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BAND-SHOE BRAKE FRICTION UNIT DEFORMATION

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Abstract. *The finite element method is used to optimize friction unit design parameters and study the influence of the friction unit deformation in the brake open state and at the beginning of braking upon the band-shoe brake efficiency.*
Keywords*: drawworks, band-shoe brake, friction unit, deformation, wearing, finite element model, friction shoe*

1. INTRODUCTION

Band-shoe brakes are widely used in heavy duty brake systems due to their design and operating simplicity and possibility to create great brake moments at relatively small controlling force. Side by side with this non-uniform wearing of the friction shoes of such brakes substantially reduces efficiency of frictional material uses and the friction unit operating life [1]. It is widely considered that non-uniform wearing of the friction shoes located on the wrap angle of the brake band is caused by changing of unit loadings in the friction pairs. However a great deal of experimental researches shows that the friction shoes located on the middle region of the brake band wrap angle and even near the edge of the brake band running-off side wear out approximately identically but sometimes even more intensively than those at the band running-on side, i.e. ones located on those their regions where unit loadings in the friction pairs are in 3-5 times greater [2]. So it is possible to assume that such irregular wearing is caused by friction unit operating peculiarities in the braking initial stage – when passing from the brake open state to braking.

Therefore substantiation of this assumption is the purpose of the work. It could be gained by studying the friction unit deformation in the brake open state and at the beginning of braking.

2. SIMULATING OF FRICTION UNIT DEFORMATION

The serial design of the drawworks LBU-1200 serves as a prototype of a finite element model (FEM) to its friction unit (Fig. 1). Its basic parameters are following: material – steel 50 (E=2·10^5 MPa, ν=0.3); its internal surface radius on the band wrap angle R_H=755 mm, length 4250 mm, thickness 5 mm, and width 220 mm. There are ear-rings on both ends of the band for its fastening to drawworks band tractions. 20 shoes made of friction material are fastened to the band within its wrap angle (270°) evenly with the angular step of 2φ=13.5°. Mass of each one is 1.9 kg. There are two spring devices located at the angles of ψ_1=65° and ψ_2=145° to the Ox axis in the friction unit for adjusting the radial gap in the friction pairs in the brake open state.

For simplification of the finite element model, the action of the shoes and spring devices is presented by the appropriate forces. It is obvious, that influence of the shoes on the band rigidity can take place only when it is bended with decreasing of its radius. It is set by preliminary calculations that the bend rigidity of such parts of the brake band is increased by 5.3 times.

The band width is constant along its length. So for the purpose of model simplification and calculation time cutting, we create a two-dimension FEM with quadratic elements.

Loadings of the FEM include the following forces:

- friction shoe weight G_H (18.66 N). All G_H act upright and are applied to the band in the places of shoe fastening;
- brake band weight G_C (579.34 N). It acts upright as well and is a volume force (it is not shown in Fig. 1);
- unknown P_1 and P_2 forces. They are used for adjusting of the radial gap ε between the friction shoe and brake drum working surfaces.

The boundary conditions of the FEM consist of displacement limitations on the *M* and *N* joints. Joint *N* is immoveable but joint *M* has a possibility to change its position at angle γ (γ=12°) to the axis *Ox*. Joint M origin position corresponds to the brake closed state. to provide the average value of the radial gap ε=3.5 mm, the joint displacements should be Δ_x=-16.5 mm and Δ_y=3.5 mm.

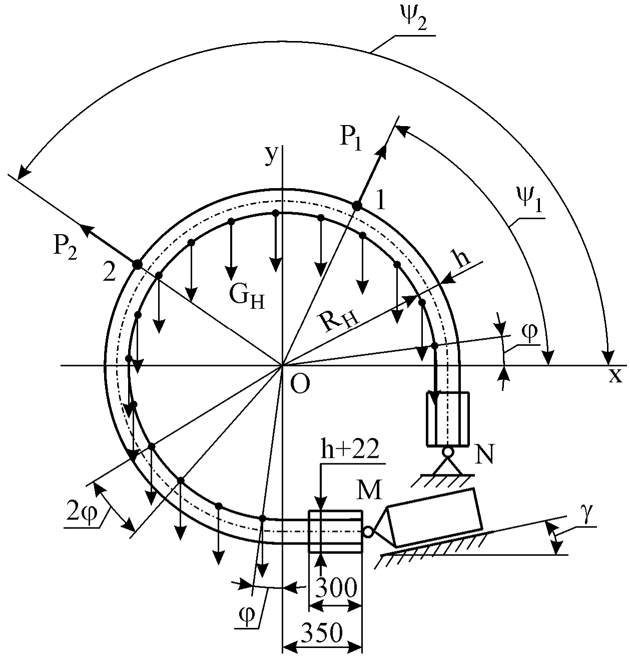


Fig. 1. Calculation sketch of the drawworks friction unit

3. OPTIMIZATION OF THE FRICTION UNIT DESIGN

The purpose of the next research of the FEM in the brake open state and at the braking beginning is to ascertain optimum values of P_1 and *P2* forces and the displacement (radial gap) distribution of the friction unit. When studying of the model, the values of P_1 and P_2 forces, the distribution of radial gap ε along the band on its wrap angle, and radial gap scatter range $\Delta_R = \varepsilon_{\max} - \varepsilon_{\min}$ (where ε_{max} and ε_{min} are the maximum and minimum values of the radial gaps) should be calculated.

A mathematical model of the following type is assumed to be obtain

$$\Delta_R = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_1^2 + a_5 X_1 X_2 , \tag{1}$$

where X_1 and X_2 are the encoded values of P_1 and P_2 factors accordingly.

$\Delta_R \rightarrow$min is the goal function of the model.

For the sake of research simplicity and to obtain the model coefficients a_i statistically estimated, we use the experiment planning method – symmetric composition *D*-optimum plan 3^2//9 [3]. The values of P_1 and P_2 factors are varied in the intervals obtained on the basis of the experimental data: 750-770 N for P_1 and 400-460 N for P_2. For getting of the second order of the mathematical model, we vary the factor values at three levels. The results of ANSYS calculation are computed by using MathCAD.

Now consider the description of procedure for studying of the friction unit deformation at the beginning of braking. The purpose of this part of the research is to find the friction unit regions which are the first to be in a contact with the brake drum and find out the influence of friction forces acting on these regions on unit deformation changes as well.

In this case, the friction unit FEM is loaded by the P_1 and P_2 forces got by their optimization with the aid of $\Delta_R \rightarrow$min criteria. The research procedure is following:

1. Decreasing the Δ_x and Δ_y values, we determine their values at which the gap ε in some point K_1 will be some micrometers less zero. We check the value of angle ψ_{K1} where the point K_1 is positioned, the values of Δ_x and Δ_y displacement, and the plot of radial gap changes within the band wrap angle.

2. Using obtained the Δ_x and Δ_y values, we change the boundary condition (Δ_R=0 for the point K_1) and repeat the solution of the FEM. Thus we determine radial reaction N_K in the point K_1.

3. Then we repeat the task solution with the following changes – the boundary condition in the point K_1 is cancelled and is changed by applying the reaction N_{K1} and force of friction $f \cdot N_{K1},$ (where f is the coefficient of friction) in this point.

4. RESEARCH RESULTS

The results of the FEM research of the friction unit deformation by using the plan $3^2//9$ are displayed in Fig. 2 and Table 1. After computing these data gives the equation of regression for the range of scatter for the radial gap

$$\Delta_R = 4{,}602 - 0{,}424 \cdot X_1 + 1{,}900 \cdot X_2 + 8{,}995 \cdot X_1^2 + 12{,}650 \cdot X_2^2 - 15{,}202 \cdot X_1 \cdot X_2 . \quad (2)$$

This mathematical model is reliable after Fisher criterion: $F = \frac{S_{RO}^2}{4 \cdot S_R^2} = \frac{172{,}504}{4 \cdot 6.608} = 6.53$

that is more than the critical value of F-criterion (F_{KP}=3.1 [3]) at 5% level of meaningfulness. The reliability of the model is confirmed by the check point (point K in Table 1) as well.

Table 1. Plan and results of the friction unit FEM studying

Points number of the plan	Factors		Radial gap range scatter Δ_R, mm		Relative error $\left\| \frac{\Delta_{Rm} - \Delta_{Rf}}{S_R} \right\|$
	X_1	X_2	Δ_{Rf}*	Δ_{Rm}**	
1	1	1	9,812	12,521	1,054
2	1	-1	37,784	39,125	0,522
3	-1	1	40,551	43,758	1,247
4	-1	-1	9,027	9,569	0,211
5	0	1	22,515	19,152	1,308
6	0	-1	16,403	15,352	0,409
7	1	0	15,006	13,173	0,713
8	-1	0	16,105	14,021	0,811
9-12	0	0	4,620	4,602	0,007
K	-0,090	-0,129	4,510	4,502	0,003

* - received with the aid of FEM computation;

** - received by calculation of mathematical model (2).

The surface of response of equation (2) has the shape of an elliptic paraboloid with the minimum value in the point *of* X_1=-0.090 and X_2=-0.129 (Fig. 3), that corresponds to the spring forces of P_1=759.10 N and P_2=426.13 N. Δ_R equals 4.502 mm in this point. So it is close to the value of Δ_R=4.510 mm got by computation of the FEM for the optimum values of P_1 and P_2. It is seen from Fig. 4 that the friction unit deformation at the beginning of braking caused by the joint M displacement to the values of Δ_x =-10.5 mm and Δ_y=-2.23 mm gives the first contact between the friction unit and the brake drum in the point of K_1 (Fig. 4, plot 2); ψ_{K1}=123.8°. There is the normal reaction of 0.31 N and tangential one (force of friction) of 0.109 N in the contact. By acting of these forces, the friction unit region at the K_1 point moves away from the brake drum and instead of this a new "friction unit-drum" contact is appeared at the running-off band side (Fig. 4, plot 3, point K_2, ψ_{K2}=270°). The normal reaction in this new contact is equal to 1.94 N.

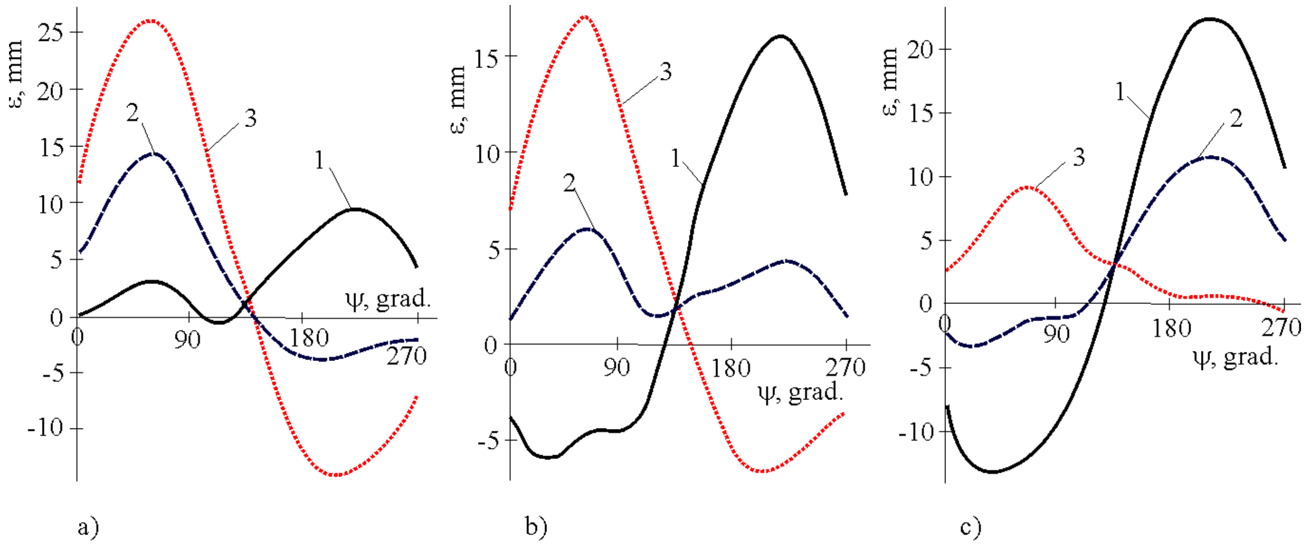


Fig. 2. Relations of the radial gap ε for the band-shoe brake in its open state from the values of P_1 and P_2 forces (N): P_1=750 (1), 760 (2), 770 (3); P_2=400 (a), 430 (b), 460 (c)

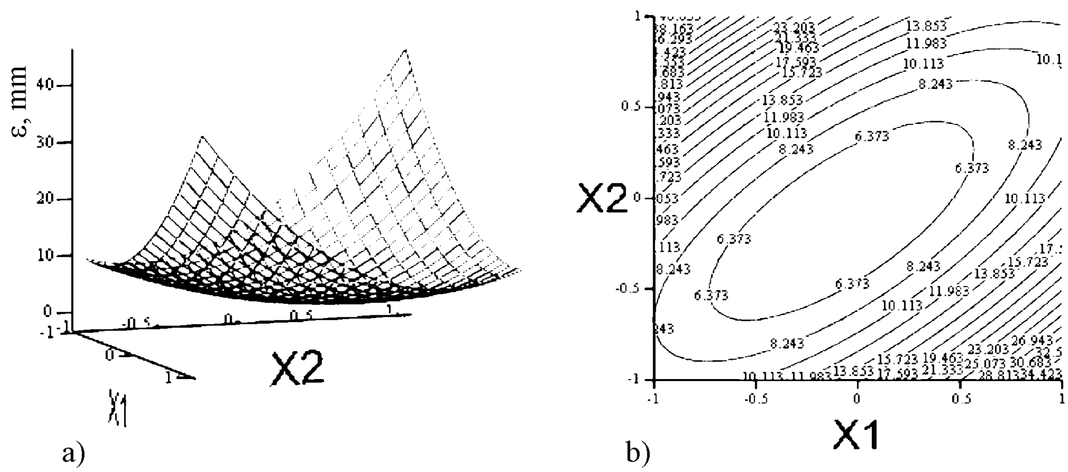
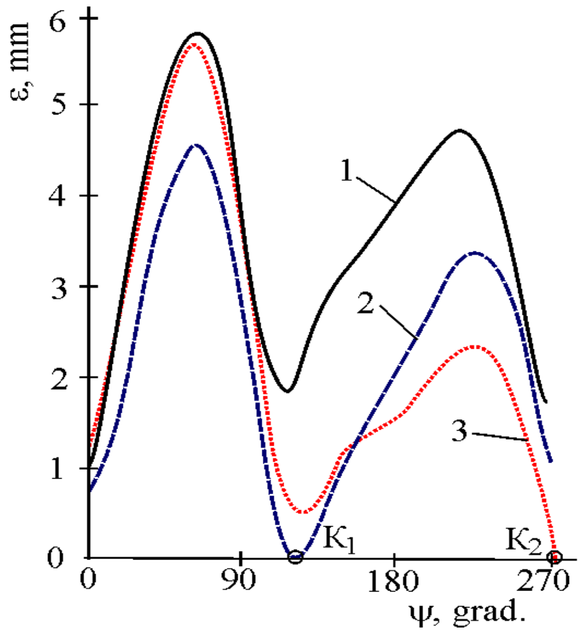


Fig. 3. Surface of response for mathematical model (a) of its sections (b)

The action of this reaction and appropriate force of friction applying in the point K_2 changes the picture of the friction unit deformation to that one which practically repeats plot 2 in Fig. 4 but with the radial reaction increased to 1.02 N (i.e. approximately in 3 times). Such a change of the friction unit deformation allows us to assume that at the very beginning of braking enforced radial vibrations are initiated in the friction unit. Obviously owing to such a vibration, considerable dynamic loadings in these "shoe-drum"contacts and their more intensive (in comparing to the other regions) wearing appear. Moreover, it is these friction unit deformation changes for brakes of such designs that lead to the considerable noise effect accompanied by impacts and non-uniform braking observed in practice.



In addition, it is possible to assume that the position of the devices for radial gap adjusting influences the location of the friction unit region of the first contact with the brake drum. So this device design should provide not only uniform radial gap in the working contact of the brake in its open state but useful conditions for its operating at the beginning of braking as well. The study of such conditions could be the object of further researches.

5. CONCLUSIONS

The finite element method is used for simulating and studying the friction unit deformation of the band-shoe brake of serial design in its open state and at the beginning of braking. Optimization of forces stretching the friction unit is fulfilled to provide uniform radial gap in the brake working contact in its open state.
The relation between the friction unit deformation parameters at the beginning of braking and irregular wearing of the friction shoes located on the brake band within its wrap angle is set.

6. REFERENCES

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