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Research of a fibrous layer at refining in the refiners

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Research of a fibrous layer at refining in the refiners

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Abstract. A subject of research – a fibrous layer in the refiners at refining. By means of the tension compression chart it is shown that parameters of a fibrous layer are adequately described by Maxwell-Thompson's model for liquid friction and the Hooke model for boundary friction of a plate. Deborah's number of a fibrous layer is also investigated. Deborah's number of a fibrous layer at refining changes in the range from 7 to $2.1 \cdot 10^6$ and depends on a nature and concentration of the refining material, the angle of knife crossing, the frequency of rotation of rotor and width of the platform of contact. For decrease in power consumption at refining both chips and pulp of high concentration it is recommended to increase the speed of sliding of knife of rotor along stator knife. It is possible to reach by increase in frequency of rotation of rotor and by decrease of an angle of crossing of knife. At refining of pulp of low concentration for decrease in power consumption of refining it is recommended to reduce the frequency of rotation of rotor and to increase the angle of crossing of knife of rotor and stator. At the high density of contact of plate knife in the range from 5 to 10^6 of Deborah number the deformation component of friction coefficient decreases together with power consumption of refining process.

1. Introduction

The refiners is the principal processing equipment for refining of fibrous materials in pulp and paper industry. At refining of fibrous materials in refiners the main properties of products are forming [1, 2]. These machines belong to the most power-consuming equipment in production of paper, a cardboard and wood plates [1-6]. The relevance of a research of a fibrous layer in refiners at refining is confirmed by publications which includes the analysis of various aspects in the field of power interaction [3, 5, 7] and hydrodynamics [8-10].

At compression of a fibrous layer in an inter knife gap of refiners its concentration increases up to 15-60% [3]. At refining in modern refiners time of deformation of a fibrous layer is $3 \cdot 10^{-5}$ s [5]. The model of a fibrous layer was defined by many authors at much longer time of loading. Such assumption leads to essential errors. As model of a fibrous layer at refining in the refiners the model of a standard viscoelastic body is offered [11, 12]. In present publication the properties of a fibrous layer at refining are investigated and approaches providing the decrease in energy consumption of the refining equipment are developed.



2. Experimental Part and Results

2.1 Model of a fibrous layer

To study the characteristics of fibrous materials we use the phenomenological approach [4]. There are two methods of processing of phenomenological data: integrated and analytical. The integrated method is based on experimental data, the dependences thus received reflects the behavior of material under the influence of variable factors. An example of integrated approach is the Nutting equation. This equation is successfully applied to the description of behavior of many materials [4].

To describe the properties of fibrous viscoelastic semi-finished products Maxwell-Thomson's model is most widely used [3,11-14]. Parameters of this model are received by studying charts of dependence between tension and deformation at constant speed of deformation. Authors of many investigations are trying to use more difficult laws of deformation by increasing number of elements in mechanical models [15,16]. It should be noted that such approach allows to pass to difficult laws of deformation, however it not always leads to high-quality measurements of character of deformation. Therefore for practical purposes it is enough to use standard model of a viscoelastic body [17,18].

Dependences of parameters of vibration of stator on the size of a gap between the knife in refiners of various standard sizes are received. The dynamic system of a set stator plate - the case of a refiner is almost linear since it does not contain nonlinear elements. Therefore amplitude of vibration of stator is proportional to amplitude of impulses of pressure and tension of a fibrous layer, and plate frequencies of vibration correspond to frequencies of crossing of knife on the knife belts of a plate. Deformation of a fibrous layer is defined by means of the gap sensor. As a result of these measurements the charts of tension of a layer at its relative deformation (Figure 1) are received. On the received charts it is possible to allocate zones of liquid and boundary friction of a plate of rotor and stator. At the process of liquid friction rotor and stator are completely separated by a fibrous layer, while at boundary friction there is a metal contact between plates. At liquid friction it is possible to allocate elastic and viscoelastic deformation of a fibrous layer. At boundary friction of a plate tension increases almost linearly.

At liquid friction of a plate of a fibrous layer most satisfies Maxwell-Thompson's model with rigidity of E_r , E_r and damper of b_1 [3], and at boundary friction – the Hooke model with rigidity of E_M (Figure 2). It should be noted that parameters of model depend on technology and operational factors of refining and have casual character.

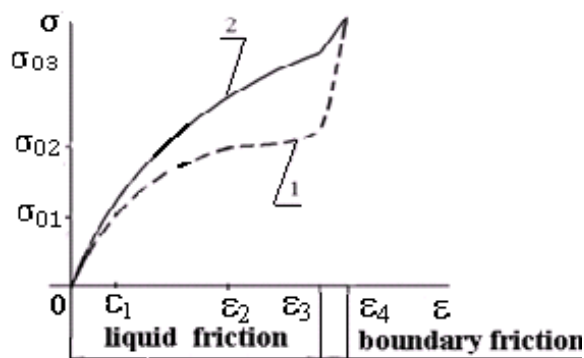


Figure 1. Tension of a fibrous layer at the of deformation: 1 - sulfate cellulose, concentration of 3%; 2 - chips refining, concentration of 45%.

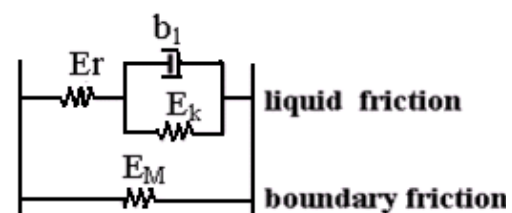


Figure 2. Model of a fibrous layer.

2.2. Time of a relaxation of fibrous materials

Relaxation processes are of great importance since during refining fibrous material is exposed to influence with high frequencies which can reach 30 kHz [7]. These processes cause the hysteresis phenomena. Existence of a hysteresis loop is often associated with process of viscoelastic deformation

[18, 19]. As the important characteristic of the process usually serves the time of a tension relaxation which value is caused by rearrangement of elements of structure of fibrous material and deformation kinetics. Time of a relaxation depends on temperature and mechanical tension [20]. Many authors notes the dependence of time of a relaxation of wood on its breed, humidity and speed of deformation. Time of a relaxation of wood comprises the gap from seconds up to tens of seconds [21, 22]. Time of a relaxation of various fibrous materials is presented in Table 1 [14].

Table 1. Time of a relaxation of fibrous materials.

Fibrous material, type of deformation and characteristic	Wood (shift)	Wood (compression)	Cellulose birch sulfate (compression) concentration of 1-6%	Cellulose pine sulfate (compression) concentration of 3-6%	Cellulose not bleached sulfate concentration of 8 - 20%	Cellulose air and dry sulfate not bleached (compression)
Relaxation time, s	37.5-41.9	4.6-4.7	$(2.8-5.6)10^{-4}$	$(2.8-4.0)10^{-4}$	$(1.5-4.2)10^{-4}$	9.4-11.7
References	[21]	[22]	[23]	[23]	[3]	[17] [20]

2.3. Deborah's number of a fibrous layer

The dependence of results of refining on Deborah's number of a fibrous layer is shown in the theory of contact interaction of knife of a plate [12-14]. Deborah's number of a fibrous layer can be defined as (1):

$$\xi = T_{\sigma}V/a_H, \quad (1)$$

where a_H - width of the platform of contact of knife of rotor and stator; T_{σ} - time of a relaxation of a fibrous layer; V - speed of sliding of knife of rotor on stator knife.

Deborah's number is in direct ratio with speed of sliding of rotor knife on stator knife. There is an effect of "emersion" of knife at high speeds of sliding, characteristic of viscoelastic materials. At small speeds of sliding ($V \rightarrow 0$, $\xi \rightarrow 0$) introduction of each knife is identical at big and small density of contact of rotor and stator. This results from the fact that the fibrous layer manages to be restored completely in a flute between the knife. At increase in speed of sliding affects the density of knife contact. At increase in a step of knife of a plate the gap between the knife decreases at the same loading [11].

Width of the platform of contact of knife of a plate is determined by a formula [12](2)

$$a_H = \left(\frac{3Pb}{4E^*}\right)^{1/3}, \quad (2)$$

where, b - width of a knife of a plate, P - the normal loading operating on a knife; $E^* = E_L/(1 - \nu^2)$, E_L - the long module of elasticity of fibrous material, ν - Poisson's coefficient.

Width of the platform of contact of knife a_H depends on properties of fibrous semi-finished products and the enclosed load P . The maximum width of the platform of knife $a_{Hmax} = b/\cos\beta$, where β - the angle of crossing of knife of rotor and stator. At refining of chips and pulp of high concentration width of the platform of contact can exceed maximum due to clogging of inter knife channels of a plate [3].

Speed of sliding of knife of rotor on knife of stator [24] (3)

$$V = (V_N^2 + V_t^2)^{1/2} = \left\{ \left[\omega R (1 - \sin^2 \alpha)^{1/2} / \sin \beta \right]^2 + \left[\omega R \cos(\beta - \alpha) / \sin \beta \right]^2 \right\}^{1/2} \quad (3)$$

where V_N , V_t - being the normal and tangential speeds of sliding of knife; ω - the angular frequency of rotation of rotor; R - external radius of a plate; α - a tilt angle of knife to radius.

Deborah's number at refining of fibrous semi-finished products ($V=100$ m/s, $a_H=2\cdot 10^{-3}$ m) is presented in Table 2.

Table 2. Deborah's number at refining of fibrous materials.

Fibrous material	Wood	Cellulose concentration 1-20%	Air dry cellulose
Number Deborah	$(2.3-21.0)10^5$	7.5-28.0	$(4.7-5.9)10^5$

The dependence of number of Deborah of a fibrous layer on the speed of sliding, width of the platform of contact and the angle of crossing of knife is presented in Figures 3-5.

2.4. Friction coefficient between rotor and stator

The coefficient of friction consists of two components: adhesive and deformation [25]. The deformation component of friction force is equal to resistance to relative movement of rotor against stator for deformation of a fibrous layer. The adhesive component of friction force is necessary for overcoming resistance to a cut of the bonds arising as a part of adhesive interaction of the rubbing surfaces. On the basis of theory of contact interaction of knife [12-14] the dependence of a deformation component of coefficient of friction between plates μ is received from Deborah's number, in application to wood pulp with pressure $\hat{p} = 0.08$ (Figure 6). On these graphics two areas A and B are allocated. The area A corresponds to refining of pulp of low concentration, and area B - refining of chips and pulp of high concentrations. Time of a relaxation for wood varies from seconds up to tens of seconds, and those for the pulp of low concentration comprise $(1.5-5.6)10^{-4}$ s (Table 1).

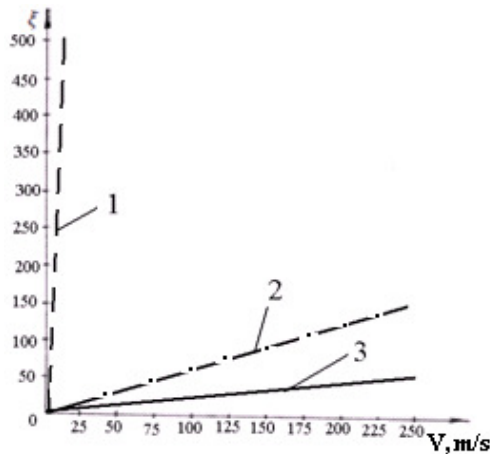


Figure 3. Dependence of Deborah number on the speed of sliding of knife ($a_H = 2\cdot 10^{-3}$ m):

- 1 - fir wood chips, concentration of 50%;
- 2 - cellulose, concentration of 20%;
- 3 - cellulose, concentration of 3%

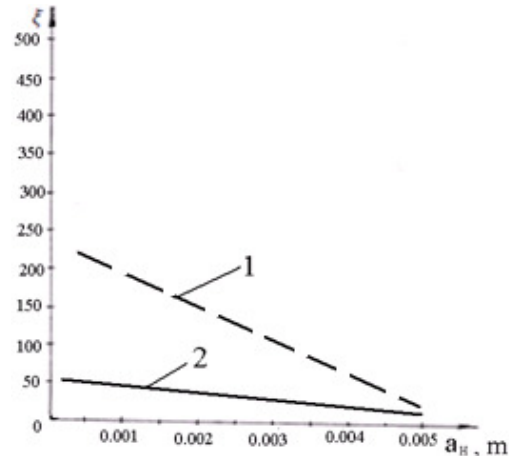


Figure 4. Dependence of Deborah number on width of the platform of knife contact ($V = 100$ m/s), cellulose concentration:

- 1 - 20%;
- 2 - 3%

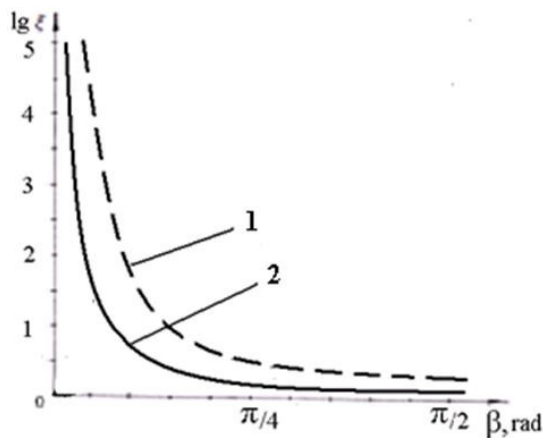


Figure 5. Dependence of Deborah number on a angle of knife crossing of plate ($a_H = 2 \cdot 10^{-3} \text{m}$, $\omega = 157 \text{ rad/s}$):
 1 - fir wood chips concentration of 50%;
 2 - cellulose concentration of 3% .

Therefore, analyzing the received schedules and a formula of number of Deborah, for reduction of a deformation component of coefficient of friction between plates (decrease in power consumption of refining) at refining of chips and pulp of high concentration it is necessary to increase the speed of sliding of knife of rotor on stator knife. And it can be reached by increase in frequency of rotation of rotor and reduction of an angle of crossing of knife. At refining of pulp of low concentration it is recommended to reduce the frequency of rotation of rotor for decrease in power consumption of refining and to increase the angle of crossing of knife of rotor and stator.

Density of contact of knife of rotor and stator also influences a deformation component of coefficient of friction between plates. At the high density of contact in the range from 5 to 10^6 number of Deborah this component of coefficient of friction decreases and the power consumption of process of refining also decreases. Therefore it is recommended to use a plate with a high density of contact.

3. Conclusion

Parameters of a fibrous layer are well described by Maxwell-Thompson's model during liquid friction and the Hooke model during boundary friction of a plate.

Deborah's number of a fibrous layer at refining changes from 7 to $2.1 \cdot 10^6$ and depends on a nature and concentration of the refining material, the angle of knife crossing, the frequency of rotation of rotor and width of the platform of contact.

For reduction of deformation component of coefficient of friction between plates (decrease in power consumption of refining) at refining of chips and pulp of high concentration it is necessary to increase the speed of sliding of rotor knife along stator knife. This can be achieved by increase in frequency of rotation of rotor and reduction of an angle of crossing of knife. At refining of pulp of low concentration it is recommended to reduce the frequency of rotation of rotor for decrease in power consumption of refining and increase the angle of crossing of knife of rotor and stator.

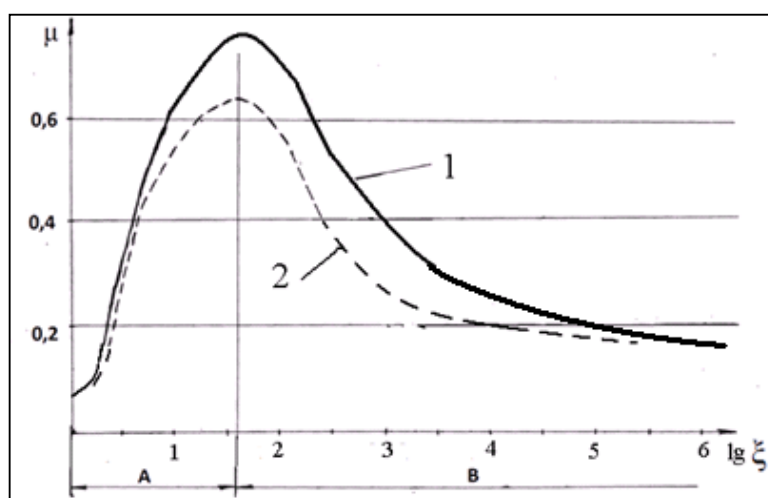


Figure 6. Dependence of a deformation component of coefficient of friction between plates from Deborah's number: 1- at the low density of contact $l/b = 4$; 2 - at the high density of contact $l/b = 2$; A - a zone of refining of pulp of low concentration; B - a zone of refining of chips and pulp of high concentration

At the high density of knife contact of a plate ($l/b > 2$) in the range from 5 to 10^6 Deborah number the deformation component of coefficient of friction decreases and the power consumption of process of refining decreases. Therefore it is recommended to use a plate with a high density of contact.

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