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EFFECT OF STOCHASTICS OF DIMENSIONAL PARAMETERS OF HAULING LAMINATED BUSHLESS CHAIN ELEMENTS OF IMPROVED STRUCTURE ON THEIR BEARING STRENGTH

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The distribution densities of dimensional parameters of a hauling laminated bushless chain of improved structure were investigated in this paper. The authors suggest calculating the non-uniform load of internal and external links plates by probability coefficient K_m , for which the minimum, the most probable and the maximum values were determined. The formula for K_m determination depending on plate size variety due to a gap random value Δ and plate elastic deformation value under permitted payload was obtained. The effect of stochastics of dimensional parameters of hauling laminated bushless chain elements on their bearing strength is proved.

Keywords: hauling laminated chain, mathematical expectation, dispersion, bearing strength, permitted payload

According to Reshetov (1989), the bearing strength of chain gears equipped with power transmission bush and roller chains is determined (according to the basic criterion of their efficiency – chain hinges wear) for the case when pressure in hinges must not exceed the permitted pressure under given working conditions. Taking into account the fact given above, permitted actual force F that can be passed by the chain with sliding joints equals to:

$$F = [P_0] \times A / K_e$$

where:

P_0 – permitted pressure in hinges for average operating conditions

A – supporting surface projection of the bush hinge (mm²)

K_e – operation coefficient

Hauling laminated bushless chains (HLBC), which are widely used under easy working conditions in conveyers of various transporting machines, are calculated on bearing strength according to Ivashkov's method (Ivashkov, 1960).

The above-mentioned methods determining the bearing strength of power transmission bush and roller chains and HLBC do not take into account the stochastics of chain parts dimensional parameters such as centre-to-centre distance and diameters of plates holes, diameters of rollers and other, certainly influencing the inequality of pressures in chain hinges and tensions arisen in plates. It results in decreased chain bearing strength (Raskin, 1972), especially for the HLBC of improved structure, which is schematically shown in Figure 1.

Therefore, the theoretical research concerning the effect of stochastics of improved structure HLBC dimensional parameters on their bearing strength is an important problem.

Material and methods

The works of Ivashkov (1960), Hlushchenko (1953), Reshetov (1989), Serensen (1975), Kadnár (2011 and 2007) and others are devoted to the investigation of bearing strength, and the durability of machine hinged joints, including hinges of HLBC, is considered by Sukhariev (1977).

Investigating the stressed condition in chain hinges in operation (Ivashkov, 1960), it was accepted that hoop stress on a contour in the interval from $-\pi/2$ to $\pi/2$ (an angle of contact in the hinge is $2\varphi_0 = 180^\circ$) is permanent and distributed uniformly, while according to Sukhariev (1977), the maximum angle of contact is $2\varphi_{\max} \approx 85^\circ$ and stresses change according to the cosinusoidal law.

When calculating the operation coefficient, Reshetov (1989) states that it is necessary to take into account the stochastic nature of parameters it is determined by. According to Kryvyi et al. (1999), bearing strength was determined taking into account the stochastics of chains contact steps in parallel two-contour transmissions equipped with power transmission bush and roller chains.

The aim of work: determining the effect of stochastics of dimensional parameters of improved structure HLBC on their bearing strength.

Basic tasks:

1. To develop research methods dealing with the effect of stochastics of HLBC dimensional parameters on their bearing strength.
2. To determine the coefficient of plate non-uniform loading K_m at transmission of HLBC under permissible hauling effort
3. To find the minimum, the most probable and the maximum values of K_m and to determine their effect on the bearing strength of HLBC.

where:

$[p_0]$ – permitted pressure in hinges

A_n – bearing surface area

K_e – operation coefficient

As the dimensional parameters of HLBC (the diameters of rollers d of the hole of smaller and larger diameters d_1 , d_2 of plates) are stochastic values, then we use Figure 1 and Figure 2 to determine the permitted useful effort. To overcome the useful resistance force F_0 (Figure 1a), it is necessary to apply a certain effort $F > F_0$. Taking into account that the internal plates (2, 3) with the hole of diameter d_1 are pressed on the cylindrical end levels of the roller (5), and the external plates are connected in the same way with the roller (9), we will accept that the roller performs a flat parallel translation while applying the effort F . Then, if the gap Δ is present in the hinge, made by the hole (7) of greater diameter d_2 of the plate (2) and the diameter of cylindrical end levels d of the roller (9) (Figure 1), only the plate (3) will be deformed at first. Then, choosing the gap Δ , another internal plate (2) begins to deform. Having reached the loading of the right internal plate (3) by F_1 (Figure 2) and its elastic deformation $\Delta_{nl,p}$, the left internal plate will be deformed to the value $\Delta_{nl,l} = \Delta_{nl,p} + \Delta$ and will pass the loading F_2 .

Results and discussion

In this case, the bearing strength of HLBC is permitted useful effort F_g , which will be determined from the relationship:

$$F_g = \frac{K_m [p_0] \times A_n}{K_e} \quad (2)$$

where:

K_m – coefficient taking into account the non-uniformity of plate loading

According to Kryvyi et al. (1999), we have:

$$K_m = 2 - \frac{|F_1 - F_2|}{F_1 + F_2} \quad (3)$$

where:

F_1 and F_2 – loadings passed by the left (2) and right (3) internal plates (Figure 1). According to Equation (3), when $F_1 = F_2$, $K_m = 2.0$ and the bearing strength of HLBC is equal to F_g . When $F_1 = 0$ or $F_2 = 0$, then $K_m = 1.0$ and the chain can transmit actual load due to permitted pressure in the hinge of one plate

Expressing F_1 and F_2 in terms of the rigidity of plates and their deformations, when interplacing of plates holes is as represented in Figure 2, after simplification of Equation (3), we get:

$$K_m = 2 - \frac{|\Delta|}{2\Delta_{nl,p} - |\Delta|} \quad (4)$$

where:

$2\Delta_{nl,p}$ – (Figure 2) deformation of plate under its loading effort, which equals to $[p_0] \times d \times t$

Figure 2

Schematic diagram of plates loading deformation 1 – total effort F_δ passed by the HLBC in case of identical sizes and identical deformations of both plates; 2 – dependence of permitted load F_1 from deformation of internal plate (3); (Figure 1) 3 – dependence of load F_2 from deformation of internal plate (2); 4 – dependence of total load F_δ in case of different size deformations of plates (2 and 3)

t – plate thickness

$\Delta > 0$ – instantaneous value of gap $\Delta = d_{2vl} - d_{1z,p}$ (Figure 1)

As the value Δ is formed by total dimensional parameters which are stochastic values, the value Δ will be a stochastic one, and taking into account Venttsel' (1969), we will accept hypothetically that it is submitted to the normal law of distribution.

Suppose that mean values of centre-to-centre distances of plates holes and areas of their dispersion are identical for both external and internal plates, that is:

$$\bar{A}_z = \bar{A}_v = A_n \quad (5)$$

$$6\sigma(A_z) = 6\sigma(A_v) = \delta \quad (6)$$

where:

A_n – nominal value of centre-to-centre distances of external and internal plates holes

$\sigma(A_z)$ and $\sigma(A_v)$ – root-mean-square deviations of stochastic values A_z and A_v

δ – corresponding field of admittance which is placed symmetrically on the value A_n

Based on the above-given facts and taking into account that $B = A + 0.5 d_2$ (Figure 1b) as well as based on the normal law of distribution, the density distribution of values B will be determined by the formula:

$$f(B) = \frac{12}{\sqrt{2\pi(4\delta_A^2 + d_2^2)}} \exp \left\{ -\frac{72[B_i - (A_n + 0.5\bar{d}_2)]^2}{4\delta_A^2 + \delta_{d_2}^2} \right\} \quad (7)$$

The interval of the value B is:

$$A_n - 0.5\delta_A + 0.5(d_n - \delta_{d2n}) \leq B \leq A_n + 0.5\delta_A + 0.5(d_n + \delta_{d2n}) \quad (8)$$

where:

δ_{d2n} and δ_{d2n} – upper and lower limits of diameter tolerances of plates larger holes

The mean value $\bar{B}$ of the value B and dispersion $D(B)$ will be:

$$\bar{B} = A + 0.5\bar{d}_2 \quad (9)$$

$$D(B) = \frac{4\delta_A^2 + \delta_{d_2}^2}{144} \quad (10)$$

Using Figure 1b, the stochastic value C is given in the form:

$$C = A + 0.5d_{2np} - 0.5d_l + 0.5d_{np} \quad (11)$$

where:

d_{2np} – diameter of the larger hole in the right plate;
 d_l and d_{2np} – diameters of the left and right ends of the roller

Due to the central limit theorem and taking into account that the members of the right side (Venttsel', 1969) are submitted to the normal law of distribution and the stochastic value C is subordinated to the Gauss's law of distribution, the density of distribution $f(C)$ of the value C is expressed as:

$$f(C) = \frac{12}{\sqrt{2\pi(4\delta_A^2 + \delta_{d_2}^2 + 2\delta_d^2)}} \exp \left\{ -\frac{72[C_i - (A_n - 0.5\bar{d})]^2}{4\delta_A^2 + \delta_{d_2}^2 + 2\delta_d^2} \right\} \quad (12)$$

where:

δ_A , δ_{d_2} and δ_d – tolerances of dimensions: centre-to-centre distance of plates holes; diameters of the larger plates holes and diameters of rollers ends

The characteristics of stochastic value C dispersion according to the above-given pattern when determining in relation to the stochastic value B are:

mean value:

$$\bar{C} = A_n + 0.5\bar{d}_{2np} \quad (13)$$

dispersion:

$$D(C) = \frac{4\delta_A^2 + \delta_{d_2}^2 + 2\delta_d^2}{144} \quad (14)$$

Then, the density of distribution of the stochastic value $\Delta = B - C$, which is submitted to normal law, equals to:

$$f(\Delta) = \frac{12}{\sqrt{2\pi(8\delta_A^2 + 2\delta_{d_2}^2 + 2\delta_d^2)}} \exp \left\{ -\frac{72\Delta_i^2}{8\delta_A^2 + 2\delta_{d_2}^2 + 2\delta_d^2} \right\} \quad (15)$$

and its distribution characteristics are:

mean value:

$$\bar{\Delta} = 0 \quad (16)$$

dispersion:

$$D(\Delta) = \frac{4\delta_A^2 + 2\delta_{d_2}^2 + 2\delta_d^2}{144} \quad (17)$$

We find the mathematical expectation $M(|\Delta|)$, variance $D(|\Delta|)$ and distribution density $f(|\Delta|)$ of a random variable of module $|\Delta| = |B - C|$:

$$M(|\Delta|) = \frac{\sqrt{2}}{2} \cdot \sigma(\Delta) \cdot e^{-\frac{\bar{\Delta}}{2\sigma^2(\Delta)}} + 2 \cdot \bar{\Delta} \cdot \left[\frac{\bar{\Delta}}{\sigma(\Delta)} \right] \quad (18)$$

where:

$\Phi\left[\frac{\bar{\Delta}}{\sigma(\Delta)}\right] = \frac{1}{\sqrt{2\pi}} \cdot \int_0^{\frac{\bar{\Delta}}{\sigma(\Delta)}} e^{-\frac{t^2}{2}} dt$ – value of Laplace function, $\bar{\Delta}$ and $\sigma(\Delta)$ average value and average quadratic deviation magnitude Δ :

$$D(|\Delta|) = \Delta^2 + \sigma^2(\Delta) - \left[\sqrt{\frac{2}{\pi}} \cdot \sigma(\Delta) \cdot e^{-\frac{\Delta^2}{2\sigma^2(\Delta)}} + 2 \cdot \bar{\Delta} \cdot \left(\frac{\bar{\Delta}}{\sigma(\Delta)} \right) \right]^2 \quad (19)$$

$$f(|\Delta|) = \frac{12}{\sqrt{2\pi(2\delta_A^2 + \delta_{d_2}^2)}} \exp \left\{ -\frac{18|\Delta_i|^2}{2\delta_A^2 + \delta_{d_2}^2} \right\} \quad (20)$$

$$0 \leq |\Delta| \leq \delta_A^2 + \delta_{d_2}^2; \quad |\bar{\Delta}| = 0.133\sqrt{\delta_A^2 + \delta_{d_2}^2}; \quad D|\Delta| = 0.01\sqrt{\delta_A^2 + \delta_{d_2}^2}$$

The theoretical distribution curves of the stochastic values Δ and $|\Delta|$ are given in Figure 3.

The minimum value of coefficient K_m occurs when $|\Delta|$ is maximum, that is:

$$K_{mmin} = 2 - \frac{3\sigma(\Delta)}{2\Delta_{il} - 3\sigma(\Delta)} = 2 - \frac{0.5\sqrt{\delta_A^2 + \delta_{d_2}^2}}{2\Delta_{il} - 0.5\sqrt{\delta_A^2 + \delta_{d_2}^2}} \quad (21)$$

The maximum value of coefficient K_m occurs when $|\Delta| = 0$, that is $K_{mmax} = 2$.

The most probable value $K_{m.n.i.}$ is determined according to the following relation:

$$K_{m.n.} = 2 - \frac{0.133\sqrt{\delta_A^2 + \delta_d^2}}{2\Delta_{II} - 0.133\sqrt{\delta_A^2 + \delta_d^2}} \quad (22)$$

Figure 3 Theoretical distribution curves of stochastic values

1 – stochastic value Δ , 2 – stochastic value $|\Delta|$

The estimation criterion of the effect of stochastics of HLBC dimensional parameters on bearing strength is assumed to be the minimum permitted value $K_{m.s'}$, which is obtained at risk level 0.05 outside the top limit of the interval. To do this, it is necessary to find the quantile of the stochastic value $|\Delta|$, that is such a value Δ_m for which the function of distribution is $F(\Delta_m) = P\{\Delta < \Delta_m\} = p = 0.95$.

Conclusions

1. The theoretical research method for the effect of stochastics of HLBC elements parameters on bearing strength was offered, and relationships for determining the permitted useful effort that can be passed on the chain were obtained.
2. There were determined distribution densities of dimensional parameters of improved structure HLBC and analytical relationships to determine the coefficient K_m , taking into account the non-uniform loading of chain plates at certain values of gap Δ and elastic plates.

3. The relationships to determine the minimum, the maximum and the most probable value at a certain level of coefficient K_m were obtained.

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