Interference joint of enhanced bearing capacity

I L Ryazantseva and O S Dyundik
Omsk State Technical University, 11, Mira Ave., Omsk 644050, Russian Federation

Abstract. State of the art technology implies the application of increasing power at high speeds, therefore various interference joints strength enhancing is an urgent task. On the basis of the review of the existing interference joints bearing capacity improving research methods, the approach being implemented by the joint internal member mounting surface modification with the help of grooves of shallow depth is proposed. The experimental results of the modification various parameters influence on the fit bearing capacity are presented. It is reasonable to use the given engineering solution for fit strength restoring when performing the repair work.

Key-words: modification, interference, bearing capacity, deformation wave, contact pressure

1. Introduction
Nowadays the technological progress development level includes the modern machines power and specific speed increase, therefore interference joints bearing capacity increasing problems are relevant. In papers [1] and [2], the bearing capacity estimating various methods mainly based on the technological ways of enhancing the fit strength are presented: the microgeometry optimization of mating surfaces and their cleaning; application of adhesive, abrasive and other layers; thermal and chemo-thermal treatment of one of the jointed parts and many others.
The proposals to increase the interference joints bearing capacity are known. The residual stresses in the material of one of the parts are proposed to be produced by autofrettage [3], burnishing [4], rolling [5] and thereby the adhesive (friction) forces of the joint are increased.

2. Problem statement
Interference joint bearing capacity is possible to be increased if the shallow depth grooves proportioned to the interference are produced on the mating surface of one of the jointed parts having a high hardness [6]. However, for realizing this method, it is necessary to solve the problem of defining the modification parameters influence on the fit strength.

3. Theory
Figure 1 a shows the joint modified by the ring grooves with the constant width of $l_x$, and the grooves are located at the equal distance of $l_j$ from each other. At the joint temperature assembling, external member 2 material is deformed in various ways at the different parts of the joint. Within the grooves, displacement in the radial direction is less than at the contact areas. Part of the material enters the groove (figure 1 b) while forming the deformation wave with a height of $\Delta U_2$ preventing the relative displacement of parts, in this case the axial displacement.
The bearing capacity of the joint with the modified mating surface depends on the type of the external member (bushing) material deformation. The material can undergo the elastic, elasto-plastic and plastic deformation. For the elastic deformation of the bushing material, the joint bearing capacity is defined by the value of the frictional force acting at the contact areas and depending on the contact
pressure value, as well as by the ability of each elastic deformation wave to resist the parts axial displacement.

With considerable interference and certain modification parameters, the case when part body 2 is deformed elastically, is possible. However, plastic deformation propagating to the shallow depth occurs in the contact areas by the groove boundaries, due to the material contact pressure concentration. The external member material flows into the grooves by increasing the deformation waves bearing capacity. In addition, the actual contact area and correspondingly the friction force increase. This loading case is more preferable.

![Figure 1. Interference joint modified by ring grooves.](image)

The most unfavorable case of loading is when plastic deformation propagating at a great depth and reducing the friction force at the contact areas occurs in the external member material. This type of joint bearing capacity is provided mainly by deformation waves filling the grooves partially or completely. Although the joint bearing capacity decreases, it continues to operate unlike the smooth cylindrical joint.

4. Experimental results

The joint geometry (\(l_g\) is the grooves width, \(n\) is the grooves number) influence on the bearing capacity of cylindrical joints with ring grooves was studied. Full-scale experiment which elements are completely presented in [5] was conducted. The joints modified by one and several ring grooves on the shaft mating surface were tested. Joints basic parameters are \(d=40\) mm; \(d_2=70\) mm; \(l_2=40\) mm, the maximum interference is 0.06 mm. The shaft material is 45X steel, the bushing material is 45 steel. The parts were normalized and hardened which led to providing the surface hardness of the shaft from 235 to 321 HB and of the external member from 163 to 248 HB. The examined joints strength depends on the contact surfaces hardness. For reducing the impact of this factor, the joined parts of each pair were selected so that the shaft fitting surface hardness to exceed the bushing surface hardness by 60÷100 HB. The required fitting surface smoothness was ensured by grinding.

In the joints with one groove (\(n=1\)) located symmetrically relative to the joint boundaries, the size \(l_g\) was 5 mm, 10 mm, 20 mm. In the joints modified by several grooves, which width and number were chosen so that the nominal contact area value to be at least 40÷50% of the joint geometric area. The joints with 2 grooves having a width of \(l_g=10\) mm, with 4 grooves having a width of \(l_g=5\) mm, with 8 grooves having a width of \(l_g=2.26\) mm and with 16 grooves having a width of \(l_g=1.44\) mm were tested. The grooves depth was 0.05 mm. The joints were assembled by the thermal method. The joint strength was evaluated by the maximum pressing-out force value corresponding to the parts relative shifting beginning. The hydraulic press 2PG-50 was used. Pressing-out efforts were recorded by means of the reading device having a scale value of 700 N.
Since the tested joints had different interference, then for their bearing capacity comparing the $R_{p.f.}$ criterion equal to the ratio of the pressing-out force to the interference, measured in millimetres was used. The pressing-out force dependence on the mating surfaces hardnesses ratio should be noted. In this regard, for each group of test joints the average value $P_{p.f.}^{av.}$ of the criterion $P_{p.f.}$ was defined.

The value $P_{p.f.}^{av.}$ dependence graph on the groove width $l_g$ of the joints with one groove on the shaft mating surface is represented in figure 2 a, and the value $P_{p.f.}^{av.}$ dependence graph on the grooves number $n$ is shown in figure 2 b. Besides, the criterion $P_{p.f.}$ limit values of every joint group including the smooth joint were illustrated in dotted lines in figure 2 a, b.

5. Results discussion

Test results showed that as the groove width increases (figure 2 a), the criterion $P_{p.f.}^{av.}$ increases and consequently the joint bearing capacity also increases.

In the joints with several grooves (figure 2 b) the size $l_g$ influence on the fit strength is ambiguous. Joints comparison by $P_{p.f.}^{av.}$ revealed that implementation of two grooves with a width of $l_g=10$ mm in the joint made possible to increase this criterion by approximately 19% on average as compared to the smooth joint, of four grooves with $l_g=5$ mm – by 40%, of eight grooves with $l_g=2.26$ mm – by 30%, and of sixteen grooves with $l_g=1.44$ mm resulted in the parameter reduction by 4%.

All the joints additional study by using the analytical calculation model described in [5] allows to make the following conclusion: in the joints with one groove having a width of $l_g=5$ mm and $l_g=10$ mm, the bushing material operates in the elastic zone, and at $l_g=20$ mm in the bushing material near the groove, plastic deformation propagating to the shallow depth and strengthening the joint develops. Consequently, the criterion value $P_{p.f.}^{av.}$ was increased by 110%.

In the joints having 2, 4 and 8 grooves on the shaft fitting surface, the bushing material operates in the elastoplastic loading mode. The calculation revealed that in the joints having 16 grooves in all pairs, the contact pressure exceeded the value at which a dangerous plastic deformation in the material decreases, which reduces the strength of the fit. The joints bearing capacity was mostly provided by the emerging deformation waves.

Deformation wave fixing effect is confirmed by the internal member contact areas surface state. In the joints modified by one groove, on the area with which the deformation wave interacted during pressing-out, the material plastic edging with scoring and scratching formation was observed. The wider the groove, the greater the site surface destruction was.
6. Conclusions
The joint modification by making the grooves of shallow depth on one of the fitted parts mating surface is an effective way to increase the interference joints bearing capacity. It is reasonable to use the given engineering solution for fit strength restoring when performing the repair work.

The bearing capacity of the joint with the modified mating surface is provided by the contact surfaces friction force of the contact areas and by the each deformation wave ability to resist the parts relative shifting. The wider the groove, the greater the deformation wave bearing capacity is.

The grooves are the contact pressure concentrators. If the contact geometric area decreases, its average value increases. In case of the irrational parameters, the groove joint modifications can cause the dangerous material plastic deformations and joint softening.

Grooved joints properties depend on the shape, size, position and number of grooves. The results showed that by changing the joint macrogeometry it is possible to increase their static bearing capacity by almost 100%.

For the joints with modified grooves, the operating mode in which elasto-plastic deformations occur in the material of the part having a smooth mating surface is preferable.

It is expedient to make the grooves on the mating surface of the part having a large surface hardness.

7. References
[1] Balackij L T 1982 Strength of Press Joints (Kyiv: Tekhnika)
[2] Klekovkin V S, Abramov I V and Shchenyatskij A V 1995 Press joints stress-strain state control Russian Engineering Research 9 20–2
[3] Klocke F and Liermann J 1998 Roller burnishing of hard turned surfaces Int. J. of Machine Tools and Manufacture 38 (5–6) 419–23
[4] Morozov V A, Fedotov G D and Abramov A E 2014 «Bushing-housing» interference joints loading capacity increase by volumetric electromechanical burnishing Vestnik of Ulyannovsk State Agricultural Academy 3 (27) 125–33
[5] Sekercioglu T, Gulsoz A and Rende H 2005 The effects of bonding clearance and interference fit on the strength of adhesively bonded cylindrical components Mater. Des. 26 (4) 377–81
[6] Ryazantseva IL 2015 Theory and Design of Interference Joints (Omsk: OmGTU)