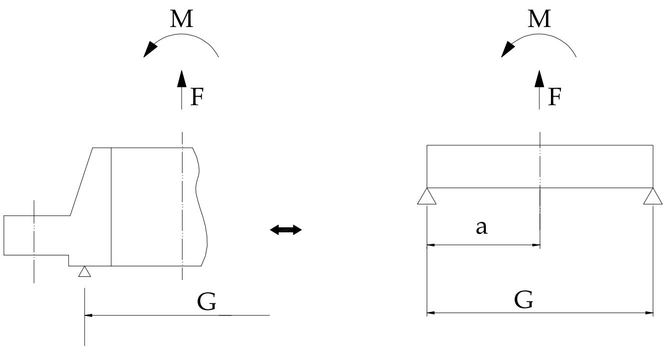
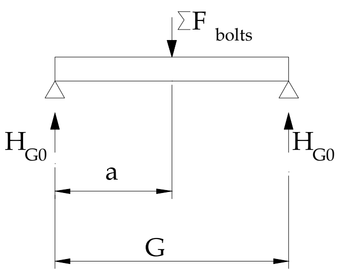
Understanding the Kellogg Equivalent Pressure Method for piping flanges



Remarks

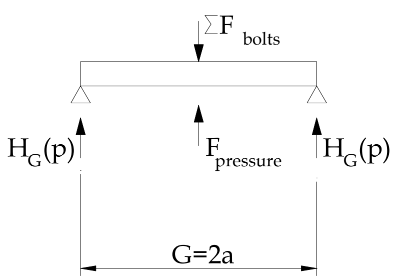
1. This method is a gasket load calculation.
2. This paper counts the gasket load in terms of force per unit length of circumference, as this approach is usual in the circular plate theory.
3. For calculation of the reaction on free-to-rotate edge, the circular plate theory gives results that are quite insensitive vs. variations of plate rigidity.

The theory assumes that the flange is a circular plate.



No pressure, no external loads

$$H_{G0} = \frac{\sum F_{bolts}}{2\pi a}$$ is the gasket load for the case *no pressure, no external loads*.



Internal pressure, no external loads

$$H_G(p) = H_{G0} - \frac{F_{pressure}}{2\pi a}$$

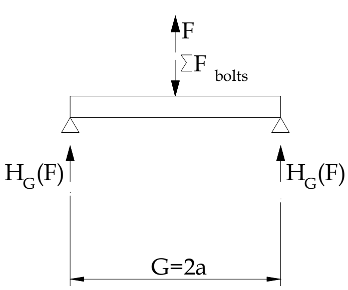
is the gasket load for the case *internal pressure, no external loads*.

$$F_{pressure} = \pi a^2 p$$

and

$$H_G(p) = H_{G0} - \frac{ap}{2}$$

Remark: A pressure load is decreasing the gasket reaction.



No pressure, external tensile force

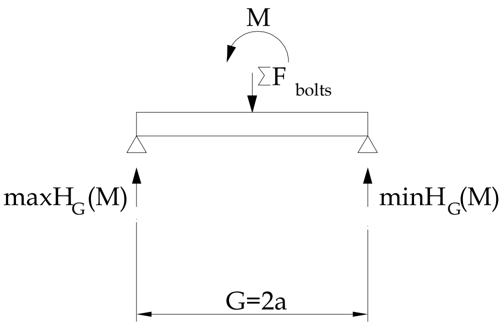
$$H_G(F) = H_{G0} - \frac{F}{2\pi a}$$

is the gasket load for the case *no pressure, external tensile force*.

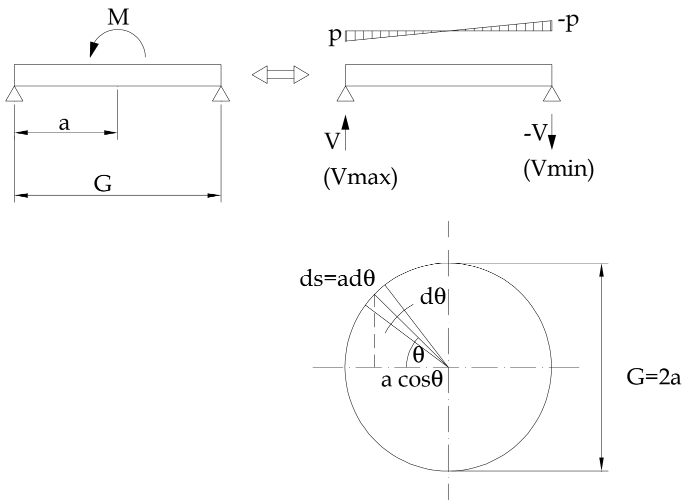
Remarks: - A tensile force $F > 0$ is decreasing the gasket load.

- A compressive force $F < 0$ is increasing the gasket load.

A bending moment is changing the gasket load, but $H_G(M)$ is variable along the gasket circumference.
The gasket load can be described by the following model, based on the theory of circular plates.



No pressure, external bending moment



$V = \frac{pa}{4}\cos\theta$ is the evaluation of the edge reaction following the circular plate theory
(see “Theory of Plates and Shells” by S. Timoshenko and S. Woinowsky-Krieger, Second edition, 1959, paragraph 63 “Circular Plates under Linearly Varying Loads)
and

$$M = 4\int_0^{\frac{\pi}{2}}\left(\frac{pa}{4}\cos\theta\right)(a\cos\theta)\,a d\theta = \frac{\pi a^3 p}{4}$$

is the moment equation.

It results:

$$p = \frac{4M}{\pi a^3}$$

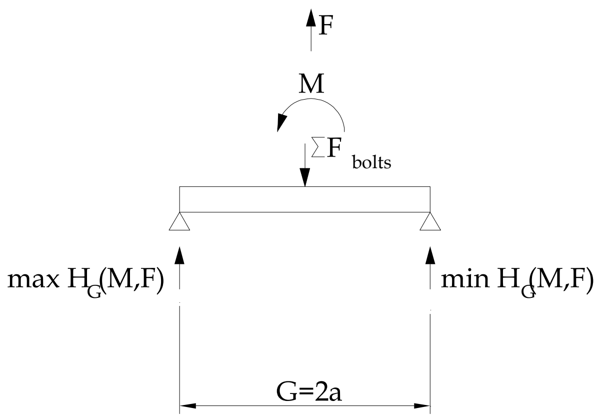
$$V_{max} = \frac{pa}{4} = \frac{4M}{\pi a^3}\frac{a}{4} = \frac{M}{\pi a^2}$$

$$H_G(M) = H_{G0} + V_{max}\cos\theta = H_{G0} + \frac{M}{\pi a^2}\cos\theta$$

$$\min_{\theta} H_G(M) = H_{G0} - \frac{M}{\pi a^2}$$

is the minimum gasket load for the case *no pressure, external bending moment.*

THE FOLLOWING EQUIVALENCES CAN BE WRITTEN:



No pressure, external bending moment and external tensile force

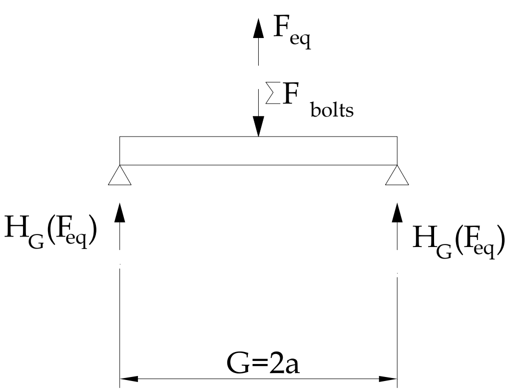
The minimum gasket load is

$$\min H_G(M,F) = H_{G0} - \frac{M}{\pi a^2} - \frac{F}{2\pi a}$$

The maximum gasket load is

$$\max H_G(M,F) = H_{G0} + \frac{M}{\pi a^2} - \frac{F}{2\pi a}$$

IS EQUIVALENT WITH



No pressure, equivalent tensile force

The equivalence is considered in terms of "tensile force that gives the reaction on gasket equal to the minimum gasket load given by the external loads":

$$\min H_G(M,F) = H_G(F_{eq}) \text{ or}$$

$$H_{G0} - \left(\frac{M}{\pi a^2} + \frac{F}{2\pi a}\right) = H_{G0} - \frac{F_{eq}}{2\pi a}$$

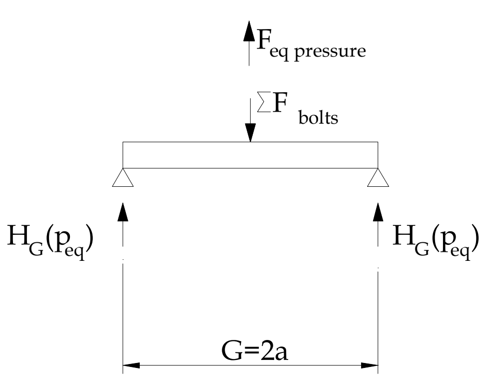
That means:

$$\frac{F_{eq}}{2\pi a} = \frac{M}{\pi a^2} + \frac{F}{2\pi a}, \text{ i.e.}$$

$$F_{eq} = F + \frac{2M}{a} = F + \frac{4M}{G}$$

Remark: This equivalence is conservative made and is really true just for a point, not for the entire gasket circumference.

IS EQUIVALENT WITH



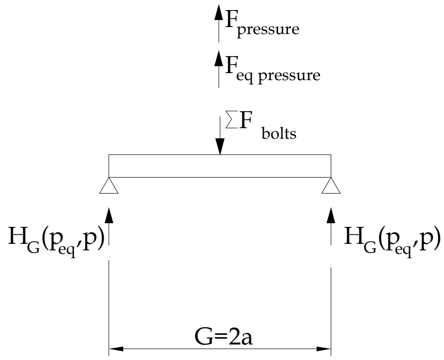
Equivalent pressure, no external loads

The equivalence is considered in terms of "pressure that gives the same effect as F_{eq}", i.e.

$$p_{eq}\pi a^2 = F_{eq}$$

$$\text{or } p_{eq} = \frac{1}{\pi a^2}\left(F + \frac{2M}{a}\right) = \frac{F}{\pi a^2} + \frac{2M}{\pi a^3}\bigg|_{a=\frac{G}{2}} = \frac{4F}{\pi G^2} + \frac{16M}{\pi G^3}$$

GASKET LOAD LIMITS



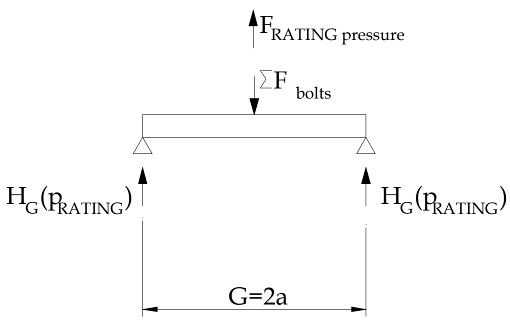
Internal pressure, equivalent pressure

For the tensile loaded part of the flange, the minimum gasket load is:

$$H_G(p_{eq},p) = H_{G0} - \frac{F_{pressure} + F_{eq\ pressure}}{2\pi a} = H_{G0} - \frac{\pi a^2 (p + p_{eq})}{2\pi a}$$

This load must be limited to the value corresponding to the rating pressure.

versus the limit given by the rating pressure



$$H_G(p_{RATING}) = H_{G0} - \frac{\pi a^2 p_{RATING}}{2\pi a}$$

The gasket tightness condition means to accept for the gasket load only values that are greater than the value corresponding to the rating pressure.

The condition $H_G(p_{eq},p) \geq H_G(p_{RATING})$ means $p + p_{eq} \leq p_{RATING}$.

For the compressed loaded part of the flange, the maximum gasket load is:

$\max H_G(M,F) = H_{G0} + \frac{M}{\pi a^2} - \frac{F}{2\pi a}$, where $F > 0$ is a tensile force, $F < 0$ is a compressive force.

This load gives a compressive stress for the gasket: $\frac{1}{b}\left(H_{G0} + \frac{M}{\pi a^2} - \frac{F}{2\pi a}\right)$ that may be limited to a maximum stress on the gasket. This condition is not covered by limiting $p + p_{eq} \leq p_{RATING}$.