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Calculation of Contact Pressures in Cylindrical Metal-Polymer Sliding Guides

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ABSTRACT

Guides (linear plain bearings) of reciprocating motion are widely used in many areas of human activity. However, at present there are no reasonable methods for their calculation, in particular metal-polymer guides. The author's method of contact strength calculation of cylindrical metal-polymer sliding guides is presented in the article. The effect of load, bushing diameter and radial clearance on the maximum contact pressures and their distribution in the guide was studied on the example of epoxy-based polymer composite material Moglice of the German company DIAMANT Metallplastic GmbH, which is used to restore tribotechnical sliding systems elements. Quantitative and qualitative regularities of dependence of contact pressures on the accepted factors of influence are established: at loading increase four times the maximum contact pressures and contact angles will increase twice irrespective of change of sizes of a radial clearance and diameter of a base; increasing the base diameter leads to a directly proportional decrease in maximum contact pressures; doubling the radial clearance leads to a √2 - fold increase in pressure, regardless of changes in the magnitude of the load and the diameter of the base. Regularities of change of contact parameters from the specified factors are given graphically.

Keywords: cylindrical metal-polymer guides, calculation method, maximum contact pressures, contact angles.

INTRODUCTION

Guides are designed to ensure the relative movement of moving parts of various equipment and mechanisms. Guides of rectilinear movement of elements are widespread in mechanical engineering. These include both flat and cylindrical reciprocating guides (linear plain bearings), which are widely used in many areas. Despite the practical necessity of the design calculation of contact pressures in metal-polymer guides in the literature there are no sound methods and solutions based on them. The peculiarity of these hybrid friction units is that the strength characteristics, and especially the modulus of elasticity of metallic and non-metallic materials, are significantly different. Known in the literature calculation methods [4÷6, 8, 9 etc.] of plain bearings with metal elements were not used to estimate the contact parameters for cylindrical guides with metal elements. Only in [7] the contact interaction of a thin elastic layer on a rigid bushing of a sliding bearing during reciprocating motion was considered. In [1÷3] the author's method of calculating contact pressures in plain bearings with metal elements, including for this type of guides [2], was given. Also in [10] the calculation of contact parameters and friction forces in metal cylindrical sliding guides was performed.

This article presents a method for calculating metal-polymer cylindrical sliding guides with a bushing made of polymer composite Moglice and presents the results of the evaluation of contact parameters.

METHODS

A cylindrical guide of rectilinear reciprocating motion (Fig. 1a) is modeled by an elastic base 2, on which a slider 3 with a pressed-in non-metallic bushing 1 is located (Fig. 1b).

There is a radial clearance $\varepsilon = R_1 - R_2$ between the polymer bushing 1 with an inner radius R_1 and the steel base of the radius R_2. The guide materials have different characteristics of elasticity and strength. Slider 3 is under the influence of the working force $F = const$. For this reason, contact pressures $p(\alpha)$ arise in the contact area $2\alpha_0$. The solution of the problem is carried out as a static plane contact problem of the elasticity theory for a cylindrical contact of cylindrical bodies of close radii loaded by a reduced radial force $N = F/l_1$.

The singular integral differential equation of the considered plane contact problem for determining the arising contact pressures in the conjugation of cylindrical close radii at their internal contact is presented in [1, 2]. Its solution was carried out by the collocation method [2, 3] using the contact pressure function of this type.

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$$p(\alpha) \approx E_0\varepsilon\sqrt{\tan^2\frac{\alpha_0}{2} - \tan^2\frac{\alpha}{2}} \quad (1)$$

where: $E_0 = (e/R)\cos^2(\alpha_0/4)$ is the collocation coefficient; $e = 4E_1E_2/Z$, E is Young's modulus; $\kappa = 3 - 4\nu$ for the state of plain deformation; ν is Poisson's ratio; $Z = (1 + \kappa_1)(1 + \nu_1)E_2 + (1 + \kappa_2)(1 + \nu_2)E_1$; $\alpha = \pm 0.5\,\alpha_0$ are the collocation points.

Since practically it is important to estimate the value of the maximum contact pressure $p(0)$ acting at $\alpha = 0$, this pressure is calculated by the formula:

$$p(0) = E_0\varepsilon\tan\left(\frac{\alpha_0}{2}\right) \quad (2)$$

The contact semiangle α_0 characterizing the contact zone of the contacted bodies for the accepted value of the load N is determined by the following equation:

$$N = 4\pi R E_0\varepsilon\sin^2\left(\frac{\alpha_0}{4}\right) \quad (3)$$

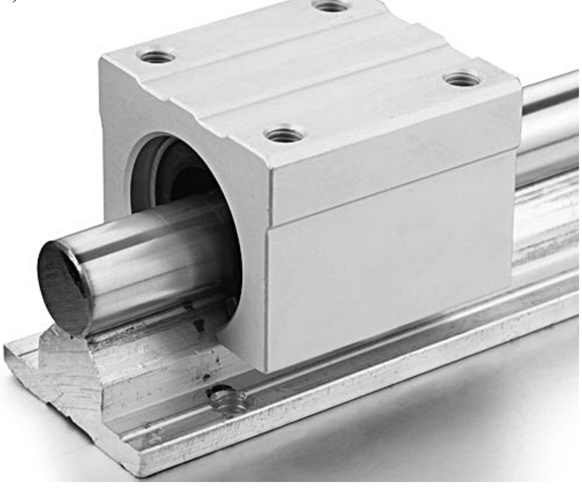
SOLUTIONS

The guide with one base is considered. Data for calculation: F = 500, 750, 1000, 2000 N; $N = F/l_1$ = 5, 7.5, 10, 20 N/mm, l_1 = 100 mm is the length of the bushing, l_2 = 500 mm is the length of the base; K_2 = 0.2, K_1 = 1; ε = 0.05, 0.075, 0.1 mm (clearance fit H9/d9); D_2 = 40, 50 mm. Guide materials: slider bushing: polymer composite Moglice (Table 1); base: steel 45 - E_2 = 210000 MPa, ν_2 = 0.3.

The results of calculation of the maximum contact pressures $p(0)$ and the contact angles $2\alpha_0$ are given in Fig. 2 - 5. Solid lines show graphs for D_2 = 40 mm, and dashed lines correspond to D_2 = 50 mm.

Figure 2 shows the dependence of the maximum contact pressures $p(0)$ on the load N at different radial clearances ε in the connection.

a)



b)

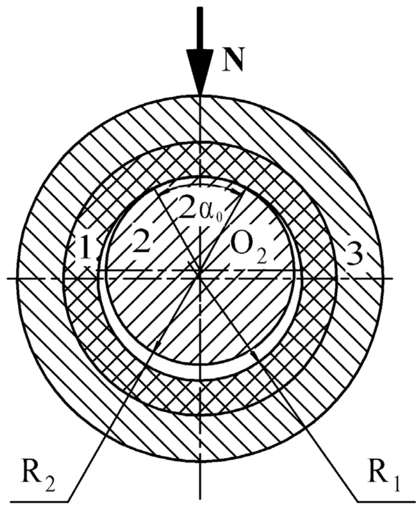


Fig. 1. Cylindrical sliding guide: a) general view, b) calculation scheme

Table 1. Physical and mechanical characteristics of the Moglice composite

Characteristics	Units	Value
Density	g/sm³	1,7
Young's modulus	MPa	11200
Poisson's ratio	-	0,4
Compressive strength	MPa	120
Flexural strength	MPa	64
Coefficient of friction on steel (lubricated)	–	0,08 – 0,95
Shore hardness (maximum)		90
Heat resistance: - short-term - long-term	°C	-40 … +125 -20 … +60

There is an almost linear dependence of *p*(0) on *N* at different radial clearances and both studied diameters. With increasing load *N* 4 times in the range of 5, 7.5, 10, 20 N/mm (4 times), the maximum contact pressures *p*(0) increase 2 times regardless of the change in the values of the radial clearance ε and the guide base diameter D_2. Increasing the base diameter D_2 by 1.25 times causes a proportional decrease in pressure *p*(0).

The dependence of the maximum contact pressures *p*(0) on the radial clearance ε at different loads *N* is shown in Figure 3.

As the radial clearance increases, the pressures *p*(0) increase almost linearly. Although in the case of a larger diameter, this dependence is close to linear. The doubling of the radial clearance *e* leads to an increase in pressure *p*(0) by 1.2 times, regardless of the change in the load *N* and the base diameter D_2.

The dependence of the initial contact semi-angle α_0 on the load is shown in Figure 4.

The qualitative nature of the increase in the angle α_0 depending on the load is similar to the increase in pressure *p*(0), i.e. it is almost linear. However, here, when the base diameter D_2 changes, the radial clearance ε at the same load does not affect the value α_0, which is regular according to equation (3). It is established that with increasing load 4 times the angles α_0 double.

It is established that doubling the radial clearance leads to a decrease in the angle α_0 by √2 times at all values of the load.

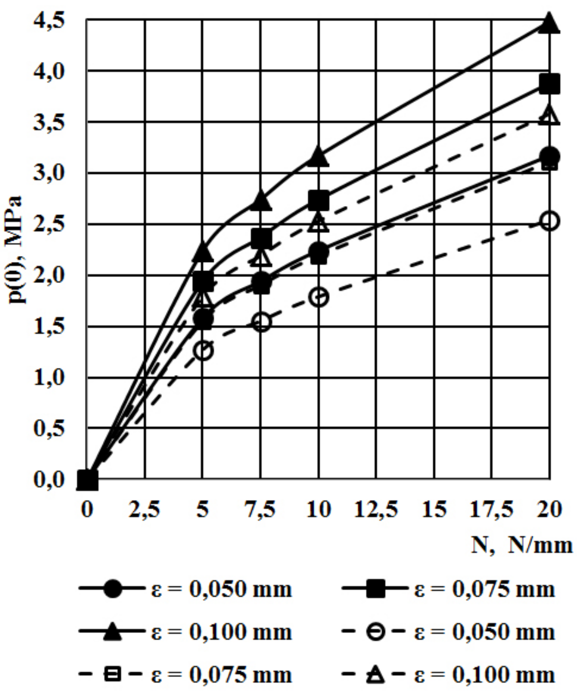


Fig. 2. Influence of load on maximum contact pressures

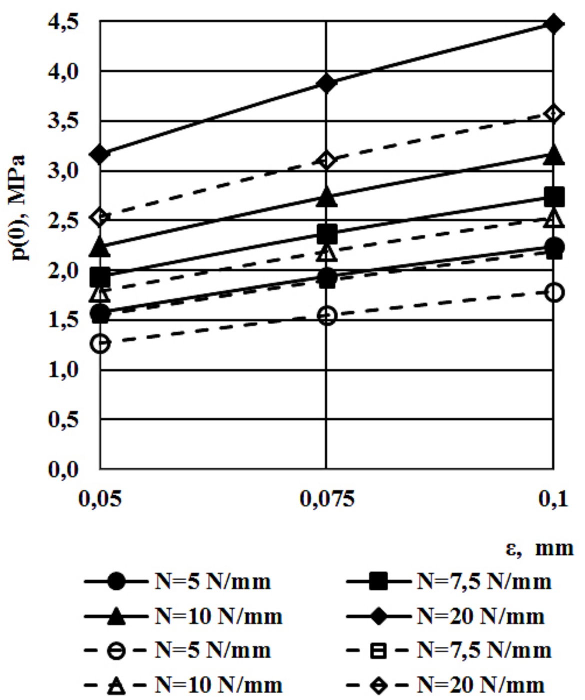


Fig. 3. Influence of radial clearance on maximum contact pressures

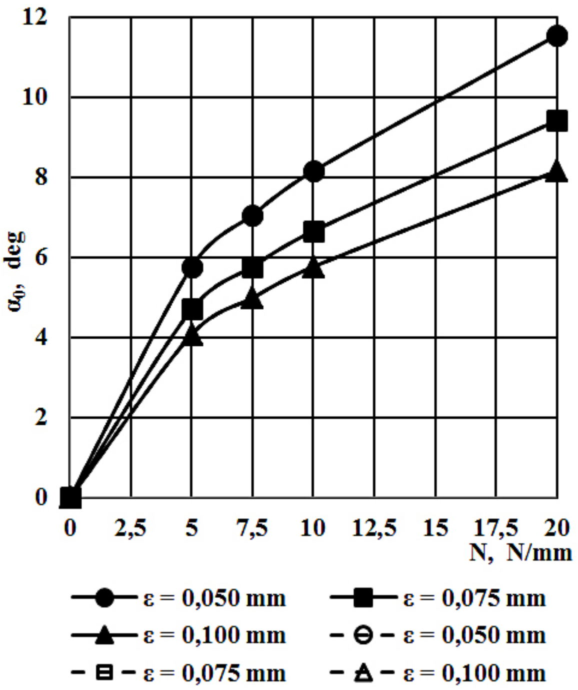


Fig. 4. The effect of load on the contact angle

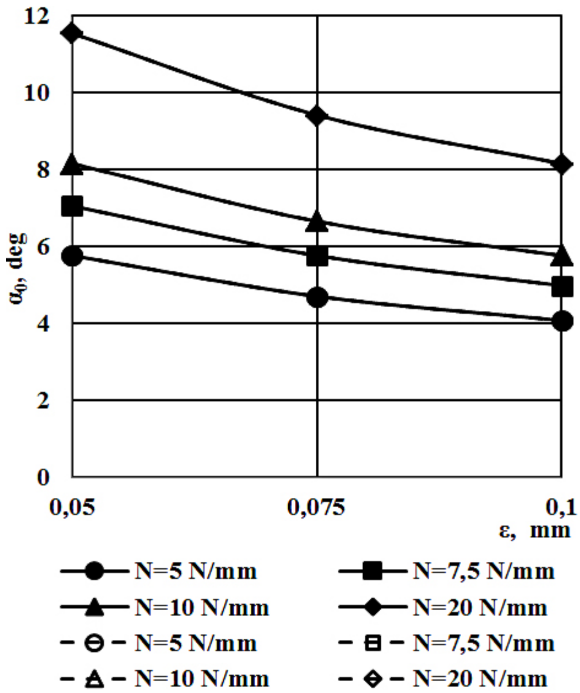


Fig. 5. Influence of radial clearance on contact angles

CONCLUSIONS

According to the proposed method of contact strength calculation the research of cylindrical metal-polymer sliding guides is carried out. The epoxy-based polymer composite material Moglice of the German company DIAMANT Metallplastic GmbH, used in tribotechnical sliding systems, was chosen for the slider bushing. As a result of solving the contact problem, quantitative and qualitative regularities of the dependence of the maximum contact pressures on the load applied to the slider, the diameter of the bushing and the radial clearance in the connection are established. Qualitative dependences of the effect of load on both the maximum contact pressure and the contact angle are similar. These numerical results indicate the effectiveness of the presented method for estimating the contact parameters in engineering practice for the cylindrical guide designing.

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