations

- **Solution**
  - **Consider the use of a sleeve around the bolts to increase the effective bolt length**
  - **or consider the use of conical spring washers to eliminate force losses over wide temperature ranges**



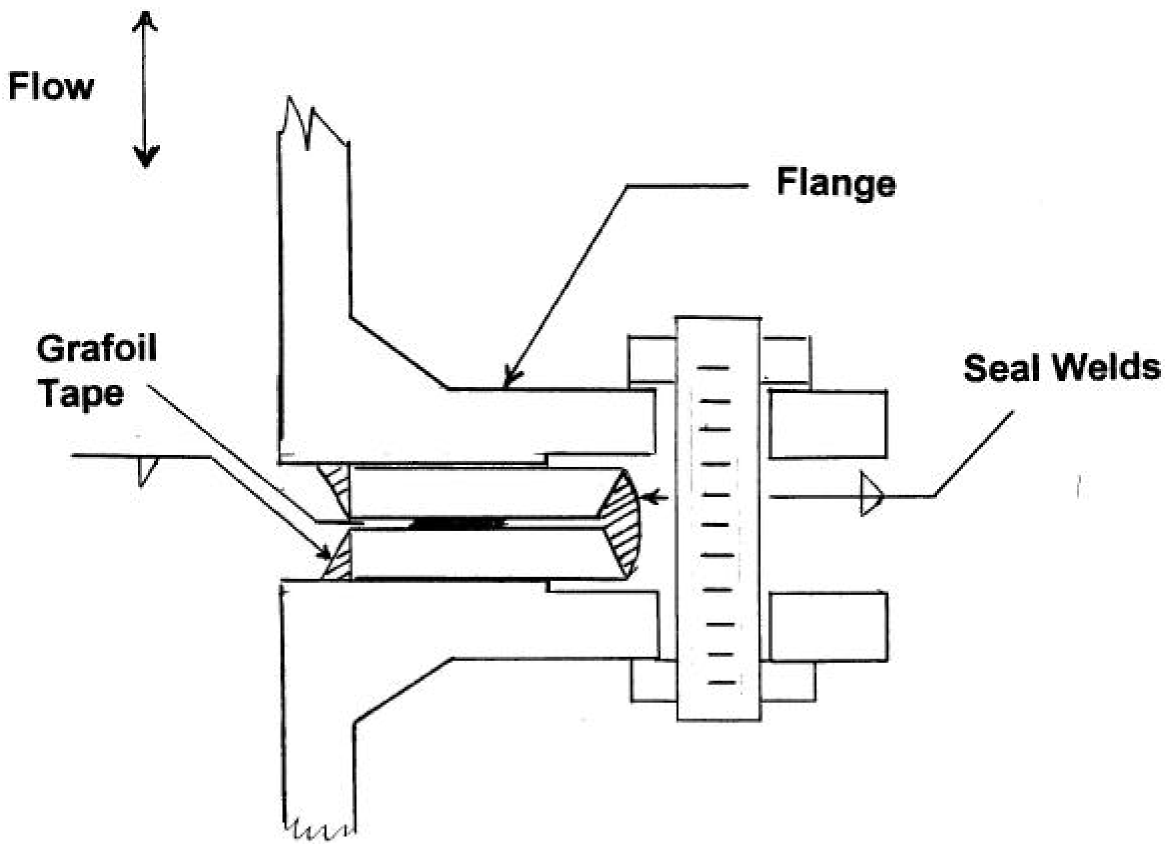


Leakage Correction
(continued)

- **Seal the joint by welding the flanges together inside of the bolt circle**
  - **Use lip seals to avoid welding directly to the flange material and to allow subsequent cutting open and rewelding**

- **Spacer blocks between flanges on their outer periphery**
  - **Blocks prevent excessive flange rotation**

Lip Seal System



Leakage Correction
(continued)

- **Loosening the bolts may stop a leak if the leak is due to flange rotation unloading a portion of the gasket**

- **A lower bolt load may reduce the amount of rotation and improve contact with the gasket**