THE STATIC-DYNAMIC ANALYSES OF LOADINGS OF FRICTION UNITS FOR BAND-SHOE BRAKES

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Abstract: *The paper is devoted to a substantiation of rational placing of friction shoes on the brake band for draw works band-shoe brakes. The opportunity of substantial growth of the shoe wear-life and brake moment both without changing the shoe number and at cutting down of their number on the brake band is shown. Software for the computer aided design of brake parameters with a choice of rational shoe placing are developed.*

Keywords: *draw works, band-shoe brake, brake drum, brake band, friction shoe, shoe number, friction mechanism arrangement, coefficient of friction, brake moment, band tension, shoe wear-life, computer aided design.*

1. Introduction

Theoretical and experimental researches of capacity for work of band-shoe brakes for draw works have shown that their friction shoes wear out non-uniformly both on the wrap angle and along the width of the shoes [1, 2]. For some levelling up of the wear of shoe working surfaces, it was offered to install the shoes non-uniformly on the wrap angle of the band. The basic idea of such an approach is to level up specific loads acting on working surfaces of the shoes installed on the running-on and running-off sides of the brake band. This enables the shoe material to be used more rationally [1, 3].

The basic limitation of this design is that when in use it is unknown in what limits of specific load changes their prediction redistribution on both sides of the brake band could be carried out.

The purpose of the paper is to relate specific load changes in friction pairs of band-shoe brakes to shoe placing and shoe number as well as to substantiate their rational placing on the wrap angle.

2. Initial assumptions

The search for ways of design improvement of a band-shoe brake friction mechanism for draw works will be carried out on a basis of the following assumptions. If all other things being equal:

- friction work and brake moment of the brake practically do not depend on the number of friction shoes placed on the wrap angle;
- the friction work varies in proportion to a wear of the friction shoe material which in its turn varies proportionally to specific pressure in the friction pairs;
- the specific pressure in the friction pairs depends on the number of shoes, their sizes and tension in the brake band. The latter decreases after each shoe in a direction of rotation of the drum, i.e. from the running-on to running-off side of the brake band;
- the specific pressure in the friction pairs decreases as the shoe number is increased. However, if the shoe number is close to the greatest possible one, i.e. when separations between the shoes are least, the brake moment increases insignificantly but the efficiency of the shoe material use falls sharply with increasing of the shoe number. Therefore in serial brakes (with uniform shoe placing on the wrap angle), the total number of shoes is a little bit less than the greatest possible one;
- the shoe next to the running-on band side is most loaded when shoes place uniformly on the wrap angle. This shoe wears out faster than other shoes. So its wear-life limits wear-life of the whole friction unit.

These assumptions enables to narrow searching for substantiations of the best shoe placing on the wrap angle up to the range restricted by two limiting cases when the number of shoes with their non-uniform placing is equal to:

1) their least possible number derived from the condition of the most effective material use of all shoes;
2) the shoe number of the appropriate serial brake with an uniform shoe placing.

3. Analyses of a band-shoe brake with a non-uniform shoe placing

For the analyses of operation peculiarities of the friction mechanism, the static-dynamic model of a band-shoe brake with shoes placed non-uniformly is developed. It is based on the mathematical relations between design and operating characteristics of these brakes stated in the paper [4] for a band with shoes placed uniformly. These relations take into account an average coefficient of friction in the friction pairs, shoe thickness and brake drum radius. Besides, it is assumed that the brake band thickness and its bending rigidity are insignificant factors, i.e. they are equal to zero. Last two simplifications are quite admitted owing to small relative thickness of the band (the ratio of thickness to radius of band curvature is smaller than 1/100 ÷ 1/140) and its low bending rigidity. These simplifications are usual for calculation techniques widely used in practice for band-shoe brakes.

Let us consider the scheme of a band-shoe brake (fig. 1). There are n friction shoes mounted on the brake band wrapping the brake drum. The shoes are placed with a variable angular pitch 2φ. The band is stretched by forces S_H and S_3 acting at the ends of its running-on and running-off sides accordingly. These two forces press friction shoes against the cylindrical surface of the brake drum, and a sliding friction force F arises between them.

Any section of the brake band together with a friction shoe can be considered as an independent brake. All these brakes are connected by the brake band. As the band has zero bending rigidity, it is stretched to a straight line passing through the extreme points of the adjacent shoes. For the same reason as well as owing to vibrations in the system and small axial deformation of the band, the tension in the band is constant along the band section between places of fastening two adjacent shoes to the band.

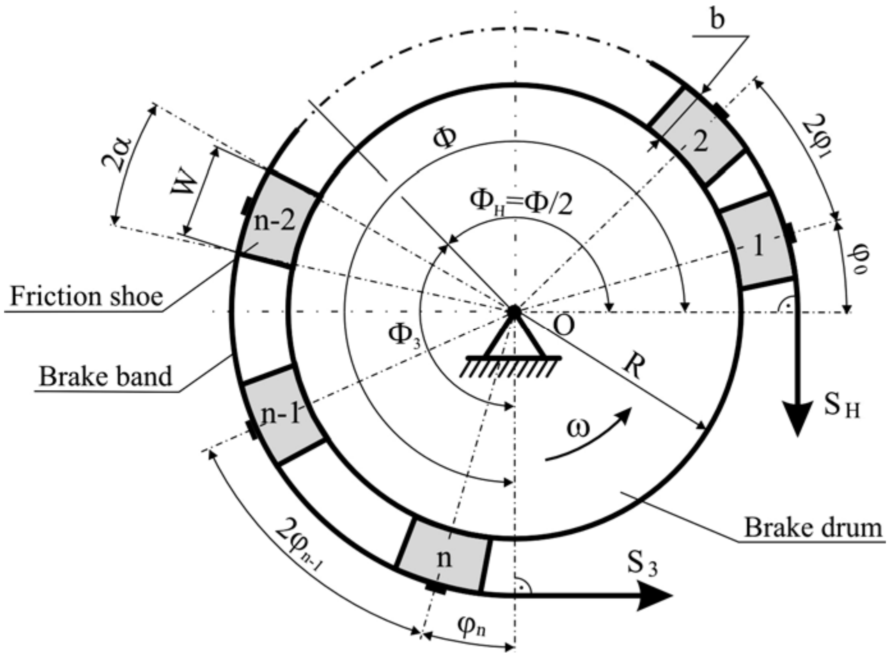

Figure 1. Structure of a band-shoe brake with shoes placed non-uniformly on the wrap angle *Φ*.

Let us consider forces applied to *i*-element of the brake (fig. 2). Band tensions S_{i-1} and S_i exert on it from the previous (*i-1*) and following (*i+1*) brake elements. The direction of their action is characterized by angles φ_{i-1} and φ_i. Forces N_i (the normal constituent of the reaction in the "drum-shoe" pair) and F_i (the force of sliding friction) act on the shoe from the side of the brake drum. Thus, $F_i = N_i f$, where f is the coefficient of sliding friction in the pair "brake drum – friction shoe".

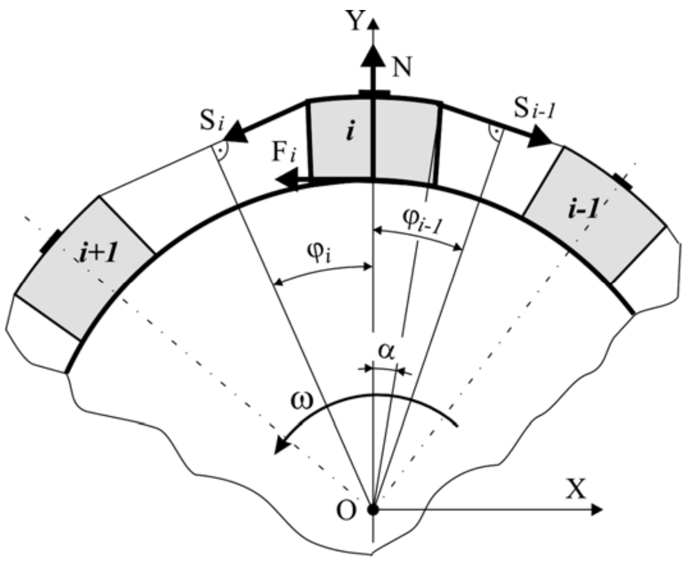

Figure 2. Forces applied to *i*-brake element.

The relations among the forces applied to *i*-brake element are revealed by making up and solving the following equilibrium equations: the sums of the moments concerning point *O*, and the sum of projections of forces on the axis *OY*. It is easy to show that brake force F_i can be defined from the equation

$$F_i = f(S_{i-1}\cdot\sin\varphi_{i-1} + S_i\cdot\sin\varphi_i) = f\cdot S_{i-1}\cdot\sin\varphi_{i-1}\left(1+\frac{S_i\cdot\sin\varphi_i}{S_{i-1}\cdot\sin\varphi_{i-1}}\right) \quad (1)$$

and the ratio of tensions S_i and S_{i-1} depends on the brake design and the coefficient of friction

$$\frac{S_i}{S_{i-1}} = \frac{1 - f\dfrac{R}{R+b}\sin\varphi_{i-1}}{1 + f\dfrac{R}{R+b}\sin\varphi_i}. \quad (2)$$

Referring to equation (2), it is evident that, at a constant pitch of friction shoe placing on the wrap angle (if $\varphi_{i-1} = \varphi_i$), the tension of the band decreases after each shoe from its running-on to running-off side. Thus, the condition $S_i < S_{i-1}$ is met. That is why forces N_i and F_i decrease ($N_i<N_{i-1}$ and $F_i<F_{i-1}$) as well. It is the reason of non-uniform wear rate of the friction shoes both along the brake band and the shoe width followed by reduction in the contact ratio of the friction pairs and, as a consequence, by reduction in the brake moment [4].

It is quite obvious that, in order to eliminate these drawbacks, the two forces pressing *i*-shoe (against the drum) on its both sides (acting on its running-on and running-off sides) should be identical, that is

$$S_{i-1}\cdot\sin\varphi_{i-1} = S_i\cdot\sin\varphi_i\ . \quad (3)$$

Thus, the normal constituent N_i of the reaction and the sliding friction force F_i become constant for each brake element along the brake band, i.e.

$$F_i = 2f\cdot S_i\cdot\sin\varphi_i = 2f\cdot S_{i-1}\cdot\sin\varphi_{i-1} = 2f\cdot S_H\cdot\sin\varphi_0 \quad (4)$$

where φ_0 is an inclination angle of the brake band on their running-on side to the first shoe (see fig. 1).

Hence, it might be expected that the wear rate for all shoes will be identical. So, condition (3) is a basis for revealing the laws of rational shoes placing for the first limiting case.

It is easy to show that condition (3) could be realized when angle φ is changed by the following laws:

$$\sin\varphi_i = \frac{\sin\varphi_{i-1}}{1 - 2f\dfrac{R}{R+b}\sin\varphi_{i-1}}; \quad (5)$$

$$\sin\varphi_n = \sin\varphi_0\prod_{i=0}^{n-1}\frac{1}{1-2f\dfrac{R}{R+b}\sin\varphi_i}. \quad (6)$$

Equation (6) states that the greater the shoe serial number n on the band the greater the rational angular pitch of their placing (angle 2φ). Besides, this angle depends on angle φ_0 – the grater the angle φ_0 the grater the rational pitches.

The brake moments developed by each brake element M_i and by the brake with n brake elements M may be found with:

$$M_i = F_i\cdot R = 2f\cdot R\cdot S_H\cdot\sin\varphi_0 \quad (7)$$

$$M = 2n\cdot f\cdot R\cdot S_H\cdot\sin\varphi_0\,. \quad (8)$$

To achieve these moments, the force S_3 should be applied to the running-off side of the brake band. The formula for finding out S_3 could be received by taken simultaneous solution of equations (3) and (6) for *n*-th brake element

$$S_3 = \frac{S_H\cdot\sin\varphi_0}{\sin\varphi_n} = S_H\prod_{i=0}^{n-1}\left(1-2f\frac{R}{R+b}\sin\varphi_i\right). \quad (9)$$

When friction shoes are placed on the wrap angle, it is important to ascertain angle φ_0. As in band-shoe brake, according to condition (3), all friction shoes are loaded equally, it may be assumed that they wear out identically. Hence, at braking, the sliding friction work is proportional to volume of the worn out friction material. Therefore, the greater the number of shoes the larger the contact ratio of the friction pairs, the smaller specific loads, and, as a consequence, the larger shoe wear-life.

The total angle φ_Σ equals the sum of all angular pitches $2\varphi_i$ (their number is $n-1$), and angles φ_0 and φ_n. From ratio (6), the equation for the total angle φ_Σ becomes

$$\varphi_\Sigma = \varphi_0 \left(1 + \arcsin \prod_{i+1}^{n-1} \frac{1}{1 - 2f \frac{R}{R+b} \sin \varphi_i} + 2 \sum_{i=1}^{n-2} \arcsin \prod_{i+1}^{n-1} \frac{1}{1 - 2f \frac{R}{R+b} \sin \varphi_i} \right). \qquad (10)$$

Formula (10) enables us to make the conclusion that, for some fixed value of angle α, the shoe number n which can be placed on the brake band depends on angle φ_0 - the smaller the angle φ_0 the greater the number n. So, to increase the shoe wear-life angle φ_0 should be reduced. The least value of φ_0 is equal to α - a half of the contact angle of a friction shoe (fig. 1).

On the other hand, as it follows from equation (8), if the shoe number n and tension S_H (consequently loads on bearings and shaft of the draw works) are fixed, the brake moment increases as angle φ_0 increases. Therefore, when locating friction shoes on the wrap angle, it is necessary first of all to determine the shoe number for $\varphi_0=\alpha$. Then, if the total angle φ_Σ is less than accepted wrap angle Φ, it is necessary to increase angle φ_0 up to be as greater as angle Φ.

Now we will study an opportunity to ascertain the law of rational shoe placing on the wrap angle for the second limiting case (when the number of shoes is equal to that at uniform shoe placing in a serial design of the brake). Relation (5) enables to assume that the simplest and rather good for describing the desirable law for shoe pitch (2φ) may be an arithmetic or geometrical progression:

- for an arithmetic progression $\quad \varphi_i = \varphi_{i-1} + d$; (11)
- for a geometrical progression $\quad \varphi_i = \varphi_{i-1} \cdot q$ (12)

where d is the difference of the arithmetical progression, in degrees;
q is the ratio of the geometrical progression.

As it was shown by our preliminary calculations, the best results could be gained by using an arithmetical progression for the running-on side of the band Φ_H and a geometrical progression – for its running-off side Φ_3. In this case, the last member of the arithmetical number row is equal to the first for the geometrical number row.

It is obvious the shoe placing pitch cannot be increased beyond all bounds. From geometrical reasons namely from the condition that the brake band should not touch a cylindrical surface of the brake drum (fig. 3), we can get the expression for finding out the limiting angle φ^*

$$\varphi^* = \arcsin \frac{W}{2(R+b)} + \arccos \frac{R}{R+b}. \qquad (13)$$

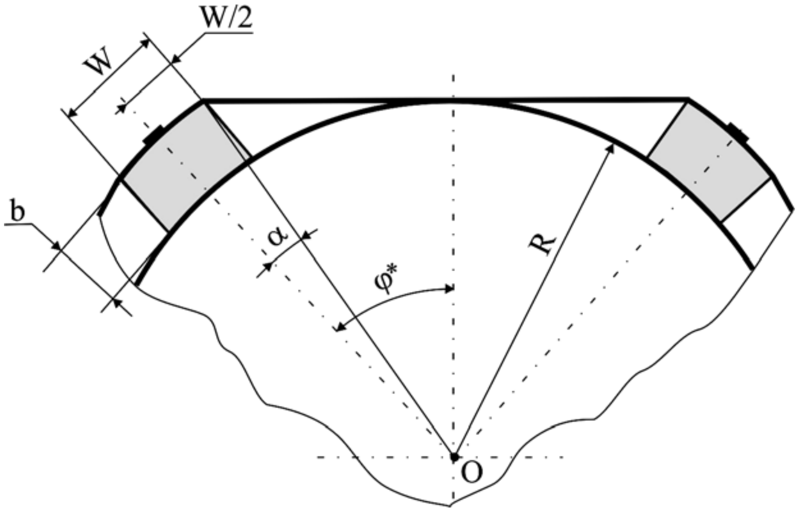

Figure 3. Limiting angle φ^*.

4. Discussion of the results

We will now use the offered model of the brake and the law of shoe placing on the wrap angle to determine friction unit parameters for draw works BU-2500EP. For comparison of efficiency of the offered decisions, all brake parameters except shoe numbers and their placing are the same as in the serial design namely: *R=725 mm*, *W=120 mm*, *b=30 mm*, the shoe material *FK-24A* in contact to steel *35XHP* has an average coefficient of friction *f=0.33*, shoe number *n=20*, wrap angle $\Phi=270^o$, angular pitch of shoe placing for the serial brake $2\varphi=13.5^o$ (or $\varphi=6.75^o$). The design tension of the brake band in its running-on side S_H is accepted equal to *160 kN.*

The design parameters of the friction units (for the offered and serial designs) are presented in fig. 4-6. They were computed by using software we developed specifically for this study.

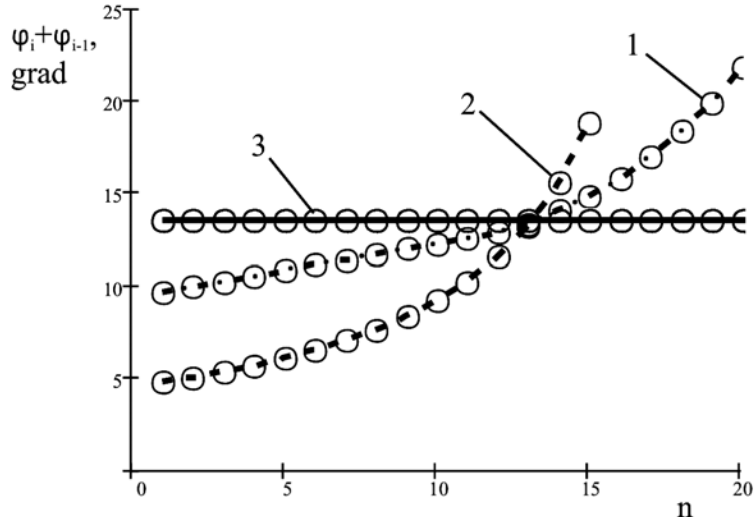

Figure 4. Angles of shoe placing on the wrap angle:
1 – the arithmetical row on angle Φ_H (12 shoes) and the geometrical row on angle Φ_3 (8 shoes);
2 - according to condition (5); 3 - serial design.

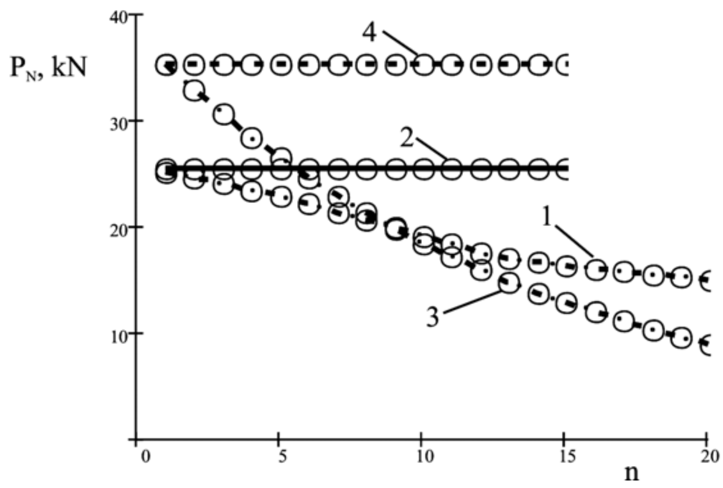

Figure 5. The forces pressing the friction shoes against the working surface of the brake drum ($P_{Ni} = S_i \sin\varphi_i + S_{i-1}\sin\varphi_{i-1}$): 4 - same as 2 but at the increased tension in the brake band (*S_H=214kN*). The other designations see fig. 4.

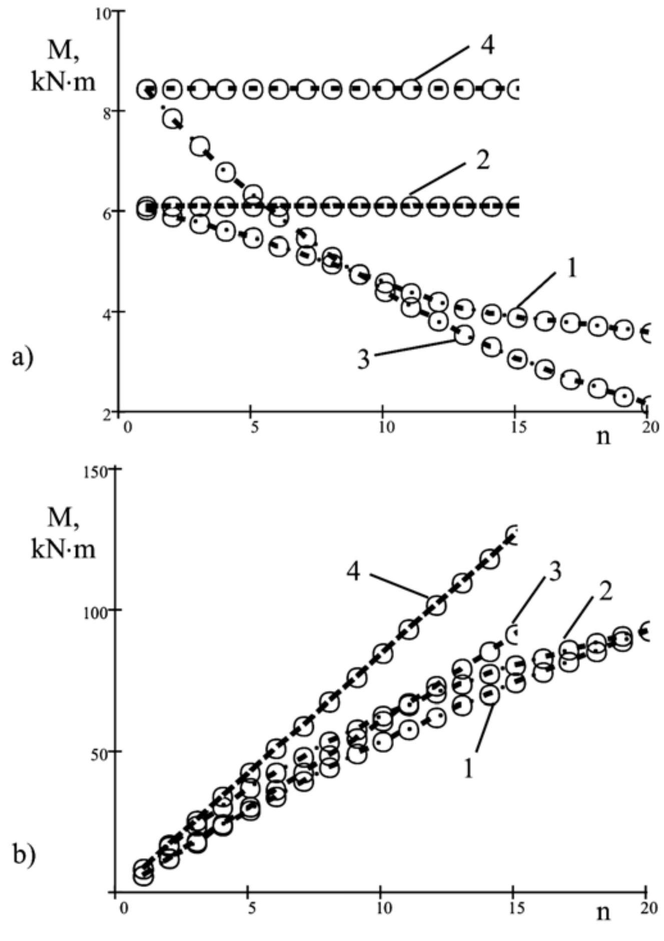

Figure 6. Brake moments created by the separate shoes (a) and cumulative totals (b) Designations see fig. 4 and 5.

Comparison curves 1 and 3 in fig. 4-6 enable us to make the following conclusions. The increase of density of the shoe placing (as well as the reduction of the shoe angular pitch and contact ratio) on the running-on side of the band at their constant total number causes essential levelling up loads on shoes and, as a consequence, the brake moments created by them. At the practically identical total brake moments (diagrams 1 and 3 in fig. 6, b) and loads on the shaft of the draw works, the force applied to the first shoe decreases *1.39* times. That should increase shoe wear-life and hence wear-life of the whole shoe set the same times.

As may be seen from comparison curves 1 and 2 in fig. 4, 5, and 6 a, the way of shoe placing according to relation (5) turned out to be the most effective - all shoes are loaded equally and they create the identical brake moments. Besides, loads on the shoes are *1.4* times less than the load on the first shoe of the serial brake. Moreover, the shoe number is reduced by *25 %*. Hence, it might be expected the efficiency of the friction material use in this case will *1.7* times be higher than the efficiency of the serial design.

If as a basis of comparison we use the identical shoe wear-life (for the first shoe in the serial design and for shoes placed in accordance with relation (5)), the offered design enables to increase the total brake moment *1.34* times (fig. 6, b). However it will require increasing the loads on the draw works shaft accordingly.

Taking into account high efficiency of the offered approach, we consider the model of the brake friction mechanism to be refined by, in particular, taking into consideration rigidity of the brake band and its deformation.

5. Conclusion

Several versions of rational friction shoe placing on the brake band for draw works band-shoe brake are considered. The opportunity of substantial growth of shoe wear-life and brake moment both without changing the shoe number and at reduction of this number is shown. The software for computer aided calculation of the brake parameters with a choice of rational shoe placing are developed.

References

1. *Braking devices*. Reference book /M.P.Alexandrov, A.G.Lisjakov, V.N.Fedoseev a.o. Moscow, Machinostroenie, 1985.

2. Volchenko A.I., Volchenko D.A., Ribin G.P. a.o. *Braking devices*. Luhansk, Luhansky Rabochy, 1995.

3. Zlobin B.A. *High-speed hole making and reserves of new engineering*. - M.: Nedra, 1977.

4. Volchenko A., Storozh Y., Storozh B., Karpyk R. *Estimation of band-shoe brake performance for drilling winches* // Buletin Ctiintific, Seria C, Vol. VXII, Partea Fascicola: Mecanica, Tribologie, Technologia Constructiilor de Masini. Baia Mare, 2003. - p. 285-290.