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ASPECTS CONCERNING THE BEHAVIOUR OF ROLLING TRACKS UNDER LIMIT LOADS

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Abstract. *The paper presents results of experimental and theoretical research concerning remanent deformations which occur in rolling tracks when the contact pressure exceeds a certain limiting value. For bearings and ball-rolling tracks, the static loading capacity is defined for a maximum force which produces a remanent deformation* $\delta_{rem}=10^{-4}d$*. Experimental studies upon the behaviour of a ball-plane contact lead to relations for the dimensions of the plastic prints produced by contact forces. The favorable influence of the cold-hardening upon the rolling tracks resistance at contact deformation it is also revealed.*

1. GENERAL CONSIDERATIONS

In the functioning of the ball-bearings and of the rolling-tracks, the base static load capacity is defined as the applied force which generates in the most loaded contact a remanent deformation with a depth $\delta_{rem}=10^{-4}d$, where d is the diameter of the ball.

The overloading of the limiting force which causes plastic remanent deformations leads to the appearance of some prints, phenomena named "Brinelling", with negative effects in function - vibrations, noises accompanied by pulsant variations of the stresses and premature out of function for the machine parts.

According to plasticity criterion Huber-Mises-Hencky, the passing into the plastic stress field is done when the magnitude of the stresses σ_i is equal to the traction flowing limit $R_{p0,2}$ for the material.

According to plasticity criterion Tresca, the passing into the plastic zone takes place when the maximum tangential stress is $\tau_{45^\circ \max} = R_{p0,2}/2$ corresponding to a value $\tau_{45^\circ \max} = 0.31\sigma_0$, where σ_0 is file hertzian contact pressure at a relative depth $z/a = 0.48$ from the contact surface, where z is the depth and a is the radius of the contact ellipse.

Establishing the decisive stresses as function of the hertzian contact pressure, for the

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steel used in bearings and rolling tracks industry the critical value for the limit hertzian pressure σ_{0cr} = 3.4GPa, is obtained.

The plastic deformation in hertzian contact contains three stages:

- flattening of the roughness, with deformation's growths of about 0.1µm;
- rising of the plastic deformations, a contact surface being obtained;
- overloading of the elasticity limit yields to the volume deformation, with deformations with growths over 1µm.

Between those, it is underlined the relation deducted by Orlov and Pineghin in the ball-plane contact, for pieces from bearing steel heat treated at 60...62 HRC and roughness conditions R_a=0.1...0.3µm:

$$\delta_{rem} = 5.6 \cdot 10^{-13} d \sigma_0{}^{4.15} \; [\mu m] \tag{1}$$

where δ_{rem} is the depth of the print, d is the diameter of the ball, in [mm] and σ_0 is the maximum herzian contact pressure, in [daN/mm^2].

The factors which determine the topography of the plastic prints are multiples: the force applied in the contact, the configuration of the surfaces, the hardness and the structure of the materials, the microgeometry of the surfaces and the number of the loading cycles.

Next will be shown an experimental results set concerning the behaviour of the rolling tracks for the machine parts like ball runways and ball bearings at limiting loads.

2. EXPERIMENTAL TESTS

The experimental study used heat treated (61 HRC) bearing steel prismatic samples and a set of balls with diameters between 6 to 15mm. The parameters studied were the hertzian contact pressure σ_0 and the diameter d of the ball, which influence the depth of the print δ_{rem} and its diameter d_{am}.

At the passing to the plastic deformations field, the classical relations for the hertzian pressure are not valuables any more, because the contact area progressively rises and than the real pressure σ_{real} is lower. According to that, to calculate the loading forces needed to the tests, the study made by Pineghin was used, which enables to obtain the ratio σ_{real} / σ_0, for a range of contact pressures between 2.5 and 6GPa.

Figure 1 shows this aspect. The topography analysis of the prints was made using a T30-Kalibr profilometer-profilograph.

2.1. Static tests

In order to load the ball-plane contact, a Brinell apparatus modified with appropriate devices, was used. The loading period was established to 30 seconds, time, which proved itself enough for the print's topography stabilization.

To interpretate the experimental results was used a calculation program with the following recursive relations:

$$\delta_{rem} = C_1 d^{x_1} \sigma_0^{x_2} \tag{2}$$

$$d_{am} = C_2 d^{x_3} \sigma_0^{x_4} \tag{3}$$

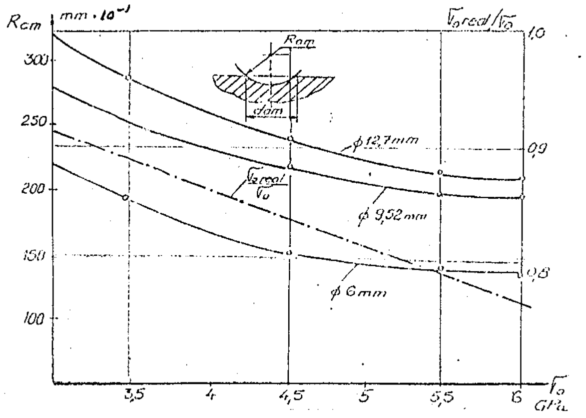

Fig. 1. Shape for the residual deformations

The statistic treatment for 360 experimental results yields the following calculation relations:

$$\delta_{rem} = 1.55 \cdot 10^{-5} d^{1.24} \sigma_0^{3.58} \quad [\mu\mathrm{m}] \tag{4}$$

$$d_{am} = 0.052 d^{0.64} \sigma_0^{1.25} \quad [\mathrm{mm}] \tag{5}$$

The figure 2 shows some results obtained, which prove a good correlation. The relation (4) can be used to calculate the static loading capacity, by introducing the condition $\delta_{rem} = 10^{-4} d$ and obtaining the limit value for σ_0.

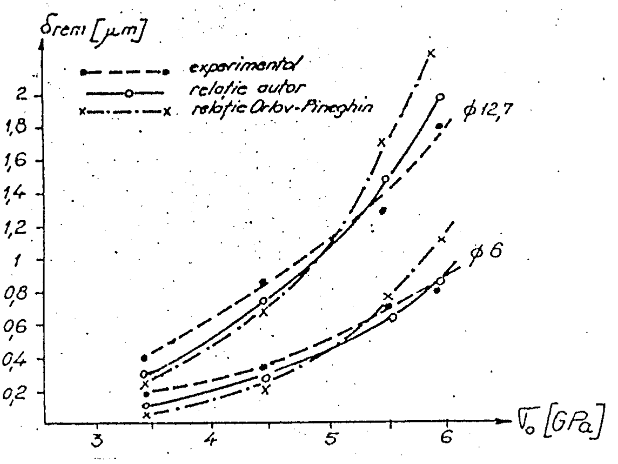

Fig. 2. Depth of the residual deformations.

2.2. Dynamic tests

The dynamic tests were made using a special installation, where the static loading is obtained with weights, and the dynamic one is applied over it. To obtain that was used an electrodynamic vibrator with frequencies between 100...350Hz its generating force being settled as function of the electric parameters and verified with a tensometric device. It was followed that the maximum contact pressure to have values comparable with the static loading values. Comparing the results obtained, it is proved that in dynamic loading tests the depth of the prints is 12-l5% higher than in the similar static loading.

3. EFFECT OF THE COLD HARDENING ABOUT THE BEHAVIOUR UNDER LIMIT LOADS

The cold hardening of the rolling tracks it is an useful process in order to ameliorate some characteristics concerning the resistance at contact deformation. Using a hardening technology by rolling with balls the active surfaces [7] the following effects are obtained:

- flattening of the roughness, the initial roughness becoming 22-37% lower;
- hardening of the surface layer to a depth which depends by the ball diameter and the working pressure, growing of 85-100HV for the microhardness being registered;
- arising of some residual compressive stresses in the surface layer, favorable in the contact's working;
- modification in structure of the hardened layer, which becomes more fine and with less residual austenite.

Between these effects, the residual stresses distribution have the most important influence about the growing of the contact resistance for the surface layer.

So, analyzing the tensor of the residual stresses on the contact's axis, where $\tau_{xy}=\tau_{zy}=\tau_{xz}=0$, the magnitude of the stresses is:

$$\sigma_{ech_0} = \frac{1}{\sqrt{2}}\sqrt{\left(\sigma_{x_0}-\sigma_{y_0}\right)^2+\left(\sigma_{y_0}-\sigma_{z_0}\right)^2+\left(\sigma_{z_0}-\sigma_{x_0}\right)^2} \tag{6}$$

and it arise to a depth $z = 0{,}48a$, where a is the radius for the contact area, its maximum value being $\sigma_{ech_{0\max}} = 0.620\sigma_0$.

In the presence of the residual stresses σ_{xR} si σ_{yR} the magnitude of the stresses becomes

$$\sigma_{ech_R} = \frac{1}{\sqrt{2}}\sqrt{\left(\sigma_x+\sigma_{xR}-\sigma_y\right)^2+\left(\sigma_y+\sigma_{yR}-\sigma_x\right)^2+\left(\sigma_x+\sigma_x-\sigma_{xR}\right)^2} \tag{7}$$

Because the plastic deformation arise when $\sigma_{ech_{\max}} = R_{p0,2}$ it can be appreciated that the resistance at contact deformation grows with the ratio:

$$c_\sigma = \frac{\sigma_{ech_{0\max}}}{\sigma_{ech_{R\max}}} \tag{8}$$

The figure 3 shows the residual stresses σ_{xR} si σ_{yR} obtained on a sample rolled with a ball ϕ 9.52mm to a pressure σ_0 =5.5GPa and 4 passes. Making the numerical calculus for this concrete situation, according to the methodology of the contact's theory results a growing coefficient for the resistance at the contact deformation $c_\sigma = 1.33$.

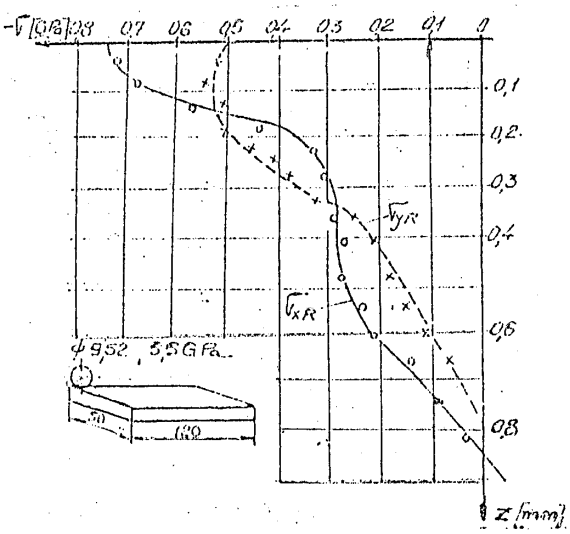

Fig. 3. Residual stresses in ball rolling.

That means in practice a growth of the static loading capacity by 1.95 times comparing to a non hardened rolling track.

The experimental tests underlined that to obtain the prints on the hardened surface we need forces of 1.75-1.95 times higher than for common surfaces.

So, the mechanic hardening it's an efficient method to increase the available capacity for the rolling tracks.

REFERENCES

1. Stribeck, R., Kugellager für Celiebige Belastungen, Z.A.D., S1-Berlin, 1970.
2. Palmgren, A., Grundlagen der Walzlagertechnik, Stockholm, 1954.
3. Orlov, A.V., Pineghin S.V., Ostatocinîe napriajenie i deformatii pri contactnovo nagrujeni, Masinostroenie, Moskva, 1971.
4. Cefranov, E., Codrescu, C., Comportarea ghidajelor cu rostogolire la sarcini limitfi, TEHNOMUS 1984, Suceava.
5. Cefranov, E., The influence of Surface's Layer Cold Hardening's about the Loading Capacity of the Ball Races, VAREHD 1992, Suceava.
6. Cefranov, E., Studii si cercetãri privind ghidajele cu rostogolire, cu aplicatii în constructia masinilor-unelte, Teza de doctorat, Institutul Politehnic Iasi, 1989.
7. Cefranov, E., Cristea, S., Cercetari privind finisarea prin rulare a ghidajelor cu rostogolire, TEHNOMUS 1986, Suceava.
8. Cefranov, E., Geosu, C., Cajvan, M., Procedeu de finisare a ghidajelor - Brevet de inventie nr. 99911/1988, Romania.

USLOVI KOJI OPREDELJUJU PONAŠANJE VALJČASTIH VOĐICA KOD LEŽAJEVA PRI GRANIČNIM OPTEREĆENJIMA

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U ovom radu su izložena teorijska i eksperimentalna istraživanja remanentne deformacije koja nastaje kod valjčastih vodjica kada kontaktni pritisak dostiže graničnu vrednost.