STATIC SEALING - CONCEPT & TECHNOLOGIES

Abstract

Since the beginning of the industrial era, sealing technologies have mostly been based on the same principle, commonly called "**non metal-to-metal contact.**" Nowadays, most new sealing products coming on the market are still following the same trend. The somewhat opposite principle called "**metal-to-metal contact**" remains marginal. Applicable international codes and standards have always almost ignored metal-to metal contact, and the ongoing evolution of those standards does not show it as a priority topic of discussion.

However, a growing number of sealing specialists are pushing towards development of the metal-to-metal principle.

This paper addresses the following:

- Review and comparison of the main features of each principle taking into account the environment in which they are used
- Analysis of mechanical compatibility of each principle with existing standard hardware worldwide
- Review of existing and upcoming flange assembly calculation methods with respect to metal-to-metal contact
- Assumptions and suggestions on the evolution of key parameters which could change the current trend in seal and joint development
- Analysis of both solutions with respect to end-users' expectations

1. Introduction

The "Bolted Flange" technology which has been around for so many years has led to a variety of norms, design rules, and standards always based upon the same working principle shown in Figure 1. A bolted flange assembly typically consists of three essential types of components: the flanges, the seal or gasket, and the bolts. Those three components assembled together must achieve a dual function which is to ensure mechanical integrity and maintain leak-tightness. For a long time, only one of the two functions has remained the focus of attention, that is mechanical integrity, and all existing codes and standards (ASME, DIN, CODAP, RCCM, etc.) were built around it. It is only in the last 25-30 years that attention has started to be paid by official laboratories to the component remaining unknown: the seal. Extensive work has been carried out in particular by PVRC, MPA, BHRG, and CETIM. New gasket factors, and the test procedures leading to the evaluation of those factors, have been released. Such factors take into account the nature of media, pressure, temperature, and tightness class. However, regardless of how much effort has been put into controlling or successfully predicting the behavior of each of the components in seating, proof test, or service conditions, it remains very clear that no major improvement has ever been brought to the joint design itself.

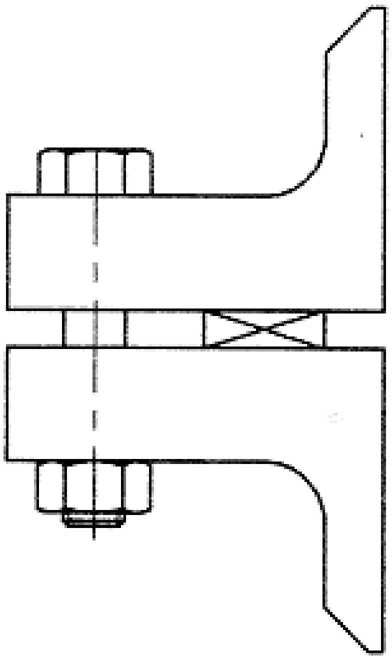


Figure 1. Non metal-to-metal principle

2. The "non metal-to-metal" principle

The "non metal-to-metal contact" principle, as already mentioned, is basically the only one recognized by current and upcoming codes and standards. Figures 2a, 2b, and 2c illustrate respectively the flat-face, male-and-female, and tongue-and-groove configurations which characterize the non metal-to-metal principle. Geometry modifications brought over the years such as going from flat-face to male-and-female have essentially been safety related.

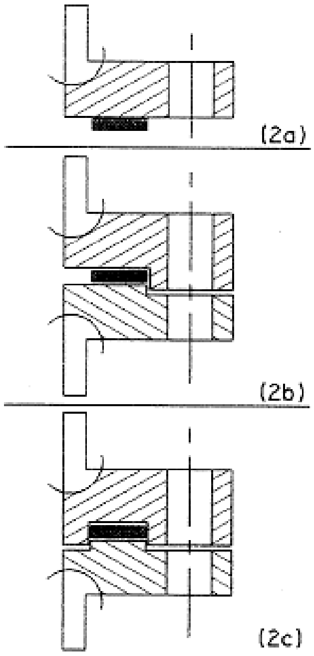


Figure 2. Standard
non metal-to-metal assemblies

The main characteristic of such a joint is that the load exerted on the joint by the bolts is entirely acting on the gasket, starting at the assembling stage and continuing over the whole "life" of the joint. No mechanical stop of any type is allowed between the flanges.

Therefore, the different types of seal or gasket used in such joints are typically designed around the same geometry: limited thickness versus significant width. Examples immediately coming to mind are, of course, sheet gaskets, metal-jacketed "heat exchanger type" seals, spiral-wound gaskets, and serrated and corrugated gaskets. There has been no major evolution in the construction and principle of those seals and gaskets since they were first introduced. It is only the materials which have eventually followed the technological and environmental trends. As an example, asbestos replacement becoming a key issue has allowed introduction of PTFE (Polytetrafluoräthylen) and flexible graphite as sealing materials on the widest possible scale.

All those gaskets, when compressed between two flanges, follow at assembling stage the essential characteristic:

$$FB = FJ \quad (1)$$

This is the equation between load exerted by the bolts (FB) and reaction load exerted by the gasket (FJ). All of the load exerted by the bolts is acting on the gasket right from the beginning at the assembling stage, and the initial gasket reaction (FJ) is then going to be modified over the whole life of the joint by a more or less unpredictable load (Fext) resulting from the various internal and/or external strains to which it will be exposed, that is, hardware weight, vacuum, pressure, external bending moments, thermal transients, etc. Depending on the application, the initial gasket reaction will be either increased (FJ + Fext) or decreased (FJ - Fext) with the possibility of both occurring simultaneously over the periphery of the gasket as shown in Figure 3 on a chart detailing load distribution versus position on gasket periphery. In this specific example typical of external bending moments, point A on the gasket would become overloaded and point C under-loaded.

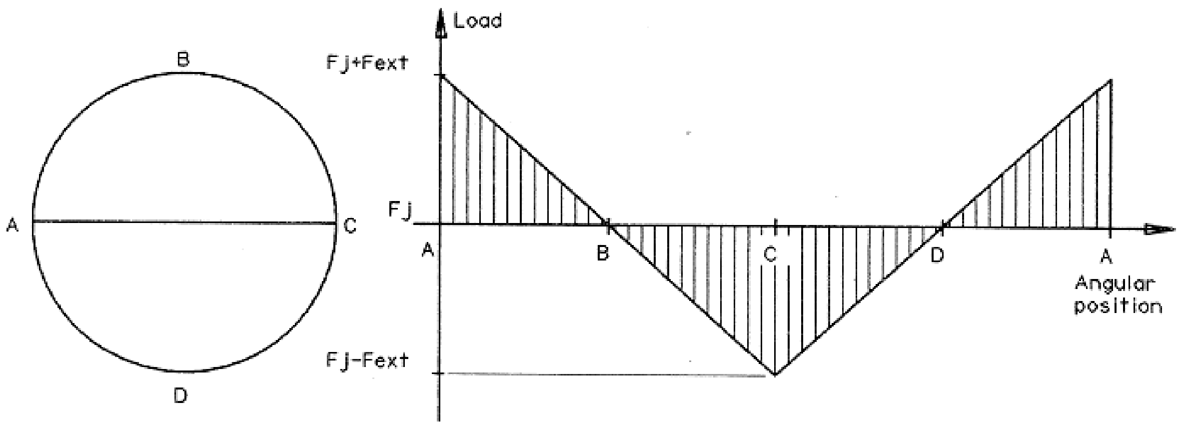
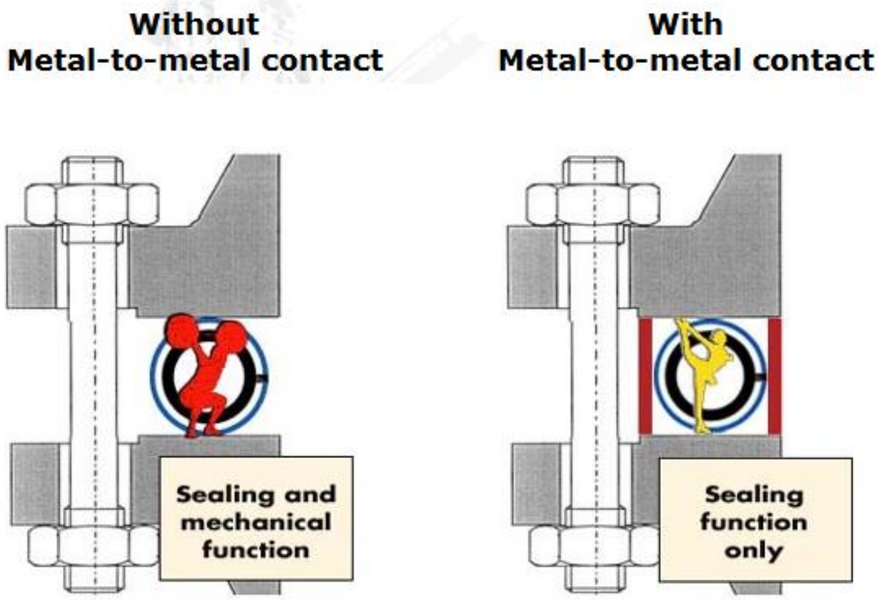


Figure 3. Load distribution on a non metal-to-metal gasket in bending moment situation

Figure 3 also confirms that it is up to the gasket, which is typically the most heterogeneous component of the joint, to adapt itself to all types of load variations, including major ones with the obvious risk of aggravating creep-relaxation in (FJ + Fext) situations or deteriorating tightness level in (FJ - Fext) situations.

At this point, the following question comes to mind:

> What would be the way to screen all or part of the external strains so that they do not interfere with gasket seating requirements?



3. The "metal-to-metal" principle

The answer to the question above looks obvious and intuitive since it is the solution used with elastomer O-Rings. It is the "metal-to-metal contact" principle, where the compression is going to be limited to a set value by means of a spacer, a groove, etc. A "metal-to-metal" configuration can very well work using the same flanges as the "non metal-to-metal" as shown in Figures 4a, 4b, and 4c, provided that some type of compression-limiting device is placed at the joint interface inside the bolt circle to act as a mechanical stop. This limiting device can be part of the gasket or a separate component and can eventually allow an easier gasket installation in all types of standard male-and-female or tongue-and-groove flanges as mentioned earlier.

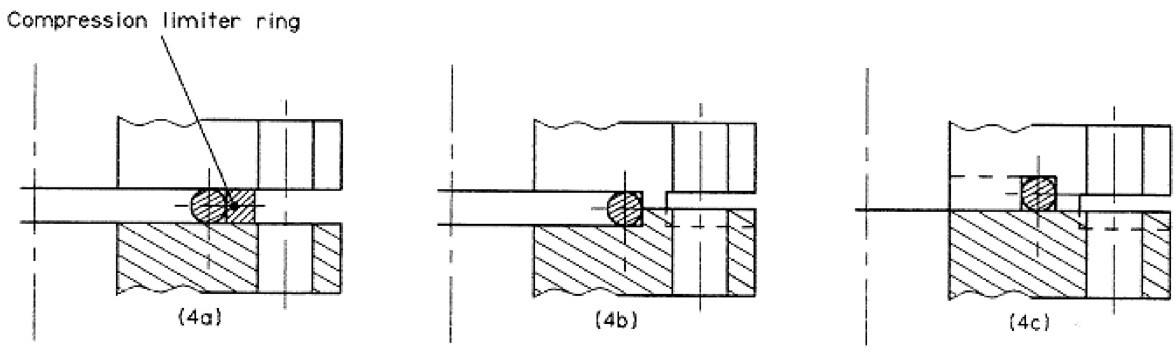


Figure 4. Typical metal-to-metal assemblies

The “metal-to-metal” configuration obviously requires seals or gaskets of a different design compared with “non metal-to-metal.” They are more recent on the market with the following examples :

- Resilient metal seals with optimized cross-section (Helicoflex®, Metal-O-Ring, C-ring, etc.)
- Low-seating-stress spiral-wound gaskets
- Die-formed flexible graphite seals

Regardless of its design and base materials, metallic or composite, seal compression has to be predetermined and its value used for the dimensioning of the limiting device. The load exerted by the bolts has to be sufficient to bring the joint to a mechanical stop on the limiting device. Any amount of loading exerted once the mechanical stop has been reached does not affect the gasket at all, and the compression limiting device takes over as a load-bearing component. Whether the compression-limiting device is a ring or a groove, excess load is such that:

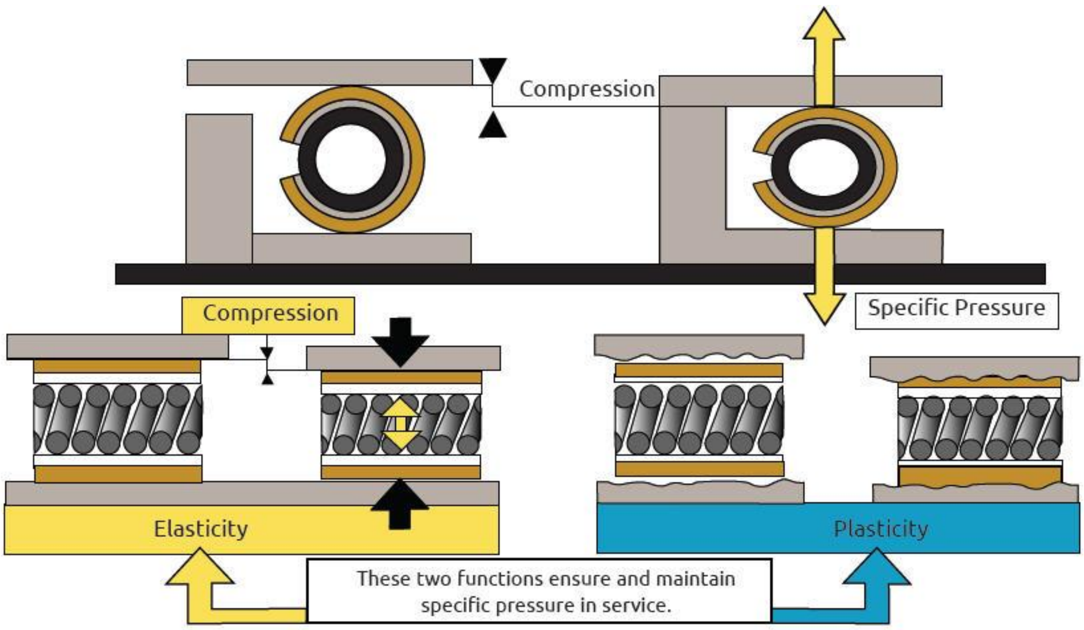
- at metal-to-metal : FB = FJ (2a)
- “beyond” metal-to-metal : FB > FJ (2b)

As a minimum requirement, the load exerted by the bolts has to be high enough over the whole life of the joint to ensure metal-to-metal contact. As for loading consistency, not only the load on the gasket always remains constant, but over its whole periphery the reaction load exerted by the gasket also remains constant as long as the mechanical stop, i.e., metal-to-metal contact, is maintained.

4. Sealing concept

A good sealing always requires two main characteristics:

- The plasticity to get the sealing
- The elasticity to keep the sealing in service, characteristic absolutely necessary in case of metal-to-metal concept.



a. <u>The plasticity</u>

The plasticity is given by the filler in case of composite gasket like SWG (spiral wound gasket), Graphite ring type Origraph® or by the outside lining for the metal gasket.

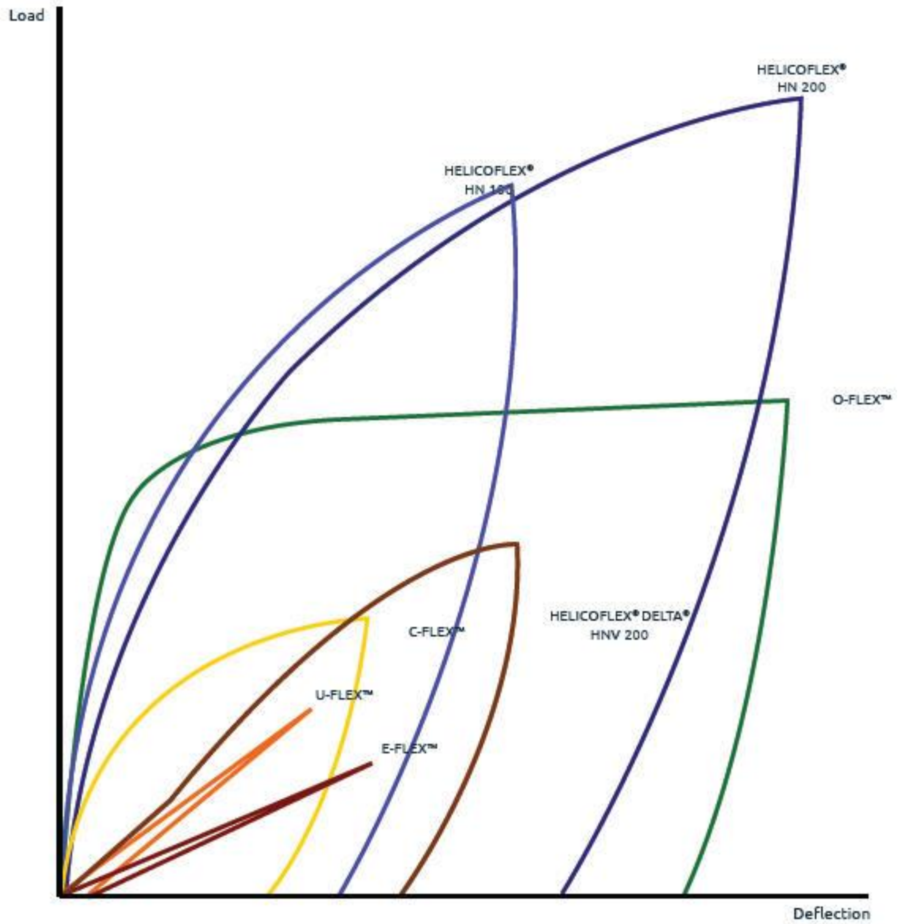
In case of metallic gaskets, we first choose the material compatible with the media so that to resist to the corrosion. Among the acceptable material we will always select the softest one if compatible with the pressure so that to get the best plasticity which give the best forgiveness regarding the surface defects of the sealing area.

The sealing performance is directly connected to the specific pressure that you get between the seal and the sealing areas of the flanges or the equipment. Such specific pressure will yield the sealing lining into the flange, softer is the lining less specific pressure and by consequence seating load you need.

b. <u>The elasticity</u>

The metal to metal contact concept requires elasticity so that to compensate the flange deflection during the service. The very important parameter is what we call the "useful elasticity" what corresponds to the springback during the thermal and pressure cycles.

This useful elasticity could vary a lot according to the type of seal, see below an overview of the elasticity for the main metallic seals



5. TECHNETICS GROUP IN THE NUCLEAR WORLD

In nuclear power plants of the installed base around the globe seals of the “metal to metal” design concept work safe and reliable since several decades, thus providing millions of operating hours of successful technology application. For the safety and mission critical applications in nuclear enrichment equipment, in nuclear power generation facilities, and in containers for transportation and storage of spent nuclear fuel such seals have been qualified according to the above criteria and technological background and are in operation, meeting most stringent requirements of design and leakage prevention, as well as specifications of procurement. Based on this long-term experience, in most of the nuclear reactor units of PWR type of Generation III+, which are under planning and construction today, the below described seals are specified, and found NSSS (nuclear steam supply system) approval. The below listed examples of various types of metal to metal seals demonstrate the wide range of applicability to systems and components of nuclear power plants

- Nuclear reactor pressure vessel closure head	HELICOFLEX® / O-FLEX®
- Steam generator and pressurizer	ORIGRAF®
- Steam Generator	HELICOFLEX®
- Reactor cooling pumps (RCP)	HELICOFLEX® / SWG
- Piping system	ORIGRAF®
- Diaphragms	ORIGRAF® / HELICOFLEX®
- Heat Exchangers RIS (Safety Injection System)	ORIGRAF®
- RRA (Shut down Cooling System)	ORIGRAF®
- RPE (Nuclear Exhaust System)	ORIGRAF®
- Tanks RPE, RCP (Reactor Cooling Pump),	ORIGRAF®
- RIS (Safety Injection System),	ORIGRAF®
- RCV(chemical & volume control system)	ORIGRAF®
- High pressure heaters (steam turbine system)	SWG + JPR
- Equipment hatch	Silicone / EPDM profiles
Pool gates	CEFILAIR® / profiles
- Reactor Building / Containment building	CEFILAIR® / profiles
- Fuel Building)	CEFILAIR® / profiles
- Steam Turbines	HELICOFLEX®
- Valves	HELICOFLEX® / ORIGRAF® / SWG
- Transportation and storage containers for spent fuel	HELICOFLEX® / O-FLEX®
- Fusion reactor	HELICOFLEX®
- Particle Accelerator	HELICOFLEX®/QDS

6. Conclusions

With the latest calculation methods for bolted flange assemblies and associated standard characterization procedures for seals and gaskets, it is important that joint designs get reviewed fundamentally. Both principles, metal-to-metal and non metal-to-metal, must systematically be considered in parallel. They require gaskets of different designs which imply different specifications for a specific joint. This becomes a key issue when reliability and lifetime come into play.

It is clear that the metal-to-metal principle offers many advantages which can only be attractive to a large variety of end-users:

At assembling stage:

A gasket for which the response curve can be accurately established can be used as a calibrated spring element in the joint, thus allowing better control and reduced discrepancy between torque applied on the bolts and actual load applied by the bolts on the joint interface. Besides, for common applications, if a torque wrench is not available, it becomes relatively easy to control that metal-to-metal contact has been reached by using a set of shims. Moreover, the mechanical stop is the most efficient protection against over-compression of the gasket.

At receiving inspection stage:

It is relatively easy to perform receiving inspection of such a seal and/or to simulate its operation on a press by inserting between the two platens a test fixture identical in terms of housing dimensions and surface conditions to the final hardware. The following can be checked:

- • The load Y2 (or seating load PY2) necessary to achieve metal-to-metal contact
- • The gas or liquid tightness performance at test pressure
- • The sealing threshold Ym on the unloading curve, obtained by bringing the platens apart

At verification and calculation stage:

The load provided by the bolts which is necessary to obtain metal-to-metal contact is the minimum required and can be designated Gasket Seating Load by analogy with the general approach.

This minimum load must be increased by a given amount in order to compensate for fluid end-load and external bending moment which both tend to bring the flanges apart. This gives a total load value called Pre-Load which is the predominant parameter in a bolted flange assembly. This applies the same way in an assembly where no gasket is installed.

Pre-Load is the only way to “screen” external stresses such as tension and shear to which the assembly is exposed. As for bolt calculation, the issue is, as in any bolted connection, to make sure that pre-load is maintained at a sufficient level over the whole life of the joint so that flange separation does not occur regardless of any type of external strain, either static or even dynamic-like vibrations.

As a final conclusion, we can confirm a clear evolution. Recent regulations such as those pertaining to fugitive emissions, as well as ever-growing concerns about reliability and safety issues in the industry in general and in sealing techniques in particular, are proving it. We must realize that when it comes to sealing technology, the seal or gasket is ONLY one of the components of the [flange + bolt + gasket] assembly. Asking the gasket to act as a dampening component to be exposed to all sorts of mechanical and thermal strains is strictly incompatible with its primary function which is to provide tightness.

The whole issue is the following:

- Tightness can be better controlled and maintained only if the mechanical strength of an assembly is adequately used.

This seems to be the only option for a significant step forward, knowing that very little evolution has been seen over the last years in terms of new sealing principles and designs.

If the asbestos issue has allowed development of new materials, it has brought no significant improvement to joint behavior.

The metal-to-metal principle based on the segregation of mechanical and sealing functions can improve the overall performance of a bolted flange assembly.

Seals and gaskets operating on this principle can evolve in parallel, using a widening range of materials, metallic and non-metallic, and knowing that the only limitation for new concepts would eventually be relaxation in service.

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Note: *The text is the tird in a series of four texts about engineered sealing solutions in nuclear energy, which arise in the context of cooperation between the portal energia.sk, Technetics Group and EEE JacobyKo. The next text will focus on the detailed references and on fundamental conclusions for the installation of metal-to-metal sealing in new nuclear power plants.*