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LONG-TERM STRENGTH OF UNIVERSAL SPINDLES

Abstract

Long-term strength of universal spindles is considered. The formula for admissible value of shaft rotations is obtained. It is proved that for providing the long-term strength of spindles the time of stationary state formation is to be increased.

In most modern rolling mills the transmission of torque to working rolls is realized by means of connections named universal spindles. The modern constructions of universal spindles allows to pass the significant torque arriving up to 3000 Nm, per one working roll at the inclination angle of spindle relative to the axis of working rolls achieving 8-10%. At present there exist many different constructions of universal spindles, but the principle placed on the base of their technology is the same it is scheme of the Hooke's joint [1].

We denote by t_0 the time of formation of stationary mode. By R denote the radius of a roller. In transversal sections of blade and crab there appear tangential stresses. If assume that the time of formation of the stationary state t_0 is sufficiently small and tangential acceleration is much greater than centripetal acceleration, and also the moments of inertial forces are much larger than moment of resistance then we'll assume that the stresses appear only due to the moment of inertial forces. If we assume that before the formation of stationary regime a roll rotates with constant angular acceleration ε then the tangential acceleration of rolls points will be

$$\omega_\tau = \varepsilon \cdot r \tag{1}$$

where r is a radius of current point of shaft, moreover $0 \leq r \leq R$.

Let's calculate the torque of inertial forces. For the element of shaft of length l with central corner $d\varphi$ and the radius r the mass dm will be

$$dm = \rho l r dr d\varphi$$

where ρ is a density of shaft material. Then the resultant of all inertial forces will be

$$F^u = \int_0^{2\pi} \int_0^R \rho l \varepsilon r^2 dr d\varphi = \frac{2\pi}{3} \rho l \varepsilon R^3 \tag{2}$$

Allowing for

$$\frac{d\omega}{dt} = \varepsilon$$

for angular velocity ω we have

$$\omega = \varepsilon t$$

At $t = t_0$

$$\omega(t_0) = \varepsilon t_0 = 2\pi n \tag{3}$$

where n is a number of rotations for per a unit of time. From (9)

$$\varepsilon = \frac{2\pi n}{t_0} \tag{4}$$

Subject to (4) from (2) we'll obtain

$$F^u = \frac{4\pi^2 l\rho n}{3t_0} \cdot R^3 \tag{5}$$

At $R = r$

$$F(r)^u = \frac{4\pi^2 l\rho n}{3t_0} \cdot r^3 \tag{6}$$

Then coordinates of application points of resultant force will be

$$r_0 = \frac{\int\limits_0^R F^u(r) \cdot r dr}{\int\limits_0^R F^u(r)\, dr} = \frac{4}{5}R \tag{7}$$

Subject to (7) for the torque we'll obtain

$$M_{kp} = \frac{4\pi^2 l\rho n}{3t_0} \cdot R^3 \cdot \frac{4}{5}R = \frac{16\pi^2 l\rho n}{15t_0} \cdot R^4 \tag{8}$$

It is known that the tangential stress in cross-sections is expressed by M_{kp} by the following form [2]

$$\tau_0 = \frac{M_{kp\cdot r}}{J_p} \tag{9}$$

where J_p is a polar moment of inertia of joint transversal section of palm and cylinder.

From (9) for maximal value τ_0 we have:

$$\tau_{0\max} = \frac{M_{kp}R}{J_p} = \frac{M_{kp}}{W_p} \tag{10}$$

where $W_p = J_p/R$ is a polar moment of impedance of joint cross-section of palm and spindle

Allowing for circular section

$$W_p = \frac{\pi R^3}{2}$$

we'll obtain

$$\tau_{0b} = \frac{2M_{kp}}{\pi R^3} \tag{11}$$

Substituting (8) in (11) we have

$$\tau_{0m} = \frac{32\pi l\rho n R}{15t_0} \tag{12}$$

As it is evident from (12) at small t_0 on rollers acts the large inertial force, i.e., practically the roller is exposed to the action of impact and as a result the larger amount of heat is released. It is known that with increasing of temperature the Young module and the yield point is also decreased [2]. Consequently, the end of way of active loading in the space of stresses situated inside the surface of loading is found to be beyond the surface of loading due to the decreasing of the ultimate stress. As a result during the time the creep strains appear.

In the paper [4] it is adopted the hypothesis on to the fact that the sum of maximal elastic works in two opposite directions in the space of stresses decreases per the value of work of viscous deformation. Proceeding from this hypothesis in the obtained destruction condition at creeping we assume that $J_1 = 0,\ J_2 = \tau_0^2$. Then the destruction condition has the form:

$$2\left(1+\nu\right)\tau_0^2 = 2\left|\sigma_T^2 - E\cdot\sigma_{ij}\varepsilon_{ij}^{\nu}\left(t\right)\right| \tag{13}$$

where E is a Young module, ν is a Poisson coefficient, σ_T is a yield point of roller material.

If we assume that [5],

$$\varepsilon_{ij}^{\nu} = \frac{1}{E}\int_0^t H\left(t,\tau\right)\left[-3\nu J_1 q_{ij} + \left(1+\nu\right)\sigma_{ij}\right]d\tau$$

for the work of elastic deformation we have

$$\sigma_{ij}\varepsilon_{ij}^{\nu} = \frac{1}{E}\int_0^t H\left(t,\tau\right)\left[\left(1+\nu\right)\sigma_{ij}\sigma_{ij} - 3\nu J_1^2\right]d\tau \tag{14}$$

where σ_{ij} are components of tensor deformation, ε_{ij}^{ν} are components of viscous component of deformation, J_1 is the first invariant of tensor stresses, $H\left(t,\tau\right)$ is a kernel of viscosity, g_{ij} are the components of metric tensor.

Allowing for $\sigma_{ij}\sigma_{ij} = 2J_2 + J_1^2$ where by repeated index goes summation, J_2 is the second invariant of stress tensor.

From (14) we have

$$\sigma_{ij}\varepsilon_{ij}^{\nu} = \frac{1}{E}\int_0^t H\left(t,\tau\right)\left[\left(1+\nu\right)\left(2J_2 + J_1^2\right) - \frac{3\nu}{E}J_1\right]d\tau \tag{15}$$

For the considered case $J_1 = 0,\ J_2 = \tau_0^2$

Then from (15)

$$\sigma_{ij}\varepsilon_{ij}^{\nu} = \frac{2\left(1+\nu\right)}{E}\tau_0^2 h\left(t\right) \tag{16}$$

where

$$h\left(t\right) = \int_0^t H\left(t,\tau\right)d\tau \tag{17}$$

$h\left(t\right)$ is determined from the test of tension-pressure of one-dimensional body.

Subject to (16) from (13) we obtain

$$2\left(1+\nu\right)\tau_0^2\left[1+h\left(t\right)\right] = 2\sigma_T^2$$

or

$$\tau_0 = \frac{\sigma_T}{\sqrt{(1+\nu)(1+h(t))}} \tag{18}$$

If compare (12) and (18) for maximal number of admissible turns we obtain

$$n \leq \frac{15t_0}{32\pi Rl\rho} \cdot \frac{\sigma_T}{(1+\nu)[1+h(t)]} \tag{19}$$

As it is evident from (19) for aborting of destruction it should be increased the time of formation of the stationary regime t_0. Form (9) it also follows that with increasing of yield point the number of admissible turns increases, but with increasing geometrical sizes and the density of roller material the number of turns decreases.

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