Main reasons of leaktightness failure of detachable flanged joints with lens seal ring

V K Pogodin¹, V E Gozbenko²

¹Irkutsk State Transport University, 15 Chernyshevsky Street, Irkutsk, 664074, Russia
²Angarsk State Technical University, 60 Chaykovskogo Street, Angarsk, 665835, Russia

E-mail: irgups-journal@yandex.ru

Abstract. The main indicator of the performance of any design of detachable joints is its tightness, which is ensured by pressing the sealing surfaces of its parts to each other with a certain force. The frequent depressurization of detachable joints arising in practice is explained by the difficulty of determining the force that takes into account the influence of the design features of the parts of detachable joints and the intensity of their change from external conditions and the time of operation. Work on the definition of tightness carried out by the authors is different in that they take into account changes in the contact characteristics and the mutual influence of irregularities of the contacting surfaces. Considering the results of previous studies on the relationship between the tightness of the sealing device and technological factors, it can be said that the role of these factors is very significant, but it is rather difficult to assess the joint influence of technological factors on the tightness of any one design. Development and operation of new detachable connections with a lens sealing ring should be carried out taking into account the analysis carried out in this study and the established reasons for their depressurization.

1. Introduction

The performance and safety of equipment operating under pressure are highly dependent on the leaktightening ability of its detachable joints (DJ). Each DJ is a set of parts, which in vessels, pipelines, pipe fittings and other equipment include a sealing joint (SJ) and fasteners. The DJ ensures the closing (opening) of the equipment and the leaktightness of the joints of the parts to be connected under operating conditions.

It is considered that the main and objective indicator of the performance of any DJ design is its leaktightness, which is ensured by pressing the sealing surfaces of its parts to each other with a certain force $Q$.

The magnitude of this force depends on the loading force of fasteners (tightening force) $Q_{tig}$, the force from the pressure $Q_p$, the force $Q_t$ from temperature effects on the DJ parts, and $Q_\tau$ from the relaxation stresses in the DJ parts during time $\tau$ at the relaxation rate $\upsilon (\tau)$, i.e.:

$$Q = f (Q_{tig}, Q_p, Q_t, Q_\tau).$$  \hspace{0.5cm} (1)

The frequent leaktightness failures of DJ arising in practice are explained by the complexity of determining the effort $Q$, which would take into account the influence of the design features of the DJ components and the intensity of their change on external conditions and the time of operation.
Existing methods for determining the efforts $Q$, at which the value of the leakage value in the DJ does not exceed the allowable values, are divided into calculated and experimental ones.

When developing theoretical methods, many researchers associate the leakage value with the characteristics of the contact space with the contact pressure values $q_1$ or specific effort $q$. At the same time, the space between the contacting sealing surfaces (the joint of the sealing surfaces) is represented as an equivalent gap and the leakage is calculated using the well-known Poiseuille formula [1-3].

However, in some works, in particular in [4], there are significant deviations between experimental and calculated values determined by the equivalent gap at contact pressures close to the yield strength of the material of the contacting parts. To reduce these discrepancies, the authors propose the use of correction factors obtained theoretically and / or experimentally.

In other papers [5, 6], the leakage rate is determined depending on the geometrical parameters of microchannels formed by sealing surfaces in the form of a set of bodies of regular geometric shape (pyramids, spheres, ellipsoids, etc.), which are used to simulate micro irregularities. Significant errors in the determination of leakage by this method are explained by the discrepancy between the support surfaces of the simulated and the real joint, as well as the difference between the real forms of individual irregularities and the adopted correct ones.

In this simulation, the joint or gaps [7, 8] do not take into account the influence of waviness and macro deviations, as well as the step characteristics of the roughnesses. The use of such models is limited to certain values of contact pressures $q_1$.

There are a significant number of papers [9-11], in which a leak is determined according to the Kozeny-Karman theory. With that, the joint is represented in the form of a porous body. In [12] it is noted that there is no rigorous proof of the Kozeny equation. A general relationship between porosity and permeability cannot exist, since two structures of the same porosity may have different permeabilities. The use of only one porosity parameter in the calculation is no different from the use of an equivalent gap. An expression, which is used to determine the permeability coefficient, is obtained for a porous body as a set of spherical balls, which is not true.

When simulating a junction with a set of capillaries [13, 14], the distribution of capillaries and their tortuosity is usually not taken into account, and the number of microchannels is determined with a large error.

In some papers [15, 16], the authors use the percolation theory, according to which the values of the relative actual contact area, at which a continuous and closed cluster is formed, are determined, that is, all microchannels in the junction are covered. With this approach, it is possible to determine the value of contact pressure at which full leaktightness is ensured, without quantitative assessment of the leakage at intermediate loads. In this case, the dependence of the relative contact area on the magnitude of the contact pressure should be known. Work on the definition of leaktightness carried out at Bratsk State University differ from the ones discussed above in that they take into account the change in contact characteristics and the mutual influence of irregularities of the contacting surfaces.

Most of the computational methods are valid for a very narrow range of their application in terms of the pressure of the medium and contact pressures, namely, for small values of these quantities. The practical use of the dependencies obtained by these authors is problematic because of the need to determine microgeometric parameters that are hard to control, as well as additional parameters that must be established experimentally or by calculation. All the considered calculation methods for determining DJ leaktightness conditions are of definite scientific interest, but they only make it possible to qualitatively evaluate the influence of various factors (pressure and properties of the medium being sealed, geometric and microgeometric parameters and mechanical properties of the mating surfaces) on the degree of leaktightness [17].

Thus, computational methods for determining leaktightness conditions are a complex and time-consuming process, which may not always end with reliable results.

Considering these circumstances, a large number of studies aimed at determining the conditions of DJ leaktightness were carried out experimentally.
In order to formulate the general principles of the approaches in conducting experimental studies, it was necessary to analyze previously defined leaktightness conditions.

The key motive for such studies has always been the fact that with the loads occurring in real SJ constructions, the microgaps do not disappear completely.

Depending on the type of the working medium (gas, liquid), the relationship between the size of a microgap and leakage is different. Thus, fluid leakage can completely stop over time due to the action of surface tension forces and the microgap obliteration phenomenon [18, 19]. The leakage of the gaseous medium does not disappear completely, even with such a close convergence of the sealing surfaces, when the microgap will narrow to a size close to the effective diameter of the gas molecule. In practice, as noted in [19], such a convergence is not achieved.

Consequently, for gaseous media, the complete leaktightness of the sealing joint with the direct contact “steel to steel” with normally applied loads is unattainable. Based on this premise, in practice they strive not to achieve “absolute” tightness, but to reduce the leakage of the medium to a value acceptable from the point of view of the technological process, explosion and fire hazard, pollution of the surrounding territory.

The analysis of numerous experimental studies of DJ leaktightness showed that they mainly considered the influence of the DJ structural and technological parameters on leaktightness.

The influence of structural factors on leaktightness has been rather well studied and is reflected in the works of many researchers [20-22]. All studies in this area are reduced to studying the mechanism of work, analyzing the stress-strain state of various DJ structures, determining the design forces perceived by the sealing ring and fasteners at all stages of the DJ, determining the required geometrical dimensions of parts and elements of the DJ, based on their strength and leaktightness.

The influence of technological factors on the integrity of the SJ has been studied by a number of authors [22-24, etc.]. In the majority of works, on the basis of experimental studies, the influence of the roughness of the contacting surfaces on the amount of leakage of the medium was considered. This situation is obviously due to the fact that many authors evaluated this factor as the most important.

Thus, in [25], the author studied the leaktightness of the DJ with a lens sealing ring under the action of liquid and gaseous media under a pressure of 70–80 MPa. He found that for a gaseous environment (nitrogen), an increase in the roughness of sealing surfaces from 0.35 to 1.35 μm according to GOST 2789 leads to the need to increase by 4–5 times the specific sealing pressure \( q_{\text{min}} \). When used as the working medium, oil \( q_{\text{min}} \) remains constant. The author also showed that with \( Ra \) roughness corresponding to 0.35–0.63 μm according to GOST 2789 and higher, leakage does not depend on the pressure of the medium. However, this result was not confirmed in the works of other researchers. For a similar joint, the authors in [26] found that with an increase in the roughness class of sealing surfaces, the effect of pressure only decreased. This is due to the change in the gas flow regime. In the laminar mode, the leakage is proportional to the second degree of gas pressure \( (p_v)^2 \), for the diffusion process \( -p_v \).

Another author [27] experimentally studied the effect on leaktightness of errors in the shape of a lens (deviation of its sealing surface from a sphere) and of a pipe (unstraightness of its cone generatrix). This author has established that the error in the shape of a lens sealing ring up to 15 microns does not have a noticeable effect on leaktightness. However, with an increase in the shape error to 35 μm, the specific sealing force is required to increase 1.4–1.5 times. The unstraightness of the tube cone generatrix over 3 .. 4 μm significantly reduces the leaktightness of the DJ, so the author recommended limiting deviations from straightness to a specified value.

Considering the known results of previous studies on the relationship between the leaktightness of the SJ and technological factors, some results can be summarized. The general conclusion may be that the role of these factors is very significant. At the same time, the results of the above studies do not allow assessing the joint influence of technological factors on the leaktightness of a single SJ design, since the authors usually took separate technological factors as a subject of study, and not their entirety. At the same time, it has been established that it is very difficult to use data obtained using some DJ
structures [28, 29] as applied to others, as constructive factors influence the results of the experiments, and these factors are individual for each DJ.

Experimental studies on the determination of leaktightness conditions should be divided according to the following criteria for assessing the leaktightness: conditional leaktightness and a magnitude of leakage of the sealing medium. Researchers took the emergence or termination of leakage of the medium being sealed for conditional leaktightness of the DJ. At the same time, the amount of gas or liquid was not measured. They recorded only the moments when this amount was sufficient to be recorded using the applied leakage control means. Researchers in these studies assumed that within the limits of the pressure of the medium \( p \), at which the leakage was not recorded, the studied SJ (or DJ) have absolute leaktightness. Taking this circumstance into account, the dependencies \( q = f(p) \) were constructed.

2. Investigation of sealing conditions

Assessment of conditional leaktightness was carried out by the emergence of traces of a sealing medium on the outside, with respect to the action of pressure, the contact surface of the SJ, the pressure drop in the cavity of the medium, or the increase in pressure in the volume behind the SJ under study. The accuracy of determining the value of \( q \) depends on the sensitivity of the instruments used. Numerous SJ studies performed using such approaches cannot currently be used due to the lack of information on the methods for evaluating conditional leaktightness, the design of the pilot plants used, the sizes of SJ, etc.

Experimental studies with a quantitative assessment of the degree of leaktightness by the amount of leakage in seals and chemical equipment DJ began to be conducted more recently [28, 29]. At the same time, in investigations, particular dependencies were mainly determined as \( B = f(HB) \), \( B = f(p) \), \( B = f(q_1) \), which were also called leaktightness conditions.

The dependencies obtained in this way do not allow us to determine the optimal combinations of geometric parameters of the SJ or the DJ, and also to use them when determining the causes of their leaktightness failure.

On the basis of the analysis performed, it can be established that the researchers who carried out theoretical and experimental studies of the leaktightness conditions and the determination of the causes of DJ leaktightness failure solved specific issues, and their studies were of a special nature (in design, in limits of applicability). Therefore, the results of these studies did not make it possible to formulate the general principles of approaches to determine the causes of frequent leaktightness failure of DJ structures with lens sealing rings.

In this regard, when determining the causes of DJ leaktightness failure with lens rings, it was necessary to study the influence of technological and design factors, in their entirety, on the leaktightness of this DJ.

Such an approach in the study of leaktightness conditions will allow forming a new approach to the development and design of other promising and existing SJ and DJ structures.

Detachable joints with a lens sealing ring (Figure 1) are widely used in vessels, pipelines and pipeline fittings operating at pressures up to 100 MPa and temperatures up to \( t = 900 \, ^\circ\text{C} \) [1, 2] in liquid and gaseous media.
Figure 1. Detachable flanged joint with a lens sealing ring: 1 – lens ring; 2 – pipeline; 3 – threaded flange; 4 – stud; 5 – nut. Points of temperature measurement of connection parts: 1, 4, 8 – studs; 2, 3, 6, 7 – threaded flange; 5 – lens sealing ring.

There are cases of leaktightness failure of such joints when used in equipment, including hazardous industries, which led to sudden fires, explosions and other industry-related situations [3]. Establishing the causes of leaktightness failure of equipment is required to be carried out on the basis of analysis of the conditions for their calculation, design, operation and repair.

The calculation of the geometrical parameters of detachable joints is historically determined by the following simplified dependencies [1]:

- diameter of contact of the sealing ring:
  \[ D_{\text{out}} = 0.5(D_a + d), \] (2)
  where \( D_{\text{out}}, d \) are outer and inner diameters;

- the radius of the sphere of the ring:
  \[ R = D_a (2\sin \alpha), \] (3)
  where \( \alpha = 20^\circ \) is the angle of inclination of the sealing surface of the connecting parts;

- the height of the sealing ring:
  \[ h_l = 2(\sqrt{R^2 - (0.5d)^2} - \sqrt{R^2 - (0.5D_{\text{out}})^2}) + c, \] (4)
  where \( c \) is the constructive surcharge, mm.

The geometric dimensions of the lens rings, determined in accordance with the dependences given, are presented in Table 1.

| \( d \), mm | \( D_{\text{out}} \), mm | \( D_a \), mm | \( R \), mm | \( h_l \), mm |
|---|---|---|---|---|
| 20 | 38 | 29 | 42.4 | 7.128 |
| 41 | 57 | 49 | 71.6 | 8.84 |
| 65 | 94 | 79.5 | 116 | 10.6 |
| 80 | 108 | 94 | 137.4 | 10.9 |
| 125 | 170 | 147.5 | 215 | 16.43 |
| 175 | 230 | 202.5 | 296 | 20.05 |

Table 1. Dimensions of sealing joint with a lens ring, obtained by calculation.
Tables 2 and 3 show the dimensions of the lens rings adopted in the current regulatory document and in the Flexitallic advertising project, respectively. Table 4 shows the dimensions of the lens rings adopted at JSC “Angarsk Petrochemical Company (ANKhK)” and during the consideration of the causes of the leaktightness failure of such detachable joints.

Table 2. The dimensions of the sealing joint with the lens ring according to the regulatory document MRTU 26-01-10-67.

| $d$, mm | $D_{out}$, mm | $D_k$, mm | $R$, mm | $h_l$, mm |
|---------|----------------|------------|---------|-----------|
| 20      | 40             | 30         | 45      | 13        |
| 41      | 65             | 53         | 68      | 16        |
| 65      | 85             | 75         | 95      | 20        |
| 80      | 125            | 102.5      | 140     | 30        |
| 125     | 175            | 150        | 201     | 38        |
| 175     | 270            | 222.5      | 301     | 52        |

Table 3. The dimensions of the sealing joint with a lens ring according to the Flexitallic advertising brochure.

| $d$, mm | $D_{out}$, mm | $D_k$, mm | $R$, mm | $h_l$, mm |
|---------|----------------|------------|---------|-----------|
| 20      | 43             | 31.5       | 50      | 11        |
| 41      | 62             | 51.5       | 70      | 14        |
| 65      | 78             | 71.5       | 112     | 20        |
| 80      | 116            | 98         | 129     | 22        |
| 125     | 180            | 152.5      | 218     | 29        |
| 175     | 243            | 209        | 296     | 31        |

Table 4. The dimensions of the sealing joint with a lens ring according to the drawing K-1674.00.00.00 OGM ZAU

| $d$, mm | $D_{out}$, mm | $D_k$, mm | $R$, mm | $h_l$, mm |
|---------|----------------|------------|---------|-----------|
| 20      | 38             | 29         | 42      | 13        |
| 41      | 57             | 49         | 65.5    | 15        |
| 65      | 94             | 79.5       | 112     | 22        |
| 80      | 108            | 94         | 115     | 23        |
| 125     | 170            | 147.5      | 160     | 31        |
| 175     | 230            | 202.5      | 243     | 42        |

The heights $h_l$ of the lens rings in all tables are different from each other. The values of $h_l$ in Table 3 are the closest to the calculated one. The greatest values of $h_l$ take place in Table 2.

The values of the radii of the sphere $R$ of the lens rings in Tables 2 and 3 are taken close to the calculated values given in Table 1.

The values of $R$ in Table 4, especially when $d$ is equal to 80 or 125, 175 mm, are significantly different from the calculated ones.

From the analysis of the size of the lens end, given in Tables 1-4, it follows that $D_{out}$ and $D_k$ in all tables differ little from each other.

In modern sources of information and regulatory documents on the calculation of detachable joints, the calculated tightening force acting on fasteners (studs) and the sealing ring is determined by the formula:
\[ Q_{tg} = Q_q + Q_n + Q_f, \]  

where \( Q_q = \frac{\pi D_k^2}{4} \times p \) is the axial force from the pressure of the medium; \( Q_n = \pi D_t q \) is the axial reaction of the sealing ring under operating conditions. \( Q_f = \frac{\Delta l}{\lambda_i + \lambda_s + \lambda_f} \) is the force caused by thermal interactions; \( p \) is the pressure of the medium; \( q \) is the axial line force acting on the sealing surface in the working conditions, adopted by the permissible amount of leakage.

\[ \Delta l = 2h_f \cdot t_f \cdot D_f + h_t \cdot t_t \cdot a_t + l_s \cdot t_s \cdot a_s \]

is the difference between the thermal elongation of the parts of the detachable joint; \( \lambda_i, \lambda_s, \lambda_f \) are the compliances of the sealing ring, studs, flange, respectively; \( t_f, t_t, t_s \) are the temperature values, respectively, of the flange, sealing ring, studs.

When the height of the lens sealing ring is equal to the thickness of the pipe wall, the effect of self-sealing in such a detachable joint is small and is not taken into account in the calculations. For this reason, the connection with the lens sealing ring can be attributed to the connections with a forced seal [3].

Changes in the force under the action of the pressure of the medium in the mounting system \( Q_{ckq} \) and the sealing system \( Q_{cyq} \) are determined by dependencies [2]:

\[ Q_{ckq} = Q_s + (1 - \alpha) \cdot Q, \]  
\[ Q_{cyq} = Q_s - \alpha \cdot Q, \]  

where \( \alpha = \frac{\lambda_s + \lambda_f}{\lambda_i + \lambda_f + \lambda_s + \lambda_m} \).

From the presented dependencies (1)-(3) it follows that the values of the forces acting on the parts of the detachable joints, to a large extent depend on the compliances of their parts and their elements. However, in these dependences, the compliances of threaded joints “pipe-threaded flange”, as well as the compliances of microroughnesses when contacting the flat rough surfaces “flange-nut” are not taken into account. Dependencies for determining \( \lambda_i, \lambda_s, \lambda_f \) adopted in reference books [1, 2], require clarification in accordance with the results of the research [3]. These circumstances are very important, since the values of the forces determined in dependencies (1), (2), (3) are used not only to calculate parts of detachable joints, but also to calculate the stress-strain state of other parts of the equipment, which include such detachable joints.

For safe operation in detachable joints, the following conditions must be met:

- for the mounting system:
  \[ Q_{ck} \leq n \cdot F_s \cdot [\sigma]; \]  
- for the sealing system:
  \[ Q_{cy} = \pi \cdot D_t \cdot a < [q]. \]

where \( n \) is the number of fasteners (studs) or elements; \( F_s \) is the cross-sectional area of the fastener (stud); \( [\sigma] \) is the allowable stress for the material of fasteners; \( [q] \) is the permissible contact pressure on the sealing surface; \( a \) is the contact width of the sealing surface.

If the definition of condition (4) does not cause any difficulties when designing a detachable joint, then when determining the leaktightness condition (5), difficulties arise in accepting the values of contact pressure \( q \) or contact effort \( q_l \).

These difficulties often arise due to the fact that the recommended value of the contact line forces, which provides the required leaktightness in working conditions, varies in different reference literature:
in reference books [1, 2], the value of $q_l$, depending on $D_k$, is recommended from 200 to 500 kgf/cm;

- in the book of D.F. Gurevich [4] for nitrogen and other gases $q_l = 20\sqrt{R}$, for hydrogen and helium $q_l = 30\sqrt{R}$, that is, the limits of variation of these values for sealing joints presented in Tables 1 ... 4, will be: $q_l = 40, 98\ldots109$ kgf/cm; $q_l = 61, 49\ldots164.5$ kgf/cm, respectively;

- simultaneously in the same book $q_l = 300$ kgf/cm for $d = 6 \ldots 45$ mm and $q_l = 500$ kgf/cm for $d = 45 \ldots 200$ mm;

- B.A. Koridorf [5] recommends the magnitude of the linear force at which the equivalent stresses $\sigma_{equ}$ reach the yield strength of the material of the lens ring on the surface of its contact with the part (tube) to be joined.

The choice of the value of the contact line forces or pressures required to ensure the leaktightness of detachable joints with a lens sealing ring for use in formulas (4), (5) should be determined from the condition for ensuring the required leaktightness, leakage which is allowed for economic reasons [6]. However, in the existing regulatory documents there is no relationship between the values of contact forces or contact pressures and the magnitude of leakage in sealing joints.

The absence of such dependencies in regulatory documents does not allow choosing the optimal geometric and force values of the structures of detachable joints and may be one of the reasons for their leaktightness failure. However, such dependencies exist and can be applied [3, 6].

3. Determination of the dependence of the leakage of gas in the sealing connection "torus cone"

For the design of the “torus – case” sealing joint (Figure 2) the dependencies of the leakage value on the nitrogen gas pressure are presented for various values of contact line forces, hardness of the material of the HRC 42 sealing joint, roughnesses of the ring sealing surfaces $R_a = 1.5$ μm, sealed surface $R_a = 0.2$ μm.

![Figure 2. The “torus–cone” sealing joint.](image)

Figure 4 shows the dependences of the leakage for a detachable joint with a lens sealing ring (Figure 1) with different line forces $q_l$ and radii $R$, hardness of the ring material HB120 and $\alpha=70^\circ$. Dependences presented in Figure 3 and 4 allow us to estimate the leaktightness of the designed detachable joint with a lens sealing ring under conditions close to the presented results.
4. Analysis of the mechanism of contact interaction of a steel lens sealing ring

When analyzing the mechanism of contact interaction of a steel lens sealing ring with conical steel surfaces of the connectable parts in a detachable joint (Figure 1), we consider it as a contact interaction of a cylinder with a plane. In this type of contact, the maximum equivalent stresses arise over the contact surface at a depth of $0.395 \varepsilon$, where $\varepsilon$ is the contact width [8]. When the value of the friction coefficient $f = 0.2$ near the contact, the values of equivalent stresses can be determined by the dependence [8]:

$$\sigma_{equ} = 0.249 \sqrt{q_l \frac{E}{R}}, \quad (10)$$

where $q_l$ is the linear contact force acting along the perimeter of the contact of the lens ring with the connected parts; $E$ is the modulus of elasticity of the material of the sealing ring of the sphere; $R$ is the radius of the sphere.

For further analysis we will use the dependencies obtained by V.I. Livshits for the “cylinder – plane” contact, at which $\sigma_{equ} = Rf$ and the friction coefficient on the sealing surface is $f = 0.2$ [9]:

![Figure 3. Dependencies of leakage value B in the “torus-cone” SJ on gas pressure $p$ and $q_l$:](image)

(a) for $R = 80$ mm: 1 – $q_l = 5$ kN/cm, 2 – $q_l = 10$ kN/cm, 3 – $q_l = 15$ kN/cm, 4 – $q_l = 20$ kN/cm, 5 – $q_l = 25$ kN/cm, 6 – $q_l = 30$ kN/cm; b) for $R = 105$ mm: 1 – $q_l = 5$ kN/cm, 2 – $q_l = 10$ kN/cm, 3 – $q_l = 15$ kN/cm, 4 – $q_l = 20$ kN/cm, 5 – $q_l = 25$ kN/cm; c) for $R = 155$ mm: 1 – $q_l = 5$ kN/cm, 2 – $q_l = 10$ kN/cm, 3 – $q_l = 15$ kN/cm, 4 – $q_l = 20$ kN/cm; d) at pressure $p = 250$ MPa: 1 – $R = 80$ mm, 2 – $R = 105$ mm, 3 – $R = 155$ mm.
• the value of the line force at which \( \sigma_{\text{equ}} \) reaches the yield strength of the material \( R_T \) at a depth of 0.395 \( v \):

\[
q_l = 16 \frac{R_T^2 \cdot R}{E};
\]  
(11)

• the amount of line force \( \sigma_{\text{equ}} \) at which \( R_T \) is reached on the contact surface:

\[
q_l = 20.5 \frac{R_T^2 \cdot R}{E}.
\]  
(12)

Let us define the limits of change of \( q_l \) with the values of \( R \) accepted in Tables 1-4.

• with accepted values \( R_{T_{\text{min}}} = 1600 \text{ kgf/cm}^2, E = 2.1 \times 10^6 \text{ kgf/cm}^2 \) and \( R_{\text{min}} = 42 \text{ mm} \) and \( R_{\text{max}} = 301 \text{ mm} \), the value of \( q_{l \text{ min}} = 104.96 \text{ kgf/cm}, q_{l \text{ max}} = 752.2 \text{ kgf/cm} \);

• with accepted values \( R_{T_{\text{max}}} = 4000 \text{ kgf/cm}^2, E = 2.1 \times 10^6 \text{ kgf/cm}^2 \) and \( R_{\text{min}} = 42 \text{ mm} \), \( R_{\text{max}} = 301 \text{ mm} \), the value of \( q_{l \text{ min}} = 643.2 \text{ kgf/cm}, q_{l \text{ max}} = 4669/6 \text{ kgf/cm} \).

Figure 4. The dependence of leakage in a detachable joint with a lens sealing ring with hardness of \( HB = 120 \), at pressure of \( p = 100 \text{ kgf/cm}^2 \) and different line forces and radii \( R \).

The values of the tightening force of fasteners (studs) of detachable joints with a lens ring, given by D.F. Gurevich [4] for medium pressures \( p = 6–700 \text{ kgf/cm}^2 \) adopted in Tables 1-4 and with the values \( D_k = 30–200 \text{ mm} \), the linear efforts \( q_l = 229–4477 \text{ kgf/cm} \) correspond.

Comparison of the values of line forces shows that when tightening the detachable joint, plastic contact always takes place, and the lens surface of the sealing ring takes the form of the sealing surfaces of the parts to be joined. After disassembly, the sealing surface of the ring has significant residual deformations, which does not allow its reuse, or it will require application of much greater tightening forces than during the first loading.

For a detachable joint of a positive seal, the magnitude of the contact forces on the sealing surfaces decreases with increasing pressure of the medium and increases with decreasing to \( q_l \) values. Such
change in contact forces on sealing surfaces with their cyclically varying pressures shows a tendency to
decrease these values from cycle to cycle, which inevitably leads to leaktightness failure of the joint and
an increase in leakage.

5. Conclusion
Based on the analysis and research [3, 6], it has been found that the main causes of leaktightness failure
of detachable joints with a lens ring are:
when designing:
- the use of calculations of geometric and force parameters without taking into account the
  assessment of leaktightness and the mechanism of work of a detachable joint;
- the use of regulatory documents in which there is no definition of parameters of the performance
  of detachable joints under operating conditions;
- the lack of leaktightness conditions for sealing joints;
- the wrong choice of combination of materials of parts of detachable joints during operation;
- the inconsistency of the roughness of the sealing surfaces with the requirements of GOST 9400-
  81;
- the lack of control of the state of the sealing surfaces of the ring and the parts to be joined before
  assembly;
- the uncontrolled tightening of the studs, which leads to an uneven distribution of forces around
  the perimeter of the contact of the sealing surfaces;
- the presence of distortions, the magnitude of which grows during the operation due to the annual
  grooves of the sealing surfaces of the ends of the pipelines at constant dimensions of the lens
  rings;
- the wrong selection of materials of parts during repairs.
Development and operation of new detachable joints with a lens sealing ring should be carried out
taking into account the analysis and the established reasons for their leaktightness failure.

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