Application of the photoelasticity method for studying the stress-strain state of the tribomechanical system “ring-bearing housing”

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Abstract. In this paper, we consider the use of the polarization-optical method for assessing the stress-strain state of films of polymeric material in the restored tribomechanical system “bearing ring - housing” and the dependences for determining the magnitude of the principal stresses are proposed.

When studying the stress-strain state, compounds with a diameter of the contact surface of 40 mm from an optically sensitive material imitating an adhesive layer were used as models. The photoelasticity method showed that the maximum stresses occurred on the axis of symmetry of the model, and the contact arc was 180 degrees. A qualitative picture of the strips indicates the identity of the stress-strain state of the adhesive joint model both for the uniform gap model and for the eccentricity models.

1 Introduction. In the practice of repair production, to restore the operability of the tribomechanical system “bearing ring - housing”, polymeric materials based on polyfunctional acrylic compounds are used [1]. A feature of the application of such materials is their low elastic modulus [2, 6, 7]. As a consequence of this, there is a need to reasonably assign a minimum level of mechanical properties depending on the degree of wear and geometry of the joint, which in turn requires investigation of the stress state and assessment of the strength of materials in contact with the bearing ring and the housing. This task is complicated by variable loads and operating temperatures, which can change the state of the polymer from elastic to plastic. In this regard, apparently, the polarization-optical method (photoelasticity method) is the only possible method for studying the stress state of thin polymer interlayers in contact problems.

2 Materials and methods. The polarization-optical method is an experimental method for analyzing the stress-strain state of objects, based on the anisotropy of optically sensitive materials under loading.

Photoelasticity allows interpretation of the pattern of bands across the field, to evaluate the nominal values of stresses and gradients, to conduct quantitative measurements. In particular, it is
possible to determine the directions of the principal stresses at all points of the photoelastic model, the magnitude and sign of the tangential stresses along the free boundaries and in all areas where the stress state is uniaxial; in the case of a plane stress state, the magnitude and sign of the difference between the principal stresses at selected points of the object under study [3].

The photoelasticity method [1,8] is based on the study of not the parts themselves, but their models.

To study the stress-strain state, models with an affine similarity (that is, with increased thickness) were used as models of a tribomechanical system “bearing ring - housing”, since the thickness of real layers of polymer material in the restored tribomechanical system “bearing ring - housing” does not exceed as a rule, 300 microns [4].

As models, compounds with a contact surface diameter of 40 mm were used. The model consisted of housing K and optically sensitive material C (Figure 1). The model of polymer interlayer C was made of evacuated epoxy resin ED-20, cured at room temperature using PEPA (polyethylene polyamine), modified TEG (triethylene glycol) [5].

![Figure 1. Qualitative distribution of the difference of the main stresses in the model](image)

Models made of optically sensitive material (adhesive bonding immitant) were made for uniform clearance between the bearing ring and the housing, and with an eccentricity styling wear of the rolling bearing bore in the gearbox housing.

The wall thickness of the model (Figure 2, a) h of an optically sensitive material for a uniform annular gap (Figure 2, b) was - 10 mm, for a model with an eccentricity - 20 mm (Figure 2, c).

The model was loaded using a ball bearing 203 with a radial load of 300 N. The value of the load was selected from the condition of the elastic behavior of the optically sensitive material.

A Zeiss-300 circular polariscope was used to observe the patterns of the bands; the patterns were recorded using a digital camera [9].
Figure 2. Models for the study of stress-strain state

The polarization-optical method for assessing the stress-strain state allows us to determine the difference between the principal $\sigma_r - \sigma_\theta$ and tangential stresses $\tau_{r\theta}$ for any point in the model.

The equations for determining $\sigma_r - \sigma_\theta$ and $\tau_{r\theta}$ have the following form [5]:

$$\sigma_r - \sigma_\theta = \sigma_0^{(1)} \cdot \frac{m}{t} \cos(2(\theta - \alpha))$$  \hspace{1cm} (1)

$$\tau_{r\theta} = \frac{\sigma_0^{(1)} \cdot m}{2t} \cos(2(\theta - \alpha))$$  \hspace{1cm} (2)

where $m$ is the strip order at the considered point of the model;
$\sigma_0^{(1)}$ is the optical constant of the model material;
$t$ is the thickness of the flat model;
$\alpha$ is the band parameter;
$\theta$ is the angular coordinate of the model point.

The optical constant of the model material was determined in accordance with the method described in [8] and amounted to $0.046 \text{ N/mm}$. Dependencies (1) and (2) do not allow determining the stress components $\sigma_r$ and $\sigma_\theta$. Except that on the free contour of the polymer interlayer, where $\sigma_r = 0$, it is possible to determine the stress values $\sigma_\theta$ from dependence (1).

Differentiation of equations (1) and (2) in polar coordinates we get:

$$\begin{align*}
\frac{d\sigma_r}{dr} + \frac{1}{r} \cdot \frac{d\tau_{r\theta}}{d\theta} + \frac{\sigma_r - \sigma_\theta}{r} &= 0 \\
\frac{d\sigma_\theta}{dr} + \frac{1}{r} \cdot \frac{d\tau_{r\theta}}{d\theta} + \frac{2\tau_{r\theta}}{r} &= 0
\end{align*}$$  \hspace{1cm} (3)

The second equation of system (3) in a graph-analytical way allows us to determine the values of normal stresses $\sigma_\theta$ from the contact arc of the polymer layer [5].

To determine $\sigma_\theta$, we transform equation (3) into the form:

$$\sigma_\theta = \sigma_\theta_0 - \int_{\theta_0}^{\theta} \left( r \frac{d\tau_{r\theta}}{dr} + 2\tau_{r\theta} \right) d\theta$$  \hspace{1cm} (4)

Denote the expression $\left( r \frac{d\tau_{r\theta}}{dr} + 2\tau_{r\theta} \right)$ by $f(\theta)$, then:

$$\sigma_\theta = \sigma_\theta_0 - \sum_{i=1}^{n} \frac{f(\theta_{i-1}) + f(\theta_i)}{2} (\theta_i - \theta_{i-1})$$  \hspace{1cm} (5)

Thus, equations (2) and (5) make it possible to determine the values of normal stresses $\sigma_\theta$ at the points of the contact surface of the adhesive joint.
The ordinates of the functions \( f(\theta) \) under the sum sign in dependence (5) are determined by the addition of the products \( \left( \frac{d\tau_{r\theta}}{dr} \right)_i \) with the corresponding doubled values of the tangential stresses \( \tau_{r\theta} \).

3 Results and discussion. The experiments show that on the internal unloaded contours of the models, one can choose such points for which \( \sigma_{\theta} = 0 \), or determine by expression (1). Thus, the unloaded contour of the glue line in the tribomechanical system makes it possible to find the boundary values of the quantity \( \sigma_{\theta0} \) involved in equation (5).

Figure 3 shows the qualitative picture of the distribution of the main stresses in the model.

![Figure 3. Qualitative distribution of the difference of the main stresses in the model](image)

Observation of the picture of isoclines (trajectories of the main stresses) showed that the main sites are located along the radius and circumference. Maximum stresses occurred on the axis of symmetry of the model. The contact arc was 180 degrees. A qualitative picture of the strips indicates the identity of the stress-strain state of the adhesive joint model, both for the uniform gap model and for the eccentricity models. In this case, the same amount and shape of isoclines are observed in different models. The number of isoclines increases with increasing load in all types of models.

Obviously, at zero clearance, the contact area “outer bearing ring - polymer layer” does not change, and therefore the stress value at any point in the model is proportional to the load (linear problem).

Experimental studies show that maximum stresses occur on the axis of symmetry, while the contact arc is 180 degrees.

4 Conclusions.

1. A calculation-experimental method is proposed for assessing the stress-strain state of a polymer film in a tribomechanical system “bearing ring - housing”.

2. The study of the stress-strain state of polymer films by photoelasticity showed that the maximum stresses occurred on the axis of symmetry of the model, the contact arc was 180 degrees;

3. A qualitative picture of the strips indicates the identity of the stress-strain state of the adhesive joint model, both for the uniform gap model and for the eccentricity models.

4. The number of isoclines for all models is identical and increases with increasing load on the model.

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