Design and Application of Spiral Wound Gasket Sealing for Big Opening Flange for High Temperature and Pressure Vessel

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Abstract. Metallic spiral-wound gasket sealing are generally applicable for the service conditions, which are subject to the periodic temperature and pressure changes, shocks or vibrations. The nominal size of the largest spiral wound gasket of flanges is according to the provisions of HG/T 20631; those more than this specification are in the scope of non-standard parts, which require customization and manufacturing. This paper aims for introducing the successful experience of the first application of customized for non-standard spiral-wound gasket sealing of large opening flange used for pressure vessel which bears high temperature and high pressure. The paper demonstrated the basic principle and critical points for the design and application of customized non-standard spiral-wound gasket sealing for the large opening flange and provided the valuable reference of actual application experience for the design and manufacturing of similar components. This paper presents the experiences summary in the study field and provides valuable reference of actual application experience for the design and manufacturing of similar components.

Keywords. High Temperature and High Pressure Vessel; Big Opening Flange; Spiral Wound Gasket; Design Application.

1. Introduction
Metallic spiral-wound gasket sealing are generally applicable for the service conditions, which are subject to the periodic temperature and pressure changes, shocks or vibrations. It works as the static sealing element at the flange connections of pump valves, heat exchangers, manholes and hand holes of pressure vessels. The gaskets are widely used in the industrial fields such as the petrochemical, mechanical, power, metallurgical, shipbuilding, pharmaceutical, health, atomic energy and aerospace industries etc. [1].

The nominal size of largest spiral wound gasket of flanges used for high temperature and high pressure vessels is DN300 (NPS12) corresponding to the pressure level of Class2500 (PN420) according to the provisions of HG/T 20631; those more than this specification are in the scope of non-standard parts, which requires customized and manufacturing.

Several research works have been carried out in this paper to report the critical points to the design and precautions to the manufacturing of spiral-wound gasket sealing of large opening flanges used for high temperature and pressure vessels by taking the successful first application of spiral-wound gasket sealing of large opening flanges during the construction of five units of hydrogenation reactors designed and fabricated independently for overseas customers as the research subject, which was in
form of metallic ring joint gasket sealing in the past. It is an experience summary in this field and provides valuable reference for the design and manufacturing of similar products.

2. Basic Principles of Spiral-Wound Gasket Sealing

2.1. Basic Principle
The basic principle of spiral-wound gasket sealing is given as follows: the gasket is secured between the flange pairs by means of the pre-tightening force of the bolts in order to generated sufficient pressure (sealing specific pressure) between the gasket and the flange sealing surface to achieve the deformation of the spiral-wound gasket surface, where the packing material is sufficient to fill up the microscopic uneven clearance between the flange and the spiral-wound gasket for sealing purpose.

After service operation for a period of time, the flanges, spiral-wound gaskets, bolts and nuts and other parts will experience aging relaxation, and the sealing pressure generated at this moment has to be higher than the operational pressure, which may ensure the sealing [2], free of any leakage.

2.2. Design Load Condition
The spiral-wound strip material: stainless steel 321; the inner and outer ring material: stainless steel 321; packing material: flexible graphite strip (graphite purity above 98%).

- Design pressure: P=21.85 MPa;
- Design temperature: 450 °C;
- Medium: Oil, oil/gas+H_2, H_2S.
- Hydrostatic test pressure: 1.25P Sm/P Sm t.
- Test temperature: Ambient temperature; Medium: Water.
- Sm- Design stress intensity of vessel component parts at test temperature;
- Smt- Design stress intensity of vessel component parts at design temperature.

3. Critical Points to the Design
The design of flange and gasket in the Code are based on the minimum specific pressure y for pre-tightening and value of gasket coefficient m as specified in the ASME Boiler Pressure Vessel Code. The specific pressure y and the gasket coefficient m are parameters related only to the form and material properties of the gasket. The flange gasket designed according to these rules may guarantee the reliability of the flange connection, but its sealing performance is uncertain [3].

Some researcher also reported that the permissible leakage rate may be applied as one of the design parameters [4].

3.1. Determination of Structure
The structure is determined with reference to ASME B16.20a, which mainly includes the determination of the diameter and width of the gasket.

Generally speaking, the larger the diameter of the gasket, the higher the leakage rate [4]. It is easy to achieve the initial sealing for the widened spiral-wound gaskets, but it could make gasket performance unstable if gaskets are excessively wide, which causes the sensitive changes of gasket stress during the operation period [5]. It may increase the sealing surface area and achieve better sealing performance by widening the gasket, but only if flange and bolts have sufficient strength as the premise [2].

When metallic spiral- wound gasket is used for flange sealing, the inner ring and the positioning ring may be applied additionally according to the flange form [2].

The overall structure of the spiral-wound gasket of Ø762mm (ID30inch) after the overlaying of inner diameter of flange in this project is given based on the comprehensive consideration and calculation, as shown in Figure 1, in which the width of the gasket is 60-75mm.
3.2. Calculation of Pre-Tightening Force of Bolts

It is crucial that the calculation and determination of bolt pre-tightening force is the key design factor to ensure the sealing reliability. It may improve the sealing performance of the metallic spiral-wound gasket with graphite material for flange connection by means of improving the gasket performance, increasing the size of flange bolts and increasing the pre-tightening force [4].

However, it doesn’t mean that the pre-tightening force of bolts should be as high as possible, which is because that first of all it is not necessary, and secondly, it will bring negative effects. The ideal compression rate of the sealing strip is 18%~30%, and the rebound rate after compression is preferred to be greater than 15%. If the bolt pre-tightening force is too high and exceeds the design compression rate of the spiral-wound gasket, it will cause that the internal pressure of the sealing strip is excessively high, which may result in a decrease in the rebound rate of the gasket and even failure of the sealing strip material. When it reaches the deformation of the flange, the outer ring becomes the force bearing point, and the gap of the sealing strip will increase, which directly leads to the leakage of the sealing [2].

If the bolt pre-tightening force is too high, it will cause that the flange has a large turning angle which results in a big separation of flange. It will bring adverse effect to the sealing [6].

The bolt pre-tightening force is calculated according to the ASME code appendix.

The minimum pre-tightening force of an individual bolt of the flange is calculated as follows:

\[
\frac{Am \times Sb}{n}
\]  

(1)

The maximum pre-tightening force of an individual bolt is determined as follows:

\[
\frac{Ab + Am}{2n} \times Sa
\]  

\[
0.8 \times \frac{Ab \times Sa}{n}
\]  

(2)

\[
(3)
\]

- **Am** - The total area of bolt cross-section required according to the equation calculation
- **Ab** - The total area of cross-section of the smallest diameter of actual bolts
- **Sa** - The permissive stress of bolt material (at room temperature)
- **Sb** - The permissive stress of bolt material at design temperature
- **n** - The number of bolts

The maximum pre-tightening force of bolts may take the minimum value of the calculation results of equation (2) and (3). According to engineering experience, if the calculation result of equation (2) is less than or equal to that of equation (3), some result may multiply by a coefficient of 0.7, and some may multiply by a coefficient of 0.9.

The principle to determine the maximum pre-tightening force is given as follows, the first is that it can’t exceed the elasticity range of the bolt material, and the other is that it can’t cause the gasket crushed during pre-tightening process. As the calculation of the above-mentioned maximum pre-tightening force is very conservative, hence, it is not necessary to multiply the safety coefficient.

Bolt pre-tightening force will be subject to “relaxation” after thermal load cycle. The higher the pre-tightening force is, the larger the relaxation occurs; in the same time, the pre-tightening force is
too high, which results in a large initial turning angle of flange, and the bolt load will be increased as well. Neither of them may bring high sealing performance. In some papers, it is reported that the pre-tightening coefficient is preferred to be approximately 1.3[6].

In general bolt pre-tightening condition, bolts are pre-tightened in the symmetrical direction step-by-step, which may reach a maximum of 110% of the pre-tightening force.

In summary, it is recommended that the cross-sectional margin for design and calculation of bolt may be limited to 17%~20%.

4. Formatting the Text

4.1. Manufacturing Requirements to Spiral-Wound Gaskets

The manufacturing requirements of gaskets have to with reference to the provisions of ASME B16.20a, but there are specific requirements for such non-standard gaskets.

4.1.1. Structure. The spiral-wound gasket has to be made from the continuous wound pre-formed SU-shaped 321 metallic strips and flat graphite strips interlaced with alternative overlapping. For the manufactured gasket, the contact surfaces of packing material and the metallic wound strips on gaskets should be basically flushed even and not lower than the metal surface. The thickness of the metallic wound strip is 0.006~0.009in.

4.1.2. Connection of Metal. The inner wound strips are provided with at least three layers of pre-formed metal strips without packing materials. The first two layers have to be secured with tack welding at least three places along the circumference with a maximum spacing of 3in. There are also be at least three layers of pre-formed metal strips without packing materials on the outer layer of wound strips, and secured with at least three tack welds along the circumference, and the last welding point is the final welding joint. The distance from the final welding joint to the previous one shall not be more than 1.5in., and four laps of loosened pre-formed metal wound strips can be used to hold the gasket in the outer ring after the final welding joint.

4.1.3. Outer Ring. All wound gaskets have been fitted into the outer ring, and the inner side is provided with suitable grooves to hold the gasket.

4.1.4. Tolerance. The tolerance of inner and outer diameter of the gasket is ±0.06 in.; the tolerance of inner diameter of the inner ring is ±0.06 in.

4.1.5. Gasket Compression. The gasket thickness will be compressed to 0.130±0.005 in with a uniform bolt pressure of 30000psi.

4.2. Requirements of Flange Sealing Surface

4.2.1. Requirements of Flange Sealing Surface Roughness. The surface roughness of the flange sealing surface sealed with spiral wound gaskets is Ra=3.2 μm~6.3 μm according to the standard requirements. While it is also reported in some papers that the roughness of the sealing surface is preferred to be Ra<3.2μm with air-sealing, and Ra<12.5μm with liquid-sealing [2].

In actual practice, is proven that the roughness of the flange sealing surface is preferred not to be too high, and it is recommended to not exceed Ra=6.3μm. As shown in figure 2, when the roughness is suitable for flange sealing surface, it will form the multiple meshing surfaces in the microscopic view, which may reduce the possibility of leakage. Otherwise, it may increase the risk of leakage in case of excessive smooth flange sealing surface in the microscopic view as shown in figure 3.
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4.2.2. Directional Requirements for Flange Sealing Surface Machining and Polishing. The initial machining tool marks of the flange sealing surface have to be the concentric circle along the circumference. During the service, the sealing surface has to be polished in the circumferential direction after replacing the gasket. Polishing in the radial direction is prohibited. The purpose is to reduce the leakage risk and improve the sealing reliability, which principle is shown in figure 4. The circumferential grooves may form a staggered meshing with the gasket in microscopic view, which improves the reliability of sealing. If polishing is performed in the radial direction, the radial grooves may increase the risk of leakage microscopically, as shown in figure 5.
5. Conclusion
There is no specific provision for the spiral-wound gasket of large opening flanges used for high temperature and high pressure vessels in the Code or standard, which requires the tailor-made design and manufacturing.

This paper aims for introducing the successful experience of the first application of tailor-made non-standard spiral-wound gasket sealing of the large opening flange used for pressure vessel which bears high temperature and high pressure and demonstrates the basic principle and critical points for the design and application of non-standard spiral-wound gasket sealing for the large opening flange, details as follows:

- The determination of the maximum pre-tightening force does not need to be too conservative, and the cross-sectional margin of the bolt may be limited to 17%-20%;
- Determination of manufacturing tolerances and compression test;
- The roughness of the flange sealing surface should not exceed Ra6.3;
- Machining and polishing marks of flange sealing surface has to be concentric circles along the circumferential direction and the radial direction is prohibited.

This paper presents the experiences summary in the study field and provides valuable reference of actual application experience for the design and manufacturing of similar components. It may be promoted in the spiral-wound gaskets used for nuclear power applications.

References
[1] Nelson N R 2021 Effective modeling of spiral wound gasket with graphite filler in gasketed flange joint subjected to bending loads Materials Today: Proceedings 44 2199-2204.
[2] Wang J 2016 Several misunderstandings of wound gasket sealing in industrial applications Industrial Technology: China’s New Technology and New Products 01 (Part 1).
[3] Fan Y G 2003 Analysis of the sealing performance of the flanged joint of metal flexible graphite gaskets Journal of Dqing Petroleum Institute 27(2) 65-67.
[4] Li Y Q 1994 Design of seal system of wound gaskets of flanges bolts and flexible graphite Chemical Engineering and Machinery 21(4) 225-228.
[5] Gao Z B, et al. 1985 Sealing performance test of expanded graphite spiral wound gasket at room temperature Petrochemical Equipment.
[6] Diao W T and Quan H Q 1991 Expansive-graphite-sandwichedspiral-wound Stainless Steel Gasket Applied to Manhole Sealing Joints of Nuclear Equipment CNIC-00504 RINPO-0008.