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Friction coefficient research at refining of fibrous semi-finished products

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Abstract. An object of research of article is the friction coefficient at refining of fibrous semi-finished products in the knife refining machines. The main consumed energy of these machines is spent for overcoming friction of rotor about stator. On the basis of the theory of contact interaction of knives the tangential coefficient of friction between rotor and stator is investigated. This coefficient depends on type of friction of rotor and stator, concentration and type of fibrous semi-finished product, pressure in an interknife gap, the given module of elasticity of material of plate, the area of contact and speed rotation of rotor. Recommendations for decrease in power consumption of process of refining are developed.

1. Introduction

Refining of fibrous semi-finished products, as a rule, happens in the knife refining machines. These machines have big power consumption, and their efficiency does not exceed one percent [1,2]. The main consumed energy is spent for overcoming friction at rotation of rotor [3,4]. The coefficient of friction consists of two components: adhesive and deformation [5]. It is necessary to distinguish radial and tangential coefficients of friction at refining. The radial coefficient of friction arises at the movement of fibrous semi-finished product from the center to the periphery of plate, tangential – when moving rotor concerning the stator [6-8]. In article the tangential coefficient of friction at refining is considered.

Article purpose – to investigate friction coefficient at refining of fibrous semi-finished products and to develop recommendations about decrease in power consumption of the knife refining machines.

2. Methods and materials

Researches were carried out on the basis of the theory of contact interaction of the knifes, developed in article [9]. The normal component of force in a zone of contact and can be written down as

$$\hat{P}_e = 2\sum_{j=1}^{N} \Delta\hat{z} \int_{-\hat{a}_j}^{\hat{b}_j} \left[e^{\frac{(\hat{x}+\hat{a}_j)\zeta}{\hat{a}_{\text{н}}}} \left(\hat{a}_j^2 - c_1\hat{a}_j - c_{2j}\right) - \hat{x}^2 - c_1\hat{x} + c_{2j} \right] \cos\varphi(\hat{x}) d\hat{x}$$

The tangential component of force can be presented as [9]

$$\widehat{T}_d = 2\sum_{j=1}^{N} \Delta\hat{z} \int_{-\hat{a}_j}^{\hat{b}_j} \left[e^{\frac{(\hat{x}+\hat{a}_j)\zeta}{\hat{a}_{\text{н}}}} \left(\hat{a}_j^2 - c_1\hat{a}_j - c_{2j}\right) - \hat{x}^2 - c_1\hat{x} + c_{2j} \right] \sin\varphi(\hat{x})d\hat{x}$$

Friction coefficient between knives of rotor and stator

$$\mu = \widehat{T}_d/\widehat{P}_e.$$

Between knives of rotor and stator there is fibrous layer which is modeled at liquid friction by model of standard body of Maxwell-Thomson, and at boundary friction – Guka model [10]. Parameters of models depend on technology and operational factors of refining and have casual character.

3. Results and discussion

Frequencies of impact of knives of plate on fibrous semi-finished product are called plate frequencies and reach 30 and more than kHz [11]. These frequencies increase from the center to the periphery of plate. In the figure 1 segment of late and plate frequencies arising when crossing knives of rotor and stator is shown. Speed of sliding of knives of rotor concerning knives of stator depends on the drawing of knives of plate, frequency of rotation of rotor and can reach the speed of distribution of sound in metal. In the analysis of vibration of stator refiner, it is necessary to consider Dopler's effect [12].

Contact forces $\widehat{P}_e$ и $\widehat{T}_d$, arising with nominal pressure of refining are calculated by the developed technique of contact interaction of knives of plate. Calculation was carried out in relation to refining of fir-tree chip by concentration of 40% on peripheral knife belt of plate. When calculating the package of computer programs Matlab is used. Results of calculation are presented in the figure 2 in which the period plate frequency of peripheral knife belt of plate is visible. At the same time sliding friction coefficient $\mu = \frac{\widehat{T}_d}{\widehat{P}_e} =$ 0.4 - 0.6.

The dependence of the contact forces arising at refining on concentration of semi-finished product is presented in the figure 3. At increase in concentration contact forces increase, and the tangential component of force $\widehat{T}_d$ increases more, than normal $\widehat{P}_e$. With increase in concentration of the ground semi-finished product from 20 to 55% friction coefficient μ increases twice with 0.4 to 0.8. For reduction of coefficient of friction at refining of chip it is recommended to pump in zone of refining water [10].

The dependence of coefficient of friction μ from pressure is shown in the figure 4. At increase in pressure from 5.0 to 7.0 bar coefficient of friction increases up with 0.14 - 0.16 to 0.6.

Rheological characteristics of fibrous semi-finished products, in particular relaxation time, significantly depend on concentration. For low concentration time of relaxation is ten-thousand fractions of second, for chip of high concentration – tens of seconds. The dependence of coefficient of friction at refining is received from Deborah's number in work [10]. In the figure 5,a dependence of coefficient of friction on the linear speed of rotor is presented. The friction coefficient at refining of fibrous semi-finished products of low concentration increases with 0.11 to 0.18 at increase in speed from 30 to 200 m/s. At refining of chip and mass of high concentration the coefficient of friction decreases with 0.65 - 0.80 to 0.42 - 0.50 at increase in speed from 30 to 200 m/s. At the low area of contact of knives of rotor and stator coefficient of friction increases, at high – decreases [10]. For decrease in power consumption of process of refining it is recommended to increase rotor speed at refining of chip and mass of high concentrations and to reduce at refining of mass of low concentration.

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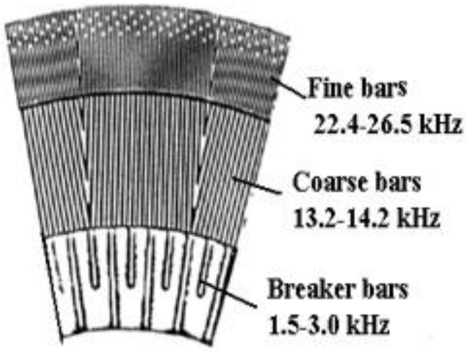

Figure 1. Segment of plate and plate frequency.

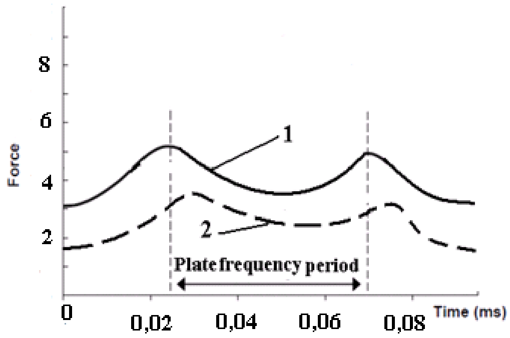

Figure 2. Dependence of contact forces, arising at refining from time: normal force $\hat{P}_e$, 2 - tangential force $\hat{T}_d$.

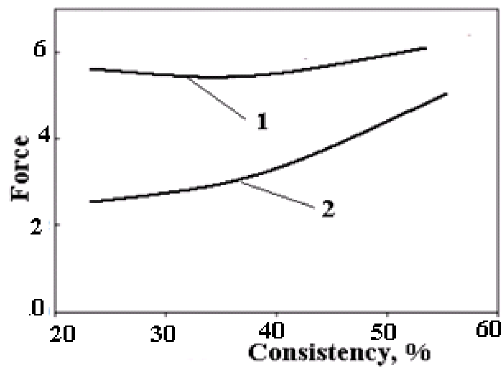

Figure 3. Dependence of contact forces, arising at refining from concentration semi-finished product: 1- normal force $\hat{P}_e$, 2 - tangential force $\hat{T}_d$.

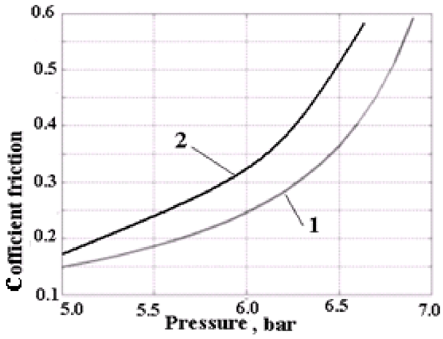

Figure 4. Dependence of coefficient friction μ from pressure: 1- concentration semi-finished product 20%, 2 - 55%.

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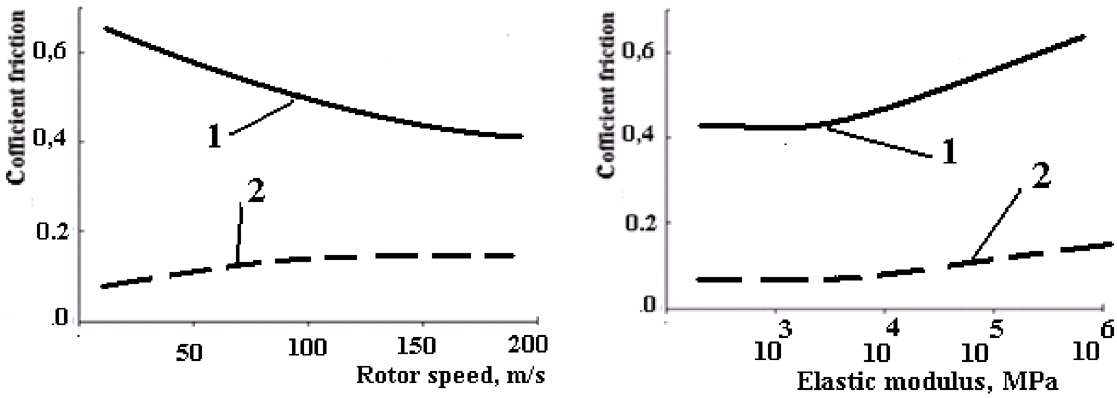
The dependence of coefficient friction at refining from the given module of elasticity of materials of plate of rotor and stator is presented in the figure 5,b. At reduction of the given module of elasticity of materials from 2.1·105 to 1.0·103 MPa the coefficient of friction decreases at 1.5-1.8 time.

In the figure 6 dependences of change of parameters of refiner at refining of fir-tree chip are presented by concentration of 45% of an interknife gap. In the drawing it is possible to allocate two zones. It is refining with boundary and liquid friction of rotor and stator. The model describing fibrous layer at these types of friction also changes [11]. The intensity of wear of plate at boundary friction sharply increases [13] therefore operation of refiners in this mode is not recommended. Upon transition from liquid friction to boundary the power of the drive of refiner and coefficient of friction decrease and amplitude of high-frequency vibration of stator increases. Vibration diagnostics of metal contact of plate rotor and stator and management of functioning is the basis for the operating systems [11,14].



a) b)

Figure 5. Dependences of coefficient of friction on the speed rotor (a) and given module of elasticity of materials of plate (b): 1 - refining of chip and mass high concentrations; 2 - refining of mass low concentration.

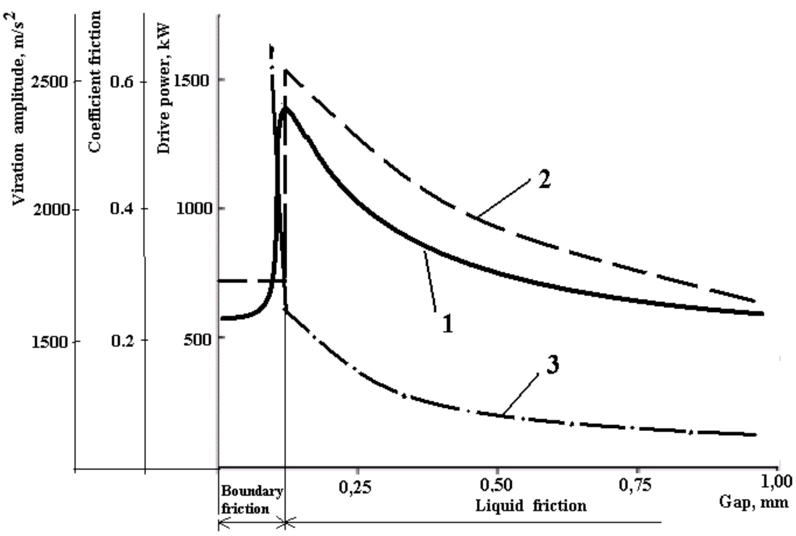


Figure 6. Dependences parameters of refiner on an interknife gap: 1- power of the drive; 2 - friction coefficient; 3 - amplitude high-frequency vibration of stator.

Analyzing schedule in the figure 6 it is possible to draw conclusion that the friction coefficient between rotor and stator of refiner has correlation with refiner drive power. The main power of the drive is spent for overcoming friction between rotor and stator. Therefore, for decrease in energy consumption of it is necessary to choose such modes at which the coefficient of friction is minimum.

4. Conclusions

The main consumed energy of the knife refining machines is spent for overcoming friction at rotation of rotor. By means of the theory of contact interaction of knives the tangential coefficient of friction between rotor and stator is investigated. This coefficient depends on ype of friction of rotor and stator, concentration and type of fibrous semi-finished product, pressure in interknife gap, given module of elasticity of material ofplate, the area of contact and speed rotation of rotor.

At boundary friction of rotor and stator the coefficient of friction and power of the drive decrease, but the intensity of wear of plate sharply increases.

With increase in concentration of the ground semi-finished product from 20 to 55% coefficient of friction increases twice with 0.4 to 0.8.

At increase in pressure from 5.0 to 7.0 bar in an interknife gap the coefficient of friction increases with 0.14 - 0.16 till 0.60. At the low area of contact of knives of rotor and stator the coefficient of friction increases, at high – decreases.

The friction coefficient at refining of semi-finished products of low concentration increases from 0.11 to 0.18 at increase in speed from 30 to 200 m/s. At refining of chip and mass of high concentration the coefficient of friction decreases with 0.65 - 0.80 to 0.42 - 0.50 at increase in speed from 30 to 200 m/s.

At reduction of the given module of elasticity of material of plate from $2.1 \cdot 10^5$ to $1.0 \cdot 10^3$ MPa coefficient of friction decreases by 1.5 - 1.8 times.

The following recommendations for decrease in power consumption of process of refining are developed:

- to use plate with high density of contact of knives;
- to apply wear proof material of plate with lower module of elasticity, than steel;
- to increase the speed of rotation of rotor at refining of chip and mass of high concentrations and to reduce at refining of mass of low concentration;
- at refining of chip to pump water in refining zone.

The offered technique of researches can be used in other machines, for example, in centrifugal pumps.

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