1037 Effect of Surface Roughness of Cask Flange and Sealability of Metal Gasket (2) Flange Surface of Serration Process and Precision Polishing

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Abstract

A rubber gasket is used as the sealing material for the hermetic boundary of spent nuclear fuel casks. However, instead of a rubber gasket, a metal gasket is used as the sealing material for the hermetic boundary of a storage and shipping cask for the long-term storage of spent nuclear fuel due to the requirement for stable sealing performance for an extended period of time.

A metal gasket is placed between the flanges that form the hermetic boundary of the cask. Generally, in Japan, aluminum, which is softer than the flange material, is used as the surface material of the metal gasket in contact with the flange. When the metal gasket is compressed, the aluminum is de-formed to fit the surface roughness of the flange and brought into close contact with the flange surface. Thus, the gap between the flange and the metal gasket is eliminated to provide good sealing performance.

In a previous paper (PATRAM2013) [1], we reported the results of an investigation of the sealing performance of aluminum as the surface material to provide the sealing performance of the metal gasket and showed that the behavior of the sealing performance largely depends on the surface processing of the flange.

In this study, to further seek for the better sealing performance of the aluminum, we conducted a test with different shapes of spiral grooves formed by the serration process, which is effective for large flanges. We found that there was a range of shapes that gave good sealing performance, and we determined this range. The sealing performance of smaller serrated flange tends to decrease. However, we considered whether the sealing performance can be improved by precision polishing to reduce the surface roughness of the flange to extremely low level. We also found that the above procedure can improve the sealing performance with an actual metal gasket.

Introduction

In the previous report [1], we assumed that if a metal gasket, represented by an aluminum gasket, was used for a serrated flange, the leak rate would be lower for larger gaskets than for smaller gaskets. To develop an effective method to reduce the leak rate of a small gasket, for example, to less than or equal to 10^{-10} Pa m^3/s, in this study we considered a precision polishing method to reduce the surface roughness of the flange to an extremely low level. To reduce the leak rate of a gasket for a serrated flange, we also evaluated other serration groove shapes, that is, the pitch and height of other grooves.

Seal mechanism of metal gasket

If a metal gasket, represented by an aluminum gasket, is used for a flange polished to have an irregular surface finish, a leak occurs in the radial direction. According to Kato et al. [2], the leak rate Qr in the radial direction is given by the following equation (Figure 1).

$$Qr = \pi\varepsilon^3 (P_1^2-P_0^2)/(12\eta \cdot \mathrm{Ln}\ (r_o/r_i))$$
$$= \pi\varepsilon^3 (P_1^2-P_0^2)/(12\eta \cdot \mathrm{Ln}\ (1+w/r_i)) \quad (1)$$

Qr: Leak rate in the radial direction (Pa m^3/sec)
ε: Gap height (m)
η: Elastic coefficient (Pa-s)
P_0: Inner pressure (Pa)
P_1: Outer pressure (Pa)
r_o: Outer radius (m)
r_i: Inner radius (m)
w : Seal width (m)
$w= r_o - r_i$

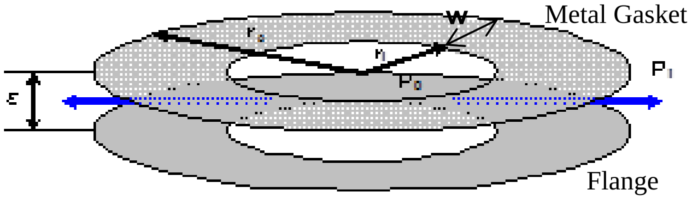
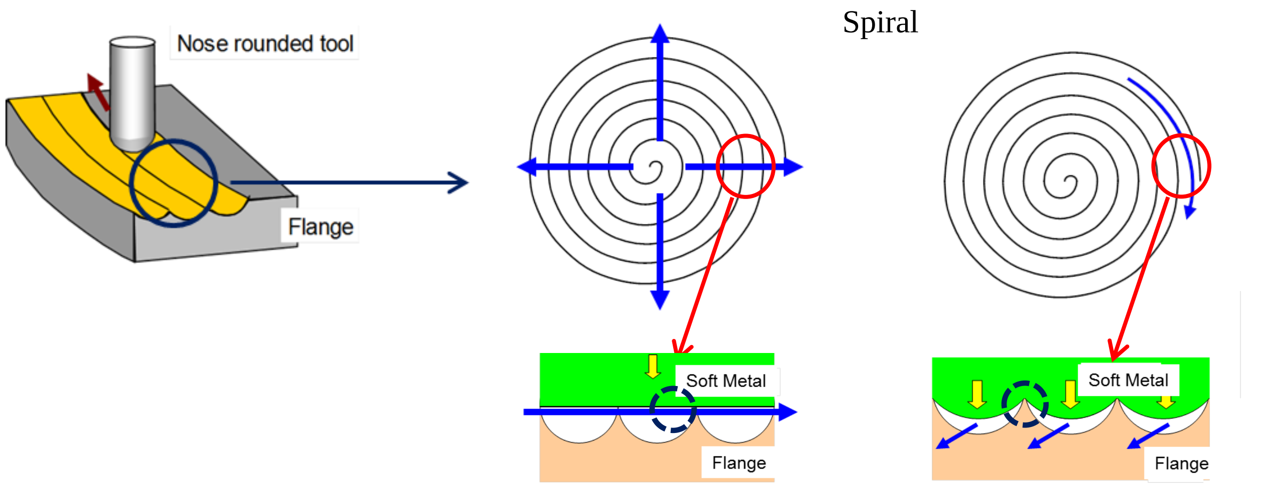


Figure 1 Conceptual diagram of the equation

As shown by equation (1), the leak rate Qr is affected more by the gap than by the inner and outer diameters and the seal width. The gap is attributable to the irregularity of the flange or the surface roughness. Therefore, the gap is reduced by decreasing the surface roughness and the leak rate is reduced [1].

The following, we describe the seal mechanism of serrated flange. The serration process is a lathing process that uses a lathe with a nose round tool. The surface of the flange is mainly made the groove of the spiral. As described in the previous report [1], a leak occurs in the radial direction vertical to the groove on the surface of a flange with a concentric serration groove and in two directions on the surface of a flange with a spiral serration groove: the radial direction and the circumferential direction along the serration groove (Figure 2).

The gasket engages into the edge of the serration groove in the flange due to the contact pressure on the gasket generated by the tightening of the flange. At a low contact pressure in the initial stage of the tightening process, the engagement of the gasket at the edge of the serration groove is weak and the leak rate in the radial direction from the gap between the edge of the groove and the gasket is high and dominates the total leak rate. At a larger angle of the edge of the serration groove in the flange, the engagement is weaker and the leak rate is higher.



Leakage in the radial direction   Leakage in the circumferential direction

Figure 2 Leak direction

At a higher contact pressure, the engagement of the gasket in the edge of the serration groove is stronger and the leak rate in the radial direction from the gap between the edge of the groove and the gasket is lower. A leak starts to occur in the circumferential direction along the serration groove, and the total leak rate becomes dominated by the leak rate in the circumferential direction. According to Nitta and Matsuzaki et al. [3], the leak rate Qc in the circumferential direction is given by the following equation (Figure 3).

$$Qc = W\varepsilon^3 (P_1^2 - P_0^2) / (24\eta L)$$
$$= W^2\varepsilon^3 (P_1^2 - P_0^2) / (24\eta\pi(w+2r_i)) \qquad (2)$$

Qc: Leak rate in the circumferential direction (Pa m^3/sec)

ε: Height of leak channel (groove height) (m)

W: Width of leak channel (groove pitch) (m)

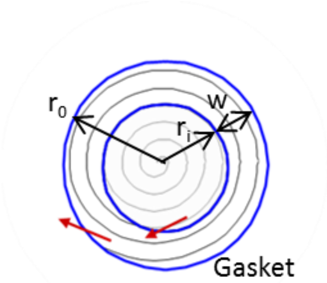
L: Length of leak channel (m)

$L = (r_o+r_i)(r_o-r_i)\pi / W$

$= w\pi(w+2r_i) / W$

w : Seal width (m)

$w = r_o - r_i$



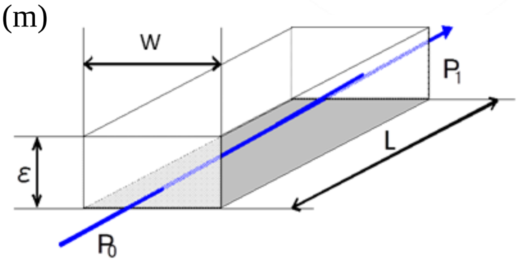


Figure 3 Conceptual diagram of the equation

Equation (2) shows that the leak rate Qc is affected more by the height and width of the flow path than by the inner and outer diameters and the seal width. At a higher contact pressure, the gasket engages into the groove that provides a flow path in the circumferential direction. As a result, the height of the flow path decreases and the leak rate is reduced.

Experiment

As in the previous test [1], a metal sheet to represent the gasket was placed on a serrated or precision-polished platen and a compression ring was placed on the platen. The sheet was then compressed with a given load and the leak rate was measured. At this time, the compression ring is the area of the seal surface. Figure 4 shows the test equipment.

Test equipment: Test press
Test specimen (flat metal sheet): Aluminum (0.5 mm in thickness)
Platen (flange): Stainless steel
Detector: Helium leak detector INFICON UL-200
Tracer gas: Helium (Atmospheric pressure)
Vacuum pressure: Max 0.1 Pa
Temperature: Room temperature
Leakage criteria: Max 10^{-10} Pa m^3/s
Sealable contact pressure: Calculated from the result of load under the leakage criteria.
Calculation formula was the following.

$$\sigma = W / (\pi \cdot w(D_0 - w))$$

$$Y = W / (\pi (D_0 - w))$$

σ: Contact pressure (N/mm^2)
Y: Line load (N/mm)
W: Load (N)
w: Width of compression ring
D_0: Outer diameter of compression ring

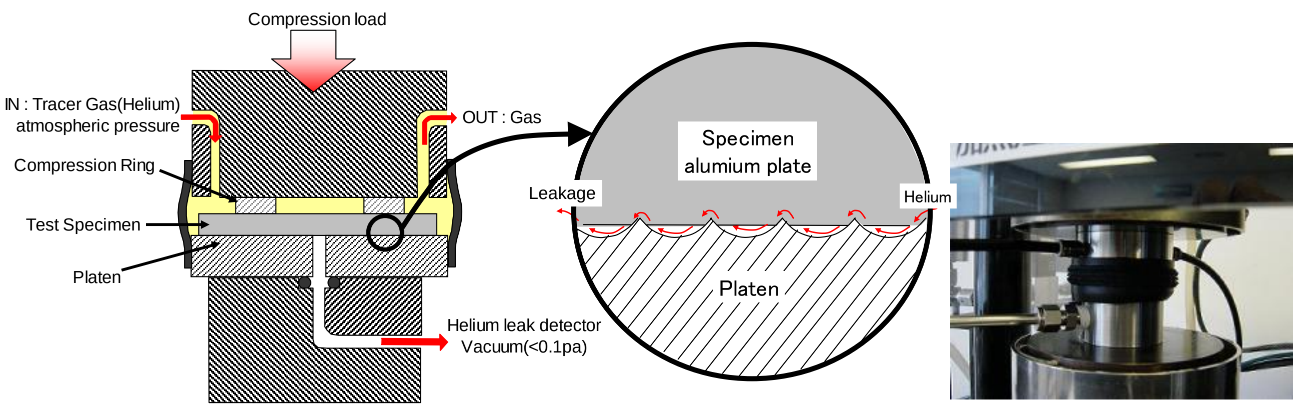


Figure 4 Outline of test equipment

Test conditions

[Condition 1: Surface finish (Precision Polishing)]

The following conditions were used to obtain a relationship between the precision polishing (surface roughness) and the leak rate.

Compression ring: 40 mm in outer diameter, 2 mm in width (seal width)

Platen surface: Precision polishing, surface roughness of Ra 0.12μm, 0.03μm, 0.003μm

[Condition 2: The shape of serration groove]

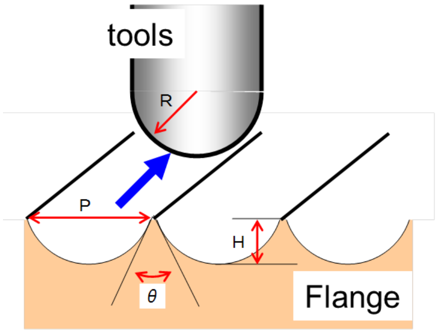
The following conditions were used to obtain a relationship between the shape (pitch, height, angle) of the serration groove and the leak rate.

Compression ring: 40 mm in outer diameter, 2 mm in width (seal width)

Platen surface: Spiral serrations (Conditions of spiral serrations are shown in Table 1 and Figure 5)

Table 1 Conditions of spiral serrations

Processing Condition		Serration Groove (Calculated value)		Flange (measured value)
Nose R Rmm	Pitch Pmm	Height Hμm	Angle θ°	Roughness Ra μm
0.2	0.089	5.0	154.5	1.5
0.2	0.194	23.5	123.9	7.1
0.2	0.265	43.9	102.6	13.3
0.4	0.125	4.9	162.1	2.4
0.4	0.265	21.9	141.9	6.8
0.4	0.395	48.8	122.8	14.1
2.0	0.283	5.0	171.9	1.4
2.0	0.630	24.8	161.9	6.1
2.0	0.889	49.4	154.5	12.5



$H = R - (R^2 - P^2/4)^{1/2}$

$\theta = 2(90° - \delta)$

$\delta = \arccos(1 - H/R)$

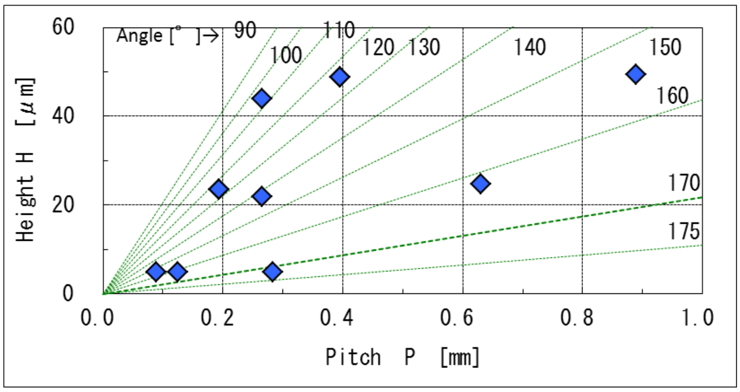


Figure 5 Conditions of spiral serrations

[Condition 3: The deviation of the position from the center of serration]

The following conditions were used to obtain a relationship between the deviation of the position of the gasket and the leak rate.

Compression ring: 100 mm in outer diameter, 1 mm, 2 mm in width (seal width)

Platen surface: Spiral serrations, R = 0.4mm, P = 0.15mm, H = 7.0μm, θ = 158.4°

Test procedure

Leak test was conducted according to the following method to identify "Sealable contact pressure".

1) Test specimen (metal sheet) was put on the lower platen.
2) Compression ring was put on the test specimen.
3) Compression ring was compressed with the upper platen until the contact pressure was 20 N/mm^2.
4) Helium gas was injected outside of the test specimen and the platen. Helium leak detector then detected the gas passing through the gap between the test specimen and the platen.
5) Leak rate was measured every 10N/mm^2 until the leak rate was under the leakage criteria (10^{-10} Pa m^3/s). Sealable contact pressure is determined by calculating the contact pressure of the leakage criteria linearly approximating the logarithm of the leakage rate and the contact pressure.

Result & Discussion

Surface finish (Precision Polishing): Condition 1

Figure 6 shows the measurement results of the sealable contact pressure that provides a leak rate of less than or equal to 10^{-10} Pa m^3/s for different levels of surface roughness obtained by precision polishing.

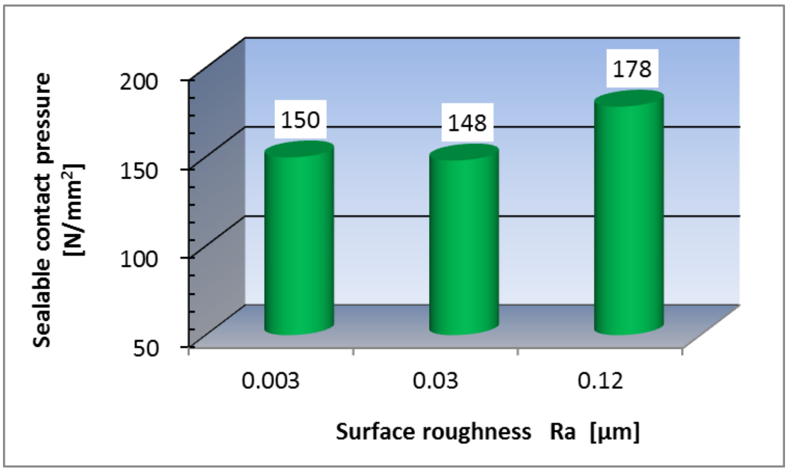


Figure 6 Sealable contact pressure of precision polishing

Figure 6 showed that even if a very low surface roughness of Ra 0.003 μm is obtained by precision polishing, the sealable contact pressure that provides a leak rate of less than or equal to 10^{-10} Pa m^3/s is as high as 150N/mm^2 (the linear load: 299 N/mm) and the precision polishing of a flange is not effective for metal gaskets such as aluminum gaskets.

The shape of serration groove: Condition 2:

Table 2 and Figure 7 show the measurement results of the sealable contact pressure (at 10^{-10} Pa m^3/s) for different shapes (pitch, height, angle) of serration grooves.

Table 2 Sealable contact pressure

Processing Condition		Serration Groove		Flange	Sealability (at 10^{-10} Pa m^3/s)	
Nose R R mm	Pitch P mm	Height H μm	Angle θ °	Roughness Ra μm	Contact pressure N/mm^2	Line load N/mm
0.2	0.089	5.0	154.5	1.5	44.4	88.8
0.2	0.194	23.5	123.9	7.1	86.0	172.1
0.2	0.194	23.5	123.9	7.1	97.7	195.5
0.2	0.265	43.9	102.6	13.3	96.7	193.5
0.4	0.125	4.9	162.1	2.4	85.0	170.0
0.4	0.265	21.9	141.9	6.8	93.5	187.0
0.4	0.395	48.8	122.8	14.1	114.2	228.3
0.4	0.395	48.8	122.8	14.1	95.5	191.1
2.0	0.283	5.0	171.9	1.4	91.5	183.0
2.0	0.630	24.8	161.9	6.1	85.1	170.2
2.0	0.889	49.4	154.5	12.5	112.1	224.3

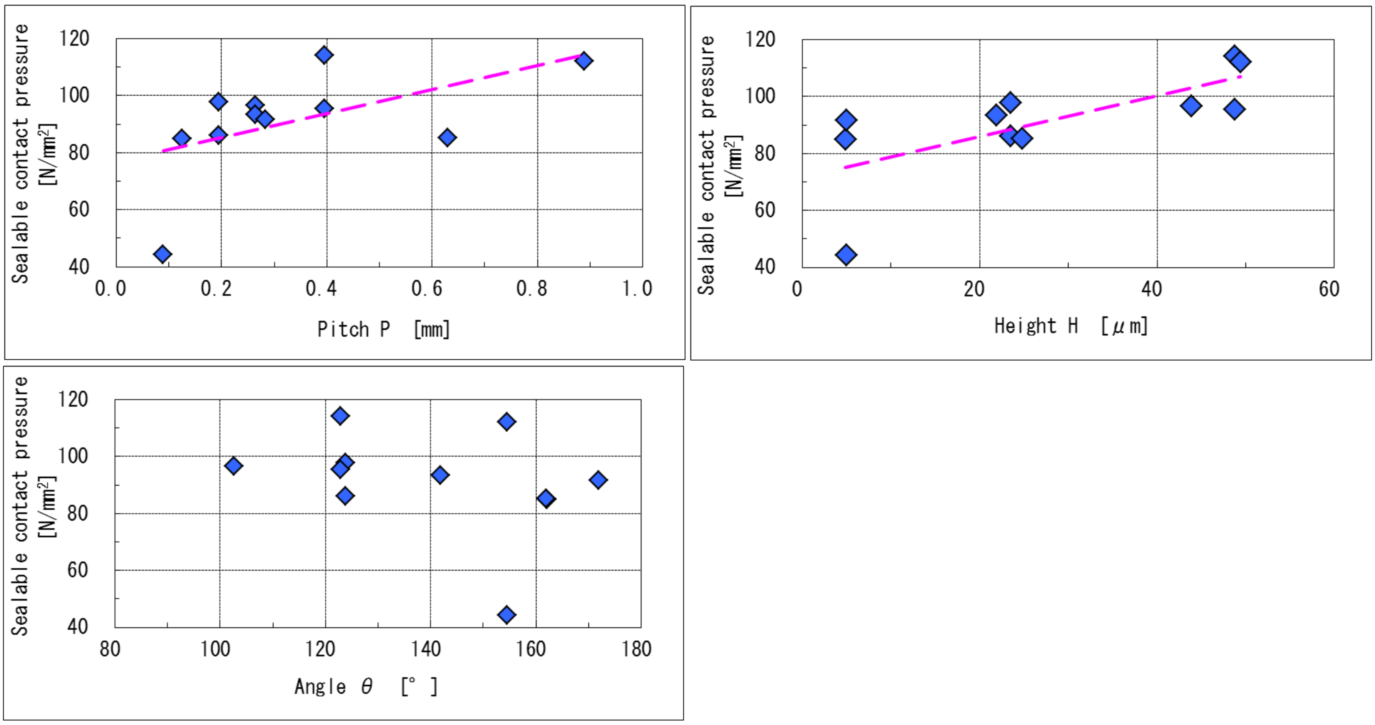


Figure 7 Sealable contact pressure and pitch, height, angle of serration grooves

Figure 7 shows that the sealable contact pressure is lower for a smaller pitch of the serration groove and for a smaller height of the serration groove and is hardly affected by the angle θ of the edge of the groove. Here, in the equation (2), the width of the leak channel becomes the pitch of the serration groove, and the height of the leak channel becomes the height of the serration groove. Therefore, the leak rate is lower is lower for a smaller pitch of the serration groove and for a smaller height of the serration groove, it considers that the sealable contact pressure is lower.

In the flange of the serration groove, in order to make the leak rate to 10^{-10} Pa m^3/s or less at a lower contact pressure than the flange of precision polishing finish it may be the pitch of the serration groove to 0.3mm or less, and the height of the serration groove to 25 μm or less.

When, the surface of a serrated flange is polished after being used a few times, the tip of the edge of the serration groove is cut off by polishing and the height of the edge of the serration groove is decreased, resulting in a lower level of surface roughness. Since the tip of the edge of the groove becomes polishing surface of flat or round, the engagement of the gasket at the edge of the groove is weaker than before polishing and the leak rate in the radial direction from the gap between the edge of the groove and the gasket is higher than before polishing. Thus, the leak rate may increase even if the level of surface roughness is reduced by polishing and therefore precautions are required in polishing a serrated flange.

The deviation of the position from the center of serration: Condition 3

If the leak in the circumferential direction is the dominant mode of leakage and the gasket is located off the center of the serration groove in the flange, as shown in Figure 8, the leak path in the circumferential direction will be cut off and the flow path will be extremely short, resulting in an increase in the leak rate.

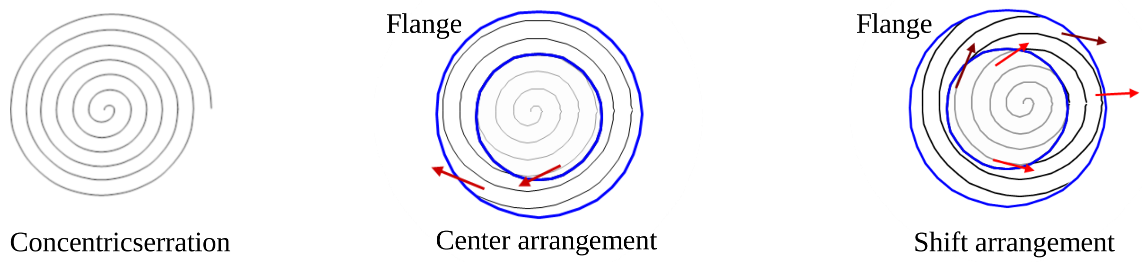


Figure 8 The deviation of the position from the center of serration

The sealable contact pressure (at 10^{-10} Pa m^3/s) was then obtained for a gasket located off the center of the serration. Figure 9 shows the measurement results of the sealable contact pressure.

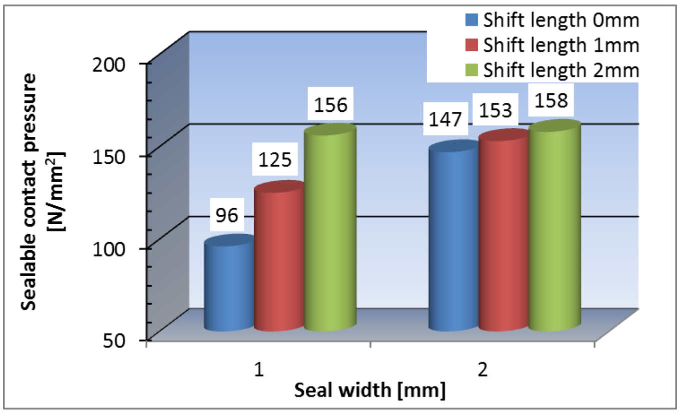


Figure 9 Sealable contact pressure of the deviation of the position

Figure 9 shows that the sealable contact pressure is higher for a larger deviation of the position of the gasket from the center of the serration. Particularly for a narrow seal width, the sealable contact pressure increases with the larger deviation of the position of the gasket. Therefore, if, as with a metal gasket such as an aluminum gasket, the seal width is narrow, it is important to put measures in place to prevent deviation of the position of the gasket.

Conclusions

this study showed that even if the flange is precision polished to a very low surface roughness of Ra 0.003 μm, the sealable contact pressure that provides a leak rate of less than or equal to 10^{-10} Pa m^3/s is as high as 150N/mm^2 (the linear load: 299 N/mm) and the precision polishing of a flange is not effective for metal gaskets such as aluminum gaskets.

For a small gasket, in the flange of the serration groove, in order to make the leak rate to 10^{-10} Pa m^3/s or less at a lower contact pressure than the flange of precision polishing finish it may be the pitch of the serration groove to 0.3mm or less, and the height of the serration groove to 25 μm or less.

In addition, this study showed that the sealable contact pressure is higher for a larger deviation of the position of the gasket from the center of the serration, and that particularly for a narrow seal width, the sealable contact pressure increases with the larger deviation of the position of the gasket.

References

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[3] I.Nitta, Y.Matsuzaki, "Experimental Study of the Performance of Static Seals Based on Measurements of Real Contact Area Using Thin Polycarbonate Films", ASME J Tribology, Vol132 (APRIL 2010).