\[ \frac{v}{v_0} = 1 + \left( \frac{\rho_0}{\rho} - 1 \right) \frac{1 + \mu}{3(1 - \mu)}. \]

which governs the relation between the relative volume \( v/v_0 \) of the cylinder in a rigid yoke, on the one hand, and the relative density \( \rho/\rho_0 (\rho_0 = 1/v_0) \) of the free body from the same material, on the other, for a given temperature \( t \) when there are no external forces (\( p = 0, \sigma = 0 \)).

It follows from Fig. 2 that the computed and experimental results are in good agreement. These data can be used to determine the dependence of the elastic moduli, the coefficient of thermal expansion, and some other physical characteristics as a function of the pressure and temperature.

**LITERATURE CITED**


**ANALYSIS OF THERMAL MODEL OF THE CONTACT**

**HEAT TRANSFER OF ROUGH SURFACES**

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A thermal model of the contact heat transfer between rough surfaces is considered, taking into account curvature of the current lines in the gaps. Theoretical relations determining the contact thermal resistance at small pressures are obtained.

**Formulation of the Problem**

One of the parameters which has a significant effect on the thermal conditions in apparatus is the contact thermal resistance (CTR) due to imperfections of the mechanical connection between the contacting surfaces.

In [1-4] a detailed analysis was made of the results of investigations of CTR by Soviet and non-Soviet authors, the mechanism of contact was explained, the physical basis of the heat transfer through the contact zone was discovered, and practical recommendations for the intensification of heat transfer were given. However, as the forms of real mechanical connections are so different and so complex, it is often a laborious task to use the results of [1-4] for the calculation of CTR. There are several reasons for this:

a) the theoretical relations are only adequately reliable for the simplest case of contacting-object geometry – tangency of plane surfaces;
b) the range of specific compression forces of the contacting surfaces investigated is not characteristic for typical problems of instrument-making. The theoretical dependences allow CTR to be determined at pressures no less than \((10-60) \cdot 10^5 \text{ N/m}^2\). In practice, instrument-making usually requires calculations of CTR at lower pressures \(-(1-10) \cdot 10^5 \text{ N/m}^2\). The recommendations for heat-transfer intensification in the contact zone available in the literature give only qualitative characteristics. The results given below allow the existing gaps to be somewhat reduced.

The heat flux \(P\) passing through the contact zone may be divided, for the purpose of analysis, into two components: a part \(P_P\) of the flux passes through the point of physical contact, and a part \(P_M\) through the medium. The corresponding conductivities are denoted by \(\alpha_P\) and \(\alpha_M\), and the total conductivity is expressed as their sum

\[
\alpha = \alpha_P + \alpha_M
\]

The first term \(\alpha_P\) in Eq. (1) is determined by the actual contact area and the thermal conductivity of the contacting materials. There are several methods of calculating \(\alpha_P\). The most widespread method which is sufficiently accurate is derived from the realization of the "button" model [5]. Here the contact is modeled using two infinite cylinders with a single circular contact spot at the center, the area of which models the actual contact spot.

The actual contact area (ACA) \(\gamma\) depends on the physical properties of the materials, their treatment, and the compression forces. The error in calculating \(\alpha_P\) is determined to a considerable extent by the error in \(\gamma\), and therefore the method for calculating \(\alpha_P\) may be improved both by making the model of heat transfer through the contact zone more accurate and by improving the method of calculating \(\gamma\). In [5, 6], the present problem is discussed in sufficient detail and, although the existing solutions cannot be regarded as final, they may nevertheless be used for the calculation.

The value of the second component in Eq. (1) is determined by the configuration of the contact-medium surfaces. In [1-3], the following relation is proposed for the calculation of \(\alpha_M\):

\[
\alpha_M = \frac{\lambda_M}{\delta_{\text{equ}}},
\]

where \(\delta_{\text{equ}}\) is the thickness of the equivalent plane layer applied between the contacting media, and is determined by equating the volumes of the effective layer and the real gap

\[
\delta_{\text{equ}} = \frac{S_N}{\delta(S_N) + 2l_T},
\]

where \(l_T\) is the value of the temperature jump if the layer is filled with gas; \(S_N\), nominal area; \(\delta(S_N)\), size of the gap, which varies with \(S_N\).

Analysis of Methods of Calculating CTR

In the literature there has been fairly detailed consideration of the heat transfer at specific pressures \(P > (10-50) \cdot 10^5 \text{ N/m}^2\), i.e., in the case when the heat transfer is determined by the conductivity through the point of physical contact, \(\alpha_P > \alpha_M\). This situation is explained by the historical development of these investigations. The first and most fundamental works arose out of engineering fields associated with turboconstruction, atomic power, and rocket and aeronautical engineering. The mechanical and thermal models on which the calculation of \(\alpha_P\) is based have been sufficiently well studied [1, 2]. The conductivity \(\alpha_M\) plays the role of a correction here, and has been less thoroughly studied than \(\alpha_P\). In instrument-making, the main contribution to the heat transfer through the contact area is often the conductivity of the intercontact medium \(\alpha_M \geq \alpha_P\), which is explained both by the small specific pressure \(1-50) \cdot 10^5 \text{ N/m}^2\) and by the use of greases and pastes with high thermal conductivity \(\lambda = (0.1-3) \text{ W/m} \cdot \text{K}\).

It was also noted that on changing the medium filling the intercontact region the conductivity \(\alpha_M\) does not change in proportion to the change in thermal conductivity of the medium

\[
\frac{\alpha_M}{\alpha_M} = \frac{\alpha_M - \alpha_P}{\alpha_M - \alpha_P} \neq \frac{\lambda_M}{\lambda_M}.
\]

Here \(\alpha_M\) are the total contact conductivities for different filling media with thermal conductivities \(\lambda_M\); \(\alpha_P\) are the conductivities through the contact point; \(\alpha_M\) and \(\alpha_M\) are the conductivities through the medium.

In the light of the above factors, the model of heat transfer was refined, and the appropriate changes