Appropriate Tightening Method of Gaskets

1. Introduction

Appropriate maintenance of high pressure vessels is indispensable for safe operation of the plant. The fluids handled may have flammable, flammable, explosive, toxic, and other properties so leaks can lead to disasters and accidents. Therefore, plant operators are conducting daily management to ensure appropriate tightening of the numerous flange tightening sites within the plant.

However, the current situation is that the number of harmful accidents caused by flange tightening has not decreased. Table1 and Figure1 show the analysis of high-pressure gas accidents in Japan. As these statistics indicate, the total number of accidents due to poor maintenance of facilities is not showing a decreasing trend, and about 30% of that constituent factor is due to “flange tightening causes”. Therefore, appropriate flange tightening is one of the major issues for the safe operation of a plant.

To increase the skills and knowledge related to flange tightening, establishing standards regarding gasket fitting represented by ASME PCC-1[1)] and training programs for gasket tightening tasks like the Seal Training Center are gathering attention.

This report will introduce a summary of items that require careful attention for gasket tightening based on trouble caused by flange tightening.

Table1 No. of cases of accidents due to poor maintenance of facilities

Year	Insufficient corrosion control	Flange tightening causes	Test control failure	Inspection failure	Vessel control failure	Total
2020	104	72	22	37	14	249
2019	155	84	13	35	10	297
2018	124	99	19	35	13	290
2017	113	97	29	30	8	277
2016	109	109	20	42	10	290
2015	93	60	31	17	21	222
2014	78	55	19	11	16	179
2013	80	56	28	16	20	200
2012	65	59	65	8	11	208
2011	67	66	66	8	20	227

Source: METI “Summary of High Pressure Related Accidents”

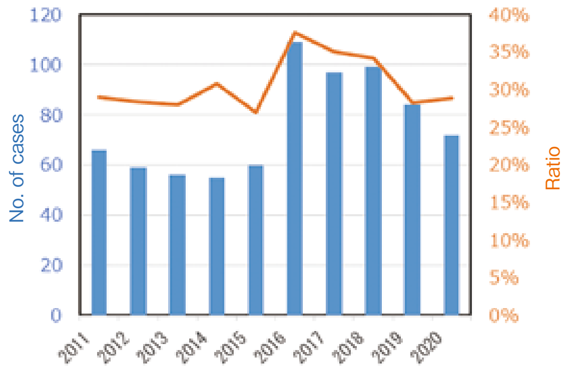

Figure1 No. of cases and ratio of flange tightening related accidents

2. Troubles related to gasket tightening

Analysis of the cause of trouble that occurred in actual gasket work cases found that the major causes were insufficient tightening, excessive tightening, and uneven tightening.

Insufficient tightening is the state where the appropriate surface pressure is not on the entire gasket. It is common in flat face flanges or when flange or bolt strength is insufficient. In addition, a decrease in gasket surface pressure due to stress relaxation may lead to leakage and damage due to the gasket being unable to resist internal pressure and being pushed out by the fluid (blow out). Figure2 shows the external appearance of a blowout gasket.

Conversely, gasket destruction may occur if gaskets are tightened excessively. This is especially common in fluorocarbon resin envelope gaskets. As shown in

Figure3, many circumferential cracks are generated and destroyed, leading to leakage.

Uneven t tightening refers to a state in which the gasket surface pressure becomes uneven. If sections of the gasket are insufficiently tightened or excessively tightened, this causes partial leakage, ruptures, and deformities. Figure4 shows uneven tightening. In this case, tightening strength was low in some sections, and friction between the flange and gasket decreased, causing leakage by being pushed out with internal pressure.

These failures are all caused by Inappropriate tightening and highlight the importance of tightening management. Therefore, we will introduce basic tightening procedures and control methods to conduct appropriate tightening tasks.

Figure2 Case of gasket blowout due to insufficient tightening

Figure3 Case of compression failure due to excessive tightening

Figure4 Case of deformity due to uneven tightening (insufficient tightening in a section)

3. Standards for the tightening procedures

In general, multiple bolts of pipe flanges are tightened, but the tightening task is normally conducted one-by-one. The axial force of a bolt of the tightened flanges changes upon the tightening of other bolts, and the axial force decreases in many cases. This phenomenon is called elastic interaction. The effect of elastic interaction is minimized by repeated multiple tightening to adjust the target bolt tightening load.

ASME PCC-1[1)] and JIS B 2251[2)] are introduced as standards that show multiple tightening procedures. ASME PCC-1[1)] and JIS B 2251[2)] standards perform diagonal tightening after circular tightening. Diagonal tightening effectively prevents uneven tightening of the gasket by increasing the tightening torque in stages. Tightening in a circular pattern reduces the inconsistent tightening load due to elastic interactions in adjacent bolts.

Table2 compares ASME PCC-1[1)] and JIS B 2251[2)]. JIS B 2251 is a standard that enables even more efficient and accurate tightening than the ASME PCC-1[1)] established earlier. In ASME, all bolts are tightened during diagonal tightening, but in JIS, only 4 to 8 bolts are tightened. It is more efficient when the number of bolts is large. Regarding the circular tightening at the target torque, ASME is until the nut stops rotating, but JIS sets an upper limit on the number of times. Furthermore, setting in JIS the target torque to 110% when the number of bolts is 12 or more is also a technique for quickly achieving the target bolt axial force. The JIS B 2251's applicable range is joint sheet gaskets and spiral

Table2 Tightening procedures in JIS B 2251 and ASME PCC-1

<table>
<tr><th colspan="2">JIS B 2251</th><th colspan="2">ASME PCC-1</th></tr>
<tr><th>Stages</th><th>Procedures</th><th>Stages</th><th>Procedures</th></tr>
<tr><td>Preliminary tightening</td><td>Only 4 or 8 target bolts
Stage-wise, diagonal tightening</td><td>Preliminary tightening</td><td>All bolts
Snag torque (≤20%)</td></tr>
<tr><td rowspan="2">Main tightening</td><td rowspan="2">All bolts tightened in a circular pattern 100%
Target torque is 110% for over 12 bolts
No. of times going around: 4 to 6 cycles</td><td>Rounds 1 to 3</td><td>All bolts are tightened in a step-wise diagonal pattern</td></tr>
<tr><td>Round 4</td><td>All bolts tightened in a circular pattern 100%
(Until the nut does not rotate)</td></tr>
<tr><td>Additional tightening</td><td>After 4 hours passes, same of tightening as the main tightening
No. of times going around: 1 to 2 cycles</td><td>Round 5</td><td>After 4 hours passes, same tightening as Round 4</td></tr>
</table>

Snag torque: Necessary torque to firmly attach the bolt seating surface wound gaskets. However, our in-house experimental results confirmed that this is also applicable for High Performance Non-asbestos Sheet by No.GF300 and fluorocarbon resin sheet gaskets.

4. Tightening control method

Quantitative tightening management methods for gaskets include a torque method, a rotation angle method, a torque gradient method, an axial force management method using an ultrasonic axial force meter, and a bolt tensioner. Each method has advantages and disadvantages, and it is necessary to select a method by comprehensively determining the balance among workability, construction accuracy, etc. Table3 shows a comparison of various control methods.

JIS B 1083 Rules for Bolt Tightening[3] proposes the torque method, rotation angle method, and torque gradient method. The torque method only controls tightening torque using a torque wrench. It is used widely as a simple and conventional control method. However, about 90% of tightening torque is consumed by the friction of the bolt face and seating, and therefore, variation is likely to occur depending on the frictional properties of each material.

The rotation angle method is a method that controls the rotation angle of the bolt by tightening. When tightening at the elastic region of bolts, the variation becomes more significant if the rigidity of the bolts is high. Conversely, when tightening at the plastic region, it is less likely to be affected by rotation angle error. Still, there is an issue that bolts become plastically deformed and cannot be reused.

The torque gradient method uses the tightening rotation angle and tightening torque gradient as tightening indicators, and the yield load of bolts is the target value. It is used to keep the variation in initial tightening small and maximally utilize the elastic region of the bolt. As with the rotation angle method of the plastic region, it is necessary to take care not to exceed the yield point and proof load.

Axial force control of the bolt is possible with high-precision tightening control because it is not affected by friction with the seating, and axial force of the bolt is controlled using devices such as ultrasonic axial force meters and bolt tensioners.

Ultrasonic axial force meters are a method that measures the length of the bolt and obtains the axial force from the difference in bolt length before and after tightening. It is applicable only in the elastic region where the axial force and bolt elongation are in a proportional relationship. The method has high precision, and the measurement itself is simple, but it is necessary to keep the surfaces of both ends of the bolt smooth.

Bolt tensioners are a method that pulls the bolt with hydraulic pressure until the pre-designated target axial force. The nut is tightened, and the hydraulic pressure is released to give the designated axial force. Extra bolt length and space are required for attaching the bolt tensioner. Both ultrasonic axial force meter and bolt tensioner have high precision but require time and cost. They are often used in important sections such as high-pressure pipes and large diameter flanges.

For non-quantitative tightening, hand wrenches are used for small diameter flanges, and impact wrenches are used for large diameter flanges. However, experience is required for even tightening because variation is high, and it isn't easy to control tightening strength.

As a sealing manufacturer, we recommend the quantitative tightening control methods shown in Table3.

Table3 Quantitative tightening control method

Tightening control method	Tightening indicator	Tightening region
Torque method	Tightening torque	Elastic region
Angle rotation method	Tightening rotation angle	Elastic region Plastic region
Torque gradient method	Tightening torque gradient of tightening rotation angle	Elastic limit
Ultrasonic axial force meter	Bolt elongation	Elastic region
Bolt tensioner	Bolt axial force	Elastic region

5. Effect of tightening procedure on bolt axial force

We will introduce the results evaluating bolt axial force and gap between the flange faces with the tightening methods of ASME PCC-1 and JIS B 2251[4]. Tables4 and

5 show the test methods, Figure5 shows the measurement results of bolt axial force, and Figure6 shows the measurement results between flange faces. Gaskets were spiral wound gaskets (No.6596V) with expanded graphite filler and joint sheet gaskets (No.6500), dimensions are JPI Class 300 24 inch.

Figure5 shows that for No.6596V, the mean value was higher in bolt axial force and the variation was lower. for JIS B 2251 than ASME PCC-1. This is because in JIS B 2251 stipulates that "for spiral wound gasket, perform circular tightening with a tightening torque of 50% after the preliminary tightening," and set the target torque as110%. The gasket width of spiral wound gaskets is narrow, and there is a tendency toward uneven tightening because the compression amount is high. In ASME PCC-1, circular tightening is until the nut does not rotate and as shown in Table5, the number of times of going around is higher for JIS B 2251.

Next, Figure6 shows the gap between flange faces, and as shown in the results for bolt axial force, for No.6596V, the tightening procedures for JIS B 2251 had a smaller gap between faces. In addition, regarding the variation of the gap between flange faces, the tightening procedures for ASME PCC-1 did not show a variation as large as that for bolt axial force.

Table4 Test conditions

Gasket	Spiral wound gasket No.6596V	Joint sheet gasket No.6500
Dimensions	JPI Class300 24inch t4.5	JPI Class300 24inch t3.0
Diameter of flange seat	ϕ692.2	ϕ692.2
Bolt	M39, 24 bolts	M39, 24 bolts
Target gasket face pressure	40MPa	40MPa

Table5 Tightening procedures

	JIS B 2251	ASME PCC-1
Tightening stages until target value	4 stages	3 stages
Tightening procedures	At preliminary tightening: Diagonal tightening At main tightening: Circular tightening	Diagonal tightening Circular tightening
Target bolts	At preliminary tightening: 4 bolts At main tightening: All bolts	All bolts
Total number of stages until completion of tightening	11 stages	8 stages
Notes	Tightening at 110% of target torque	At circular tightening, tightening until nuts do not rotate

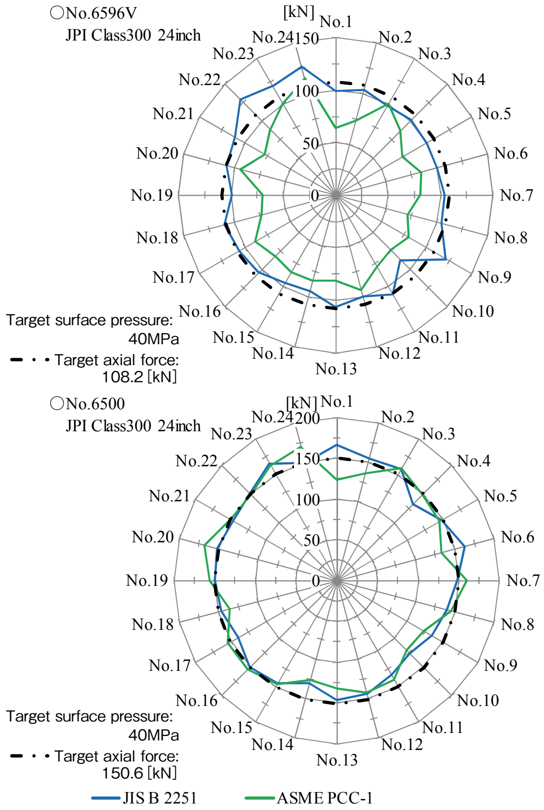

Figure5 Distribution of bolt axial force

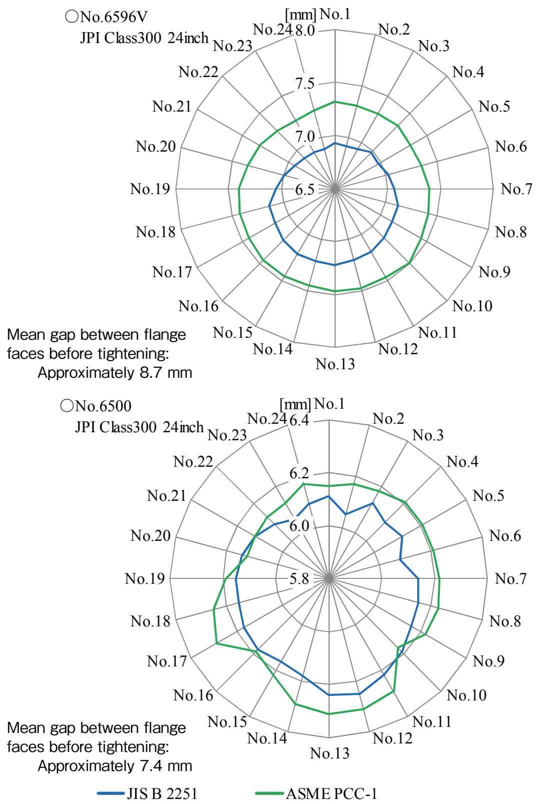

Figure6 Gap between flange faces

6. Conclusions

The equipment of domestic plants is aging, and by 2025, most of the equipment will be in operation for more than 40 years. Therefore, an "increased risk for accident occurrence" and "decreased profitability due to decreased operating rate" is anticipated. This report introduced several cases of gasket trouble, basic procedures for tightening, and methods to control tightening. Our company will continue to provide seal engineering services as a sealing manufacturer and contribute to eradicating accidents due to leakage.

7. Reference

1) ASME PCC-1, Guidelines for pressure boundary bolted flange joint assembly (2010)
2) Japanese Industrial Standards. JIS B 2251 "Flange connection tightening method" (2008)
3) JIS B 1083, Rules for Bolt Tightening (2008)
4) Takahiro Fujiwara, "Effect of tightening procedures on sealing properties", Valqua Technology News Vol. 37 (2019)

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