EXPERIMENTAL INVESTIGATION OF THE SEALING CONDITIONS OF ELASTIC CONICAL PACKING IN HIGH-PRESSURE DEVICES

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Elastic conical packing devices are widely used in different types of locks for high-pressure equipment. They have a number of advantages in comparison with plastic packing: insensitivity to temperature fluctuations, the possibility of using the lock many times, lower loads acting on the structural elements, the possibility of radial self-sealing, etc. At the present level of technological development, the more stringent requirements for the quality and precision in machining the sealing surfaces can hardly be considered as a serious drawback of these locks.

In spite of the fact that conical packing devices with a small tapering angle are widely used, there is a lack of systematized data on their airtightness that could be used in designing locks of this type. Berger's method [1], the basic principles of which are still unknown, is used in design practice. The method for calculating two-cone locks [2], which has been used lately, seems not to have been substantiated either.

The present article describes the results of an experimental determination of the minimum specific force q(kg/cm) [or the specific pressure p(kg/cm^2)] acting along the normal to the cone generatrix which would secure the airtightness of the joint in dependence on the pressure of the medium, the hardness of the material of the parts to be made airtight, the finish quality of the sealing surfaces, the dimensions of the packing (the angle of the cone generatrix, the mean diameter of the packing, and the width of the sealing surface), and the properties of the medium.

The experiments were performed on assembled steel specimens, composed of a lid and a frame with conical sealing surfaces. Gas from a high-pressure compressor was supplied to the inside of the specimens. The specimens were pressed in a membrane oil press (Fig. 1). The compressing device of the press consisted of the upper and the lower lids with free flanges and two annealed-copper membranes resting on the inside washer and held by the central bolt; along the periphery, the membranes were clamped between the lids and the flanges.

The specimen under investigation was mounted on the upper lid of the compressing device and was pressed upward by means of a wedge mechanism until it came into contact with the upper plate of the press. A manual press was used for supplying oil to the inside of the compressing device, the upper and lower cavities of which communicated through a channel in the bolt.

Due to the pliability of the membranes, the compressing device exerts the pressure P_{op} on the specimen:

$$P_{op} = \xi p_o F_{op}$$

where p_o is the oil pressure recorded by the pressure gauge, $F_{op} = 0.785\,D_{op}^2$ the operating area of the compressing device ($D_{op} = 20.9$ cm is the inside sealing diameter of the lids), and ξ a correction factor which takes into account the resistance of the membranes to the extension of the compressing device; according to a preliminary calibration of the press (performed by compressing a hydraulic dynamometer with tensometer gauges), $\xi = 0.91$.

In performing the experiments, a certain given compressive force was created by supplying oil to the compressing device. The test pressure p_g was then secured by supplying gas to the specimen. After this, the gas valve was shut. After a few minutes, the gas pressure inside the specimen was recorded. If it dropped to p_g', the compressive force exerted by the press was increased, and the exposure was repeated, beginning with p_g. This operation was repeated until the gas pressure ceased to drop.

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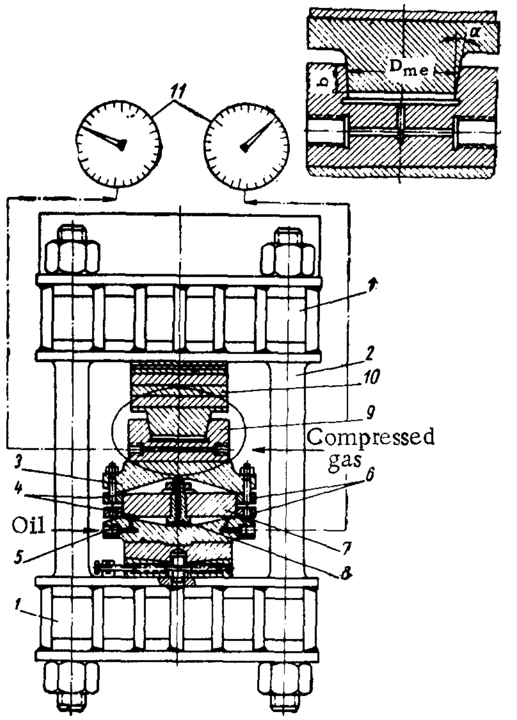

Fig. 1. Mounting of the specimen in the press. 1) Press plates; 2) columns; 3 and 5) lids of the compressing device; 4) membranes; 6) flanges; 7) inside washer; 8) center bolt; 9) specimen; 10) shims; 11) pressure gauges.

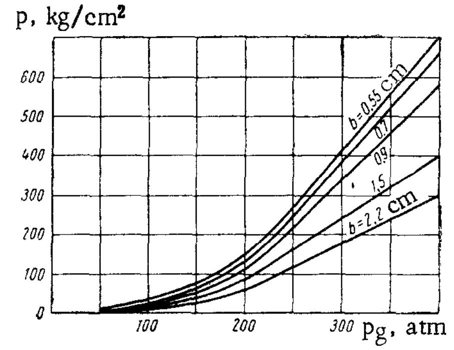

Fig. 2. Dependence of the specific pressure p on the air pressure p_g.

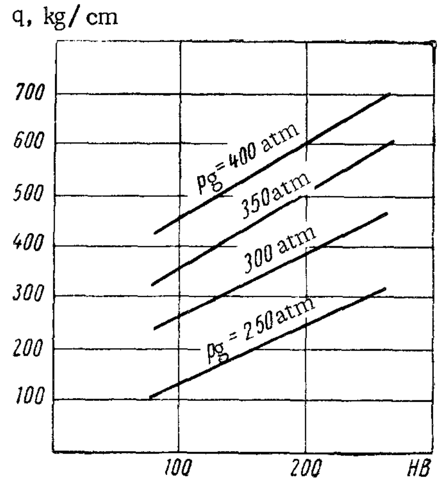

Fig. 4. Effect of the hardness of the specimen's material on the q value for b = 2.2 cm.

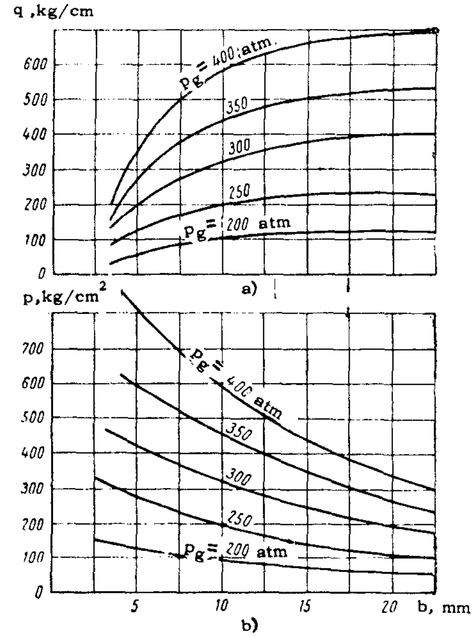

Fig. 3. Effect of the packing width b on: a) the specific force q; b) the specific pressure p.

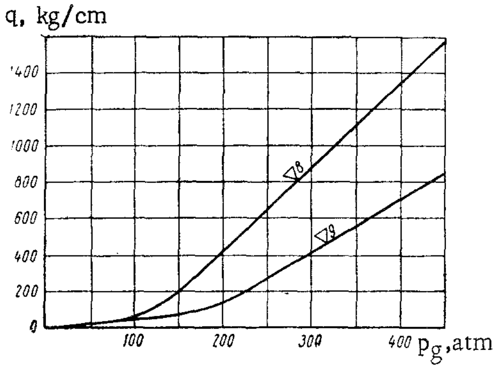

Fig. 5. Dependence of q on the air pressure p_g for different qualities of finish of the sealing surfaces ($b = 2.14$ cm; $\alpha = 11°20'$; $D_{me} = 8.48$ cm).

An exposure time of 3 min was used; in each test series, it was increased at random to 6 min or more. For small volumes of the gas system (the inside volume of the specimen and the adjoining pressure gauge tubes), not exceeding 30-40 cm^3, the above method makes it possible to determine the moment when airtightness sets in with an accuracy sufficient for practical purposes.

The q and p values were calculated by using the equations

$$q=\frac{P_{\mathrm{op}}-0.785D_{\mathrm{me}}^{2}p_{\mathrm{g}}}{\pi D_{\mathrm{me}}\sin\alpha\left(1+\frac{\mathrm{tg}\,\varphi}{\mathrm{tg}\,\alpha}\right)},$$

$$p=\frac{P_{\mathrm{op}}-0.785D_{\mathrm{me}}^{2}p_{\mathrm{g}}}{0.785\left(D_{\mathrm{o}}^{2}-D_{\mathrm{i}}^{2}\right)\sin\alpha\left(1+\frac{\mathrm{tg}\,\varphi}{\mathrm{tg}\,\alpha}\right)},$$

where D_o, D_{me}, and D_i are the outside, the mean, and the inside diameters of the packing, respectively, α the angle between the cone generatrix and the specimen's axis, and φ the friction angle ($\mathrm{tg}\,\varphi \approx 0.16$ [3]).

Figures 2 and 3 show the graphs plotted with respect to data from experiments in air on specimens made of steel 45 with a hardness HB 197 for a class ∇9 surface finish (α = 5°40', D_{me} = 8.72 cm). Figure 5 shows the dependence of q on the finish quality of the sealing surfaces. Finally, Fig. 6 provides the results of experiments performed on the same specimens, but in different gas media.

Experiments performed with the aim of determining the dependence of q on α and D_{me} have shown that the angle and the diameter of the packing hardly affect the q value.

The q value increases with an increase in the pressure of the medium. For $p_g > 180$ kg/cm², this dependence can be considered as a rectilinear dependence with a sufficient degree of accuracy (for $p_g < 180$ kg/cm², it apparently becomes nonlinear and not entirely reliable: The effect of distorting factors – the rigidity of the membranes in the press and the inconstancy of the friction coefficient – becomes pronounced in this case [3]).

The hardness of the material exerts a considerable influence on the q value. Thus, with changes in hardness from HB 111 to HB 207, the q values (air pressure: p_g = 350 kg/cm² increase by a factor of 40% for a packing whose width is b = 2.2 cm (Fig. 4). For narrower packings, the effect of hardness is even more strongly pronounced.

The quality of finish of the sealing surfaces greatly affects the value of the specific sealing force. For instance, it follows from Fig. 5 that, for ∇8, the q value (pressure: 350 kg/cm²) will be almost twice as large as for ∇9.

It is assumed that a continuous contact zone is formed neither for a ∇8 finish nor a ∇9 finish in the case of wide packings. Actually, the height of microroughnesses on ground surfaces with class-∇8 or class-∇9 finish attains 0.8 and 0.2 μ, respectively, i.e., it exceeds by a factor of several thousands the dimensions of diatomic gas molecules.

Since the leakage of a gas in its laminar flow through a long channel is proportional to the fourth power of the clearance [4], the airtightness of a packing in the case of elastoplastic compression of the outlets will mainly depend on the quality of the finish.

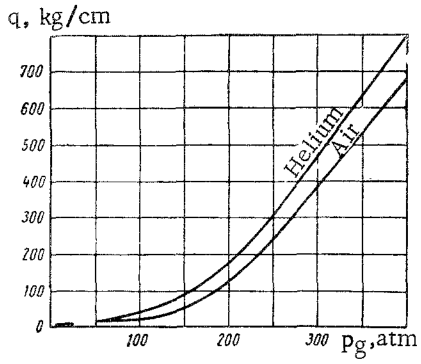

Fig. 6. Effect of the gas medium on the q value for b = 2.2 cm.

The characteristic dependence of q on the packing width was also established experimentally. For instance, it is seen from Fig. 3a that, under constant gas pressure, the q value increases with an increase in the width b and that this increase becomes gradually slower. Beginning with 16-20 mm, q remains practically constant. Thus, an increase in b beyond 20 mm will not cause a noticeable increase in the q value.

The decisive factor in determining the minimum packing width (it is always greater than 20 mm in industrial equipment locks) is the protection of the sealing surfaces from overloads in initial tightening. For instance, in the case of a simple conical lock, the packing is loaded with a specific force

$$q_t = q + \frac{0{,}785 D_{\mathrm{me}}^2 p_{\mathrm{g}}}{\pi D_{\mathrm{me}} \sin\alpha \left(1 + \frac{\operatorname{tg}\varphi}{\operatorname{tg}\alpha}\right)}.$$

A packing with greater width is less sensitive to chance damage.

If we assume that the quality of finish and the machining accuracy are uniform over the entire cone surface, the elastoplastic deformations of microroughnesses will develop uniformly over every square centimeter of the surface due to the constancy of p. Consequently, the residual clearances will correspond to a certain given p value regardless of the packing width.

This assumption agrees with the fact (see Fig. 3b) that the width of the sealing surface must be increased in order to make the packing airtight in the case of higher gas pressures.

The results of comparative experiments with air and helium (Fig. 6) show that, for the same gas pressure p_g, the q value for helium (which has smaller molecules and is characterized by a higher penetrating ability) is always larger than for air. For instance, for $p_g = 350$ kg/cm², the q value for helium is higher than the q value for air by 20%.

The above also confirms the assumption of the labyrinth (capillary) character of hermetic sealing of a wide elastic packing.

In the gradual compression of a nonhermetic joint, the hydraulic resistance of the microclearances increases, and the forces of molecular interaction between the metal and the medium should become more pronounced as the sealing surfaces come into closer contact. In the case of conical packings, this process is even more effective than in the case of flat packings, since, with the slipping of the packing cones with respect to each other, oxide films are destroyed, and the unoxidized metal surface is bared. At the moment when the inside gas pressure is balanced by the action of these forces, virtual impenetrability of the packing is achieved.

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