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Prediction of conditions of flange joints depressurization during the assembly of pipelines using technological and standard fastening elements

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Abstract. This article shows the prediction method of conditions of flange joints depressurization during the assembly of pipelines using technological and standard fasteners.

1. Introduction. Problem statement

Efficiency of solving the problem of reducing the pipelines mass is directly related to the manufacturing process of their assembly, which ensure the load reduction on parts of pipelines. This is significant primarily for space-rocket hardware and aircraft engineering, less for chemical and energy equipment, river craft and sea-borne craft. One of the approaches to the load reduction on flanges, fastening elements and pipes is pressurization of pipeline flange joints using technological and standard fastening elements.

At present it is known three modes of pressurization of pipeline flange joints with using such approach [1-3]. All of them are designed to joints pressurization, which sealed by soft metal gaskets. The possibility of reducing the tightening torque of fastening elements in comparison with standard value [4] is created due to occurrence of flange seal face and gasket firm-and-impervious joint in contact zone [1,5,6]. Reducing of torque and axial forces of standard fastening element tightening allows, in turn, to reduce the flange sizes and use lighter and less durable materials for their manufacture [7,8].

For different modes of pressurization of flange joints correlation between tightening torque of standard and technological fastening elements, in which the joint remains the pressurization, is different. Conducted experiments showed that joints depressurization can primarily occur during the replacement of technological fastening elements with standard fastening elements [9]. In this case, the initial value of the leakage of the air-helium mixture (10% He) is 10^{-12}–10^{-10} W, after the depressurization the leakage was 10^{-1} W and more.

Calculated dependencies for determining the axial forces and the corresponding unscrewing torques which influence on standard fastening elements using pressurization flange joints methods are given in paper [10,11], and this article shows only formulas for determining the axial forces which influence on standard fastening elements.

The method [1] consists in tightening the technological and standard fastening elements, temporary aging and technological fastening elements unscrewing. For this method the axial force which acting on the standard fastening elements determines in following way:

$$Q_{12} = \frac{Q_1 \cdot \lambda_{CP} + Q_1 \cdot \lambda_F}{\lambda_F} \quad (1)$$

here λ_F – compliance of technological and standard fastening elements (technological and standard elements are the same, they are screwing up by the same torque and simultaneously) λ_{CP} – summary compliance of flanges and gaskets; Q_1 – tightening axial force of technological and standard fastening elements; Q_{12} – axial force which influence on standard fastening elements after unscrewing the technological fastening elements.

The method [2] consists in technological fastening elements tightening, temporary aging and consecutive replacement of technological fastening elements with standard fastening elements. For this method the axial force which influence on standard fastening elements determines in following way:

$$Q_{2F} = \frac{Q_1 \cdot \lambda_{CP} + Q_2 \cdot \lambda_{F2} - Q_2 \cdot \lambda_{CP}}{\lambda_{F2}} \quad (2)$$

where Q_1 – tightening axial force of technological fastening elements; Q_2 – tightening axial force of standard fastening; λ_{F2} – compliance of standard fastening elements; Q_{2F} – axial force which influence on standard fastening elements after the replacement of technological fastening elements.

The method [3]consists in technological fastening elements tightening, temporary aging, standard fastening elements tightening and technological fasteners unscrewing. For this method the value of axial force Q_{23}, which influence on the standard fastening elements after unscrewing the technological standard parts, determines by the formula:

$$Q_{23} = \frac{Q_1 \cdot \lambda_{CP} + Q_2 \cdot \lambda_{F2}}{\lambda_{F2}} \quad (3)$$

It should be noted that in papers [10,11] calculations are made with assumption that all technological fastening elements are unscrewing simultaneously and all standard fastening elements are screwing up simultaneously. In spite of such idealization this approach allows to describe accurately the final state of flange joints.

With the view of prediction the joint depressurization this article proposes the determination method of correlation of tightening torques (axial forces) of technological and standard fastening elements in which contact density of flanges seal faces and gaskets (for cases of the most common lock and spherical flange joints of pipelines) are breaking.

2. Basic research material

Papers [9-11] show that axial force which corresponding to unscrewing torque of standard fastening elements exceeds the axial force which corresponding to their tightening torque.

This is due to "extension" of the flanges as a result of decrease of deflecting forces acting on them. It is the "extension" of the flanges that can affect on firm-and-impervious joint with the force Q_R and lead to contact density violation of seal faces and joints depressurization. Obviously in this case the force of "extension" of the flanges comes to difference between the summary tightening axial force of technological and standard fastening elements.

In order to determine whether the force Q_R is sufficient to depressurize the joint it should be considered what kind of the firm-and-impervious joint is in the contact zone of flanges seal face and gaskets in spherical and lock joints.

Area over which Q_R acts, in contact zone of spherical surface comes to calculated area of spherical surface of gasket F_{SSP} .

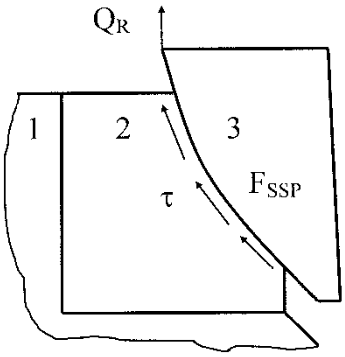

Figure 1. Direction of force Q_R and shearing stresses on contact spherical surface. Figure is showing 1 –flange with the seat for a gasket, 2 – gasket, 3 – flange with the tip, Q_R – force of flange "extension", τ – shearing stresses caused in gasket under the influence of force Q_R.

Calculated dependencies for determining the geometric dimensions including the gasket spherical parts are given in paper [12]. Experimental data and results of exploitation of real joints show that violation of density of firm-and-impervious joint occurs by gasket material at the level of the deepest ledge on flange spherical surface. Taking into account the fact that height of microroughnesses of flange spherical surface is usually Ra 1,6 μm (Rz 6…10 μm) «thickness» of firm-and-impervious joint zone is 6…10 μm [9]. Magnitude of a force Q_R, at which joint depressurization takes place can be determined from the following relation

$$Q_R = F_{SSP} \cdot \tau \quad (4)$$

where τ – shearing strength of gasket.

Beside that, it should be noted the microgeometry of flanges seal faces and gasket. Usually flanges manufacture by turning, therefore microroughnesses on their cylindrical, spherical and plane seal faces are of the form the helical line with pitch equal to the value of cutter feed [13]. According to the data [14] the value of the feed for turning operation of surfaces with roughness Ra 1,25…2,5 μm is from 0,04 mm/rev. to 0,12…0,13 mm/rev.

So far as gasket material fills the microroughnesses on the flange surface, for joint depressurization is necessary that during the unscrewing process of technological fastening elements, their replacement with standard fastening elements and flange "extension", the ledges on their surfaces were deformed the gasket material on the distance which equal to the size of microirregularity mounting base. Experimental data have shown that as a rule at the initial leakage value 10-12-10-10 W depressurization immediately occurs to a leakage value 10-5 W or more.

Microrelief of plain flange surfaces of lock joints has appearance of helical line, with microirregularity height about 10 μm (Ra 2,5 μm, Rz 10 μm) and pitch from 0,04 mm to 0,12…0,13 mm [13]. Moreover, on plain flange surfaces usually execute V-shaped pressurizing risks, which are filled with the gasket material; when the fastening elements are tightened [4]. Microrelief of cylindrical flange surfaces in which contact with gasket takes place, is similar to microrelief of plain surfaces and ledges are formed (in the process of gasket plastic deformation) with height h_1 (gasket external) and h_2 (gasket internal diameter). At the same time the height of ledges h_1 and h_2 are different along the perimeter of gasket [15]. This is due to hardening and increasing the elasticity of the gasket material under deformation caused by the action of axial forces on the fasteners tightening. In the process of successive fastening elements tightening in the total deformation of the gasket, the proportion of the plastic decreases and the fraction of the elastic component increases, which causes the different heights h_1 and h_2 along the perimeter. Cumulative value of strain remains constant and varies along the sinusoid [1,4]. While constructing the method and taking into account the assumptions made earlier, it is assumed that the average value of h_1 and h_2 is 170 ... 200 μm for pressure on a gasket made of aluminum 160 ... 170 MPa and of copper - 270 ... 320 MPa.

The greatest influence on the joint depressurization is the violation of the contact density along the cylindrical surfaces. It is the appearance of the ledges with heights h_1 and h_2 that testifies about filling the microroughness on the plain surfaces of the flanges by gasket material and about the intensive plastic flow of the gasket material. Subsequent filling by the gasket material of microirregularities already on the cylindrical surfaces of the seat for a gasket and the tip of the flanges leads to a phenomenon which similar to the punch jamming during the pressing. Such "jamming" can be one of the building mechanisms of firm-and-impervious joint in contact zone of flange seal faces and gasket.

Therefore, for total joint depressurization, there should be a violation of the contact density over plain surfaces, in the area of pressurize matchmarks along the cylindrical surfaces. Force Q_R which necessary to depressurize the joint is determined by the following formula:

$$Q_R = Q_{FS} + Q_{GS} + Q_{CS} = F_{FS} \cdot \sigma_B + F_{GS} \cdot \tau + F_{CS} \cdot \tau \tag{5}$$

where Q_{FS}, Q_{GS}, Q_{CS} – forces, which necessary for violation of contact density along the plain seal faces, in the area of pressurize matchmarks and в long the cylindrical surfaces respectively; σ_B – breaking stress of the gasket material, F_{FS} – area of plain surfaces, F_{GS} – area of pressurize matchmarks, F_{CS} – contact area along cylindrical surfaces, $F_{CS} = \pi \cdot d \cdot h_1$, where d – external diameter of gasket.

For the assessment of capability for violation of the contact density, it is considered the conditions for the displacement of the fastening elements (bolts, studs, screws), flanges and gaskets in the process of the flange "extension" . Thus, for the violation of the contact density, displacement of the of the seal surfaces points as a result of the flange "extension" should be sufficient to deform the gasket material on an amount equal or greater than the size micro irregularity mounting base on the flange surface.

If the gasket is out of the operating zone of bending moment on the flanges from the axial forces of tightening fastening elements, it is obvious that the effect of the flanges"extension" can not lead to joint depressurization. In this case the gasket has the appearance only linear movement in the direction of pipeline axis – «springing», causes by decreasing of the force which acting on it. However, the usage of such flange joints is constrained by large overall dimensions in comparison with currently used and insufficiently developed engineering methods for their design and manufacturing.

In a majority of modern flange joints, the gasket is located in the operating zone of bending moment from the axial force of the fastening elements tightening. In this case the value of points displacement of seal faces depends on the joints pressurization method, compliance of fastening elements, gasket, flanges, eccentricity from axis of working line of tightening axial force to gasket external diameter, gasket width. It is considered that under the influence of bending moment, flange cross section revolves around the center its center of mass, although in practice the center of rotation is more often assumed to be the center of the pipe wall at the point of its transition into the flange ring or the place of ring support of the free flange on the tip. In calculated dependencies which determine the the value of the axial force which influence on the standard fastening elements [10], the values of the flange replacements are determined on the axis of the fastening elements (on the action line of the tightening axial force). Accordingly, the replacement of the points of flanges seal surfaces can be defined as the correlation of the distance from the gasket external diameter to the rotation center to the distance from the rotation center to the axis of the fastening elements (action lines of tightening axial forces) multiplied by the displacement value which obtained by the formulas [10]. If this value is equal or greater than the size of the microirregularity mounting base on the flange surface, the joint is depressurized.

3. Conclusions

According to this article prediction method of conditions of pipelines flange joints depressurization method was obtained. Method consists of the following steps: testing of the joint design and find out whether the gasket is in the operation zone of bending moment from tightening axial force of fastening elements; establish data about roughness of flange seal face and gasket; determine the compliance of flanges, fastening elements and gasket; determine the value of tightening torque (axial force) of technological and standard fastening elements; determine the values of flange "extension" force which are necessary for violation of contact density of flange seal faces and gasket, displacement of flange points on seal faces and in such way establish the possibility of joint depressurization.

The assumption in this article about instantaneity and simultaneity of unscrewing of technological fastening elements and their replacement with standard fastening elements, in spite of idealization of process, lets use analytical dependencies for prediction of conditions of flange joints depressurization during the assembly (on initial stages of pipelines designing and technological process of their manufacture), without recourse to labour-intensive computer simulation by applying finite-element models.

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