Influence of the brake lining position on the efficiency of the centrifugal friction roller

Eugene V Safronov* and Andrey L Nosko
Bauman Moscow State Technical University, Faculty of Robotics and Complex Automation, Department of Lifting and Transport Systems, Russian Federation, 105005, Moscow, 2-ya Baumanskaya 5/1

Abstract. Brake roller is one of the safety elements of a pallet flow rack. At present, most widely used construction of brake roller is centrifugal friction roller (CFR). Efficiency of the CFR is ability to limit speeds of a pallet with different masses in pallet flow rack, and while the lower the speed, the higher efficiency of CFR. One of the parameters that affect to CFR efficiency is frictional lining position on the brake pads of CFR, which can be define with angle of brake lining position. The article is devoted to calculation the influence of angle of a brake lining position, its operating range finding. Analytical research was conducted for the CFR prototype. It is reported that effective areas of the angles is lies closer to the boundaries of operating range and it is non-effective to install a brake lining in the middle of the operating range.

1. Introduction
Pallet flow rack is one of the block storage or deep-lane storage systems [1-5], which consists of static part (metal construction) and dynamic part (rollers, stopping mechanism with pallet separators, brake rollers, etc) [6]. The utilization of the pallet flow rack can reduce travelling distance of the forklift by 25% in compare with single-deep racks [7] and therefore such racks can be used in automated warehouse [8-10].

There are many publication is devoted to static parts of the rack [11-14]. However, the literature is not sufficiently covered issues concerning dynamic part and safety elements – brake roller and stopping mechanism with pallet separators.

Stopping mechanism with pallet separator is need to avoid the pressure on the unloading pallet from the following behind it and therefore allow reducing the requirement for the quality of forklift drivers. Thus, it can be minimize the human factor, which is one of the main factor of accidents on the production [15].

The brake rollers serves as speed limiter, which does not allow damage of the stopping mechanism with pallet separator. Therefore, stopping mechanism with pallet separator and brake rollers is works as a system. Most widely used construction of brake roller (Figure 1) is centrifugal friction roller (CFR), consisting of axis 5 and brake insert 1 with planetary multiplier 3 and centrifugal brake 4, installing in shall 2 [e.g. 16].
Figure 1. Centrifugal friction roller (schematic diagram of construction).

The efficiency of the CFR is determined by the speed $V$ of the moving of a pallet on the CFR, while the lower the speed, the higher the efficiency of it. Thus, safety of the pallet flow rack is determine of the efficiency of the CFR. As known, brake efficiency in common depends from material of friction pair [17], coefficient of friction and its instability [18], as well as temperature on the friction surface [19-21]. In addition to the above, efficiency of the CFR also depends from the position of the brake lining on the brake pad of centrifugal brake.

Look at the scheme of the centrifugal brake of the CFR shown in Figure 2.

Figure 2. Parameters of centrifugal brake of CFR.

Speed $V$ of the moving of a pallet on the CFR can be calculated as [22]:

$$V = \frac{D}{2u} \sqrt{\frac{1}{r \cdot m} \left(\frac{D \cdot M \cdot g \cdot (\tan \alpha - w)}{u \cdot d \cdot f (1 + \eta)} \cdot [a - f \cdot b] + K \cdot (k_1 + k_2)\right)},$$

where $D$ – outside diameter of CFR shall, $u$ – gear ratio of planetary multiplier, $r$ – radius of action of centrifugal force $P_c$, $c$ – arm of the centrifugal force $P_c$ relative to axis A of rotation brake pad, $m$ – mass of the brake pad, $M$ – mass of the pallet, $\tan \alpha$ – inclination of the roller bed of pallet flow rack, $w$ – coefficient of resistance to movement of a pallets on the roller bed, $i$ – quantity of the brake pads ($i = 2$), $d$ – inside diameter of CFR shall, $f$ – coefficient of friction between CFR shall and lining, $\eta$ – coefficient of efficiency of CFR, $a$ and $b$ – arms of a normal force $N$ and a friction force $N_f$ respectively, $K$ – elastic force, $k_1$ and $k_2$ – arms of elastic forces $K$ of the springs.
Equation (1) shows that the speed $V$ of the moving of a pallet on the CFR depends on the arms $a$ and $b$, which are defined by lining position on the brake pad, as well as parameters of springs and points of its mountings, which defined initial speed $V_0$ of activation of centrifugal brake (contact of frictional lining with CFR shall). The $V_0$ can be calculated with (1) for mass of the pallet $M = 0$.

Other paragraphs are indented (BodytextIndented style).

2. Brake lining position
To exclude the effect of initial speed of activation of CFR brake in the analysis of influence of the lining position on the efficiency of CFR, the form of brake pads was chosen so that if lining is fixed in different positions, the initial speed of activation remains constant. In this case, the elastic forces $K$ of the springs, as well as the arms $k_1$ and $k_2$ of its actions, are constants.

2.1. Angle of a brake lining position
Taking into account mentioned above, look at scheme, where position of the brake lining on the brake pad is determined with angle $\beta$ of a brake lining position (Figure 3).

![Figure 3](image)

Figure 3. Angle of a brake lining position on the brake pad of CFR (springs are not shown).

Considering the mass of the brake lining significantly less than the mass of the brake pad, changing of the position of the center of gravity can be neglected.

Than (1) takes the form

$$V = \frac{D}{2u} \sqrt{\frac{1}{\text{rcm}} \left( \frac{D \cdot M \cdot g \cdot (\tan \alpha - w)}{f \cdot a \cdot f(1 + \eta)} \cdot [a(\beta) - f \cdot b(\beta)] + K \cdot (k_1 + k_2) \right)}.$$

(2)

Taking into account (2) and Figure 3 the arms $a$ and $b$ of a normal force $N$ and friction force $N_f$ can be founded as:

$$\begin{cases} a(\beta) = l_0 \cdot \sin \beta; \\ b(\beta) = \frac{a}{2} - l_0 \cdot \cos \beta. \end{cases}$$

(3)

where $l_0$ – distance between the axis of rotation of CFR and brake pad (see Figure 3).

2.2. Angle of a brake lining position
The range of the angle of a brake lining position can be calculated considering the fact that speed $V$ of the moving pallet on the CFR can not be less than initial speed $V_0$ of activation CFR, or taking into account (3):

$$a(\beta) - f \cdot b(\beta) \leq 0$$

(4)
Taking into account (4) the range of the angle of a brake lining position can be calculated from inequality

\[ a(\beta) - f \cdot b(\beta) > 0 \]  

(5)

or considering (3)

\[ l_0 \cdot \sin \beta - f \cdot \left( \frac{D_{BH}}{2} - l_0 \cdot \cos \beta \right) > 0 \]  

(6)

After transformations of the (6) the operating range of the \( \beta \) can be calculated by solving square inequality

\[ \sqrt{1 - (\cos \beta)^2 + f \cdot \cos \beta} > \frac{f \cdot D_{BH}}{2 \cdot l_0} \]  

(7)

Placing the friction lining on the brake pad outside the operating range, the CFR is jammed. In addition, it is necessary to make sure that it is constructively possible to install the friction lining within the boundaries of the operating range.

3. Results and discussion

An analytical research of the influence of the brake lining position on the efficiency of CFR was conducted for the parameters of CFR, pointed in Table 1.

**Table 1. Parameters of CFR for analytical research.**

| Parameter of CFR | Value       | Parameter of CFR | Value  |
|------------------|-------------|------------------|--------|
| Mass of the pallet \( M \), kg | 300-1500 | Coefficient of efficiency of CFR \( \eta \) | 0.73   |
| Outside diameter of the CFR shall \( D \), m | 0.089     | Coefficient of friction between CFR shall and lining \( f \) | 0.44   |
| Gear ration of planetary multiplier \( u \) | 24        | Distance between the axis of rotation of CFR and brake pad \( l_0 \), m | 0.03   |
| Inside diameter of the CFR shall \( d \), m | 0.083     | Elastic force \( K \), N | 3.4    |
| Quantity of brake pads \( i \) | 2         | The arm of elastic force \( K \) of first spring \( k_1 \), m | 0.016  |
| Coefficient of resistance to movement of a pallets on the roller bed \( w \) | 0.02      | The arm of elastic force \( K \) of first spring \( k_2 \), m | 0.042  |
| Inclination of the roller bed of pallet flow rack \( \tan \alpha \) | 0.04      |                     |        |

The operating range of the angle of a brake lining position, calculated with (7), Table 1 and design restriction of CFR, is equal \( \beta = 20^\circ \ldots 127^\circ \).

Results of the calculation of the speed \( V \) of the moving of a pallet on the CFR with (2) taking into account (3) and Table 1, is shown in Figure 4.
Figure 4. Dependence of the speed of the moving of a pallet on CFR on its mass and angle of a brake lining position (a) and effective areas of angle of a brake lining position (b)

Figure 4 shows that efficiency of the CFR is depend from the position of the brake lining and effective areas of angle $\beta$ is varies from $20\ldots40^\circ$ and $100\ldots120^\circ$ (Figure 4,b). It must be noted, that in the middle of the operating range of the angle $\beta$ the speed $V$ of the moving of a pallet on the CFR takes high values with the maximum at $\beta=70^\circ$.

4. Conclusions

Efficiency of the CFR is determined by the speed of the moving of a pallet on CFR, while the lower the speed, the higher the efficiency of it. Brake lining position, which is one of the parameters of the CFR, affecting on its work efficiency, can be defined by angle $\beta$. The operating range of its angle, depending from the inside diameter of the CFR shall, distance between the axis of rotation of CFR and brake pad, as well as, coefficient of friction between CFR shall and brake lining, is calculated with equation (7). An analytical research, conducted for the CFR prototype, showed:
1. The operating range of the angle of a brake lining position varies from 20° to 127°. Placing the friction lining on the brake pad outside the operating range, the CFR is jammed. Due to instability of the coefficient of friction is not recommended to install the brake lining close to the boundaries of the operating range.

2. The dependence of the speed of the moving of a pallet on CFR on its mass and angle of a brake lining position nonlinear and can be calculated with equations (2) and (3).

3. Effective areas of the angle of a brake lining position is varies from 20…40° and 100…120°. The lowest efficiency of CFR is correspond to the angle values in the middle of the operating range with minimum at β=70°.

References
[1] I. Sulirova, L. Zavodska, M. Rakyta, V. Pelantova, State-of-the-art approaches to material transportation, handling and warehousing, 12th International scientific conference of young scientists on sustainable, modern and safe transport, Procedia Engineering, Vol. 192, P. 857-862 (2017)
[2] N. Boysen, D. Boywitz, F. Weidinger, Deep-lane storage of time-critical items: one-sided versus two-sided access, OR Spectrum, Vol. 40, No. 4, P. 1141-1170 (2018)
[3] D. Boywitz, N. Boysen N., Robust storage assignment in stack- and queue-based storage systems, Comput. Oper. Res., Vol. 100, P. 189-200 (2018)
[4] R. Accorsi, G. Baruffaldi, R. Manzini, Design and manage deep lane storage system layout. An iterative decision-support model, Int. J. Adv. Manuf. Technol., Vol. 92, No. 1-4, P. 57-67 (2017)
[5] J. Eo, J. Sonico, A. Su, W. Wang, C. Zhou, Y. Zhu, S. Wu, T. Chokshi, Structured comparison of pallet racks and gravity flow racks, IIE Annual Conference and Expo 2015, P. 1971-1980 (2015)
[6] R. Vujanac, N. Miloradovic, S. Vulovic, Dynamic storage systems, ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering, Vol. XIV, P. 79-82 (2016)
[7] S. Wu, Ya. Wu, Ya. Wang, A structured comparison study on storage racks system, J. Residuals Sci. Tech., Vol. 13, No. 8 (2016)
[8] D. Metahri, K. Hachemi, Automated storage and retrieval systems: a performances comparison between Free-fall-flow-rack and classic flow-rack, 6-th International Conference On Systems And Control (ICSC’ 17), P. 589-594 (2017)
[9] L. Ghomri, Z. Sari, Mathematical modeling of the average retrieval time for flow-rack automated storage and retrieval systems, J. Manuf. Syst., Vol. 44, P. 165-178 (2017)
[10] M. A. Hamzaoui, Z. Sari, Optimal dimensions minimizing expected travel time of a single machine flow rack AS/RS, Mechatronics, Vol. 31, P. 158-168 (2015)
[11] C. N. Thombare, K. K. Sangle, V. M. Mohitkar, Nonlinear buckling analysis of 2-D cold-formed steel simple cross-aisle storage rack frames, Journal of Building Engineering, Vol. 7, 12–22 (2016)
[12] N. Talebian, B. P. Gilbert, C. N. Pham, R. Chariere, H. Karampour, Local and Distortional Biaxial Bending Capacities of Cold-Formed Steel Storage Rack Uprights, Proceedings of the 7th International Conference on Coupled Instabilities in Metal Structures, J. Struct. Eng.-Asce, Vol. 144, No. 6 (2018)
[13] A. Crisan, V. Ungureanu, D. Dubina, Behaviour of cold-formed steel perforated sections in compression. Part 1-Experimental investigations, Thin Wall Struct., Vol. 61, P. 86-96 (2012)
[14] A. Saleh, H. Far, L. Mok, Effects of different support conditions on experimental bending strength of thin walled cold formed steel storage upright frames, J. Constr. Steel Res., Vol. 150, P. 1-6 (2018)
[15] A. A. Aleksandrov, V. A. Devisilov, M. V. Ivanov, A role of education system in creation of safety culture, Chem. Eng. Trans., Vol. 53, P. 211-216 (2016)
[16] Patent RU170875-U1 B65G-013/075 Roller brake for gravity roller conveyors / A. L. Nosko, E.
V. Safronov

[17] A. L. Nosko, E. V. Safronov, V. A. Soloviev, Study of Friction and Wear Characteristics of the Friction Pair of Centrifugal Brake Rollers, J. Fric. Wear, Vol. 39, No. 2, P. 145-151 (2018)

[18] E. V. Safronov, A. L. Nosko, D. V. Kirillov, Choice of Materials of Friction Linings Using in Centrifugal Brake Roller, J. Fric. Wear, Vol. 40, No. 3 (to be published)

[19] O. Nosko, T. Nagamine, A. L. Nosko, H. Mori, Y. Sato Measurement of temperature at sliding polymer surface by grindable thermocouples, Tribol. Int., Vol. 88, P. 100-106 (2015)

[20] E. Safronov, A. Nosko Measurement Technique for Temperature of Friction Lining of Brake Roller for Pallet Flow Rack, Proceedings of the 4th International Conference on Industrial Engineering. ICIE 2018. Lecture Notes in Mechanical Engineering, P. 829-835 (2019)

[21] O. Nosko, Tribology Letters, V. 61, 1 (2016)

[22] E.V. Safronov, A.L. Nosko, Selection of the gear ratio of the multiplicator of friction brake roller, Fundamental and Applied Problems of Technics and technology, 5 (331), P. 81-87 (2018) (in Russian)