Experimental study of profile connections of auxiliary tool multi-purpose machines in cyclic loading

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Abstract. At present wide application in the machine tool industry has a professional connection with equiaxed circuit. These torque transmission connections have a number of operational advantages over traditionally used such as: high accuracy, stiffness, wear resistance, strength and vibration resistance. The practice of using these compounds in the critical nodes of metal-cutting machines in particular multi-purpose CNC machines has shown that these compounds have high flexibility in the requirements for reusable assemblies of the connection when replacing technological sets of tools. Experimental studies of these compounds of models made of optically active material allowed us to study the processes of contact interaction of parts of the compound under cyclic loading.

1. Introduction

The use of the modular principle of the construction of multi-purpose machines (MS), proposed and developed by Professor Averyanov O. I. [1, 2], allows one to solve a number of scientific and practical problems. They are related to ensuring high accuracy and rigidity of individual modules of the machine through the introduction of innovative torque-transfer connections with the profile surface of the coupling parts.

Let us consider the modular system of the auxiliary tool.

According to research works [1, 2, 3, 4] the system includes three subsystems of the auxiliary tool (PVI), namely:

1) PVI for CNC drilling and boring and milling groups;
2) PVI with a cylindrical shank for a CNC turning group;
3) PVI with a basing prism for a CNC lathes group.

The first subsystem of the auxiliary tool, which is used in the MS, is of greatest interest. It should be noted that for connection with the spindle of the machine, tool mandrels with a cone 7:24 with a round cross-section profile are used, as a rule. In some intermediate, the pump is used as a tool joint with a Morse taper, collet and coupling of tools with the cylindrical shank.

The automatic replacement of the toolholder with the taper 7:24 is necessary to ensure the position accuracy of PVI, as well as stiffness in the process of operation of the IPU. Increasing requirements for the quality of the MS accuracy and performance with a significant increase in the number of spindle speeds up to 45000 rpm determine correspondingly high requirements for connections, which often do not meet the traditional and special taper 7:24.

Improving the design of joints based on mandrels SK, HSK and HSK does not always meet the requirements for technological and operational reliability of MS. First of all, this is due to the axial and transverse movements and angular rotations of the PVI during the rotation of the tool mandrels before processing the products, as well as during the manufacture of products [5, 6]. This leads to a decrease in the accuracy of manufacturing products due to the change of bases in the spindle - auxiliary tool - cutting tool. Attempts to improve the accuracy of the quality of the geometry of the shape of the landing surfaces of the mandrels in their manufacture do not allow one to fully ensure the required accuracy, for example:
the diametrical size of the main bearing holes in the housing parts; deviation from the alignment with the
overall axis of the landing surface of the holes for different types of bearings, as well as a number of other
technological requirements. There are known works [5, 6, 7] which considered and solved with the
replacement of the traditional connections on the profile with the equiaxed contour of the cross section with
higher precision and rigidity. At the same time, there are unexplored questions of changes in elastic
displacements in the joints of compounds, which is important not only for determining the contact stiffness of
the compound, but also for assessing their bearing capacity under cyclic loading.

As is known, the machining of products of the auxiliary tool is under the action of alternating forces.
The combined effect of contact pressure and cyclic shear micro-displacements, which are the result of
elastic deformations of the conjugated parts of the auxiliary tool, can be the cause of fretting wear.

2. Materials and methods

The article presents the results of experimental studies of models of the progressive moment because
connections of details of TK MS occur on the basis of the relevant compounds by the static photoelasticity
method.

Polarization-optical methods are widely used in the study of contact problems. Polarization-optical
methods, characterized by visibility, allow us to investigate not only the stress state of the interacting bodies
throughout the volume and determine the components of the stress tensor, but also visually track how the
VAT changes when the position of the interacting bodies relative to each other in the implementation of
loading schemes.

The theory of similarity and dimensions were developed in the works of M. M. Frocht, N. So.
Prigorovsky, O. K. Slavin, N. D. Tarabasova [8], allow solving a wide class of contact problems and with
a sufficient degree of accuracy to assess the stress state in nature and model.

3. Study of stress-strain state of compounds

In order to study the VAT profile connections, we made models of the shaft and hub with the equiaxed
contour. An optically active compound based on an epoxy resin cured with maleic anhydride (ED16-M)
was used as the material of the models. The thickness of the plates of the material of the models is \( b = 6 \)
mm. The accuracy of determining the contact angles and the difference of the main stresses was provided
by both the technology of making models and the technique of the experiment. Each coupling model was
a hub and shaft with an equiaxed contour (figure 1-2).

Thus, the study of RK-3 profile-based connection of models of the polarization-optical method has made
it possible to evaluate the influence of radial clearance operating conditions (load cases) and the values of
the angles characterizing the position of the parts of the connection, the indirect account of an error of a
form to change the values of the contact angle and the maximum shear stresses in the interface zone.

During the experiment, for each case of loading, the positions of the profile connection with respect to
the direction of the line of action of the radial force were investigated. It was assumed that the distribution
of the load on the contacting surfaces at a particular loading scheme depends on the adopted position,
characterized by the position angle \( \psi \).

It is established that the nature of the change in the value of the contact angle and shear stresses for each
of the three contact zones is different both in the transmission of torque by the connection and in the account
of the joint action of the radial load.

In the first case, this is due solely to the error of the geometric shape of the mating connection models.
In the second case, this is explained both by the error of the shape of the mating models and the
redistribution of contact stresses in the zones from the action of radial load (figures 1 and 2).

![Figure 1 Stress state of models 1, 2 in the scheme of loading by torque](image)
Figure 2 Stress state of models 1, 2 in the scheme of loading by torque and radial force

In the analysis of the graphic dependence of the contact angle on the external load during the transmission of the connection torque and radial force for the corresponding models 1, 2, 3, we set the change in the contact angle from the position of the connection.

The results of the assessment of the values of the contact angles allow one to draw the following conclusions:

1. The magnitude of the contact angles during transmission with the torque connection increases with increasing load, with the nature of the increase being close to linear.
2. The value of the contact angle during transmission by the connection of torque and radial force varies for each contact zone of the connection and depends on the value of the angle of the relative position $\psi$ of the connection.

The estimation of the values of maximum shear stresses is determined using the known dependence of Tymoshenko S. P.:

$$\tau_{\text{max}} = \frac{1}{2} \sigma_0 \cdot n,$$

where $\tau_{\text{max}}$ – maximum shear stress;
$n$ – the order of bands;
$\sigma_0$ – the price band model.

The order of the band is determined by counting the number of bands for each contact zone in the conjugation of the general picture of the stress state, which is fixed in the photo or on the screen BPU – IMASH-KB2.

The price of the strip model is determined by the formula of Freight M. M.:

$$\sigma_0 = \frac{\lambda}{2 \cdot c \cdot t} = \frac{\sigma_0^{0.1}}{t},$$

where $\sigma_0^{0.1}$ – the price of a strip of material equal to $\frac{\lambda}{2 \cdot c}$, obtained with a model thickness of 1.0 mm.

The price of a strip of material is established experimentally on coordinate-synchronous polarimeter KSP-7 by a compensation method.

According to the values of the maximum tangential stresses, the corresponding graphical dependences for the considered models of coupling, external load schemes and positions are constructed connections (figure 3).
To determine the influence of the radial load on the stress state of the joints, we made a comparative evaluation of the considered models of coupling 1, 2 for the most loaded contact zones in the transmission of torque, torque and radial force.

Comparative evaluation of contact parameters in different loading schemes and gaps showed a significant effect of the radial component of the complex load $F_r (M_r, F_r)$. Under the influence of radial load, the maximum shear stresses increased by 25%, with an increase in the contact angle by 36.9% for coupling model 1 and for coupling model 2 by 33% and 24.5%, respectively.

According to the research of Undacova N. S. and Suslov A. G. when working with RK-3 profile joints, the influence of the radial component of the complex load is significant from the point of view of fatigue fracture of the contact surfaces of joints, connections and wear.

According to the obtained experimentally values of angles of contact, the calculated values of maximum shear stresses, patterns of interference fringes, it is possible to assess the impact of design parameters (gaps) and operating conditions (load cases, regulations) on the stress state of the joints of the models profile joints.

It can be assumed that the influence of the radial force is noticeable, since it leads to a significant change in the values of the maximum tangential stresses in the contact interaction zone.

Since this preserves the number of contact zones, it can be assumed that this is due to the displacement of the shaft relative to the hub in the direction of the radial force by the number of elastic contact deformations.

In practice, it is proved that after a certain time of operation, under the action of variable shear stresses, the contact surface of this connection is destroyed at voltages below those that are reliably resisted under the action of a static load.

In the calculations of profile connections with the equiaxed contour, the initial data of the maximum shear stresses for the coupling models were taken. The stress state of the contact zones of the coupling models for different angular positions of the joint (at angles from 0° to 360°) was investigated, namely: the difference between the values of the maximum tangential stresses under the action of the torsion moment and the torsion moment and radial force was determined.

We set the limits, change the intervals of values of the difference of the values of the maximum shear stresses under the action of external loads during the period of connection, which set the cycles variable of the maximum shear stresses for each surface area of the corresponding model (figure 4).
The analysis of the research results showed that the change in the variables of the maximum shear stresses in the contact zone during the transfer of the complex load by the compound per revolution is subject to a periodic law that is close to sinusoidal. Since the magnitude of the shear stress amplitude also varies for the contact zones during the operation of the connection at the corresponding loading stage, it can be assumed that the joints of the profile connection operate under non-stationary conditions. The work of the profile connection in the conditions of variable shear stresses of small numerical values can be the

**Figure 4** Graphic dependences of change of the tangential stresses, MPa
cause of the process of fretting-wear joints, which reduces its operational reliability, namely: accuracy and contact stiffness.

4. Conclusion
1. As a result of the study of profile connections with an equiaxed circuit, it was found that under the action of radial load the maximum shear stresses increased by 25%, with an increase in the contact angle by 36.9%; for conjugation model 1 and for conjugation model 2 by 33% and 24.5%, respectively.
2. Calculations have established that the change in the values of the maximum shear stresses during the operation of the profile connection is subject to the pulsation cycle.

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