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Research mill fibrous semi-finished products with the help theories of contact interaction of knives

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Abstract. In the article an attempt to describe a stage of power interaction of knives is made at mill fibrous semi-finished products by means of the theory of discrete contact of knives sets. Time of a relaxation of fibrous semi-finished products is investigated. This time makes from $4{\cdot}10^{-4}$ seconds for semi-finished products of low concentration up to tens seconds for wood. Pressure in a zone of contact of knives of a rotor and stator is theoretically investigated. Dependences of size of pressure on relative introduction of knives in a fibrous material and displacement of a rotor are received. Theoretical researches are confirmed experimentally. Deborah's number ξ for a ground fibrous material is investigated. Dependences of this number from knife backlash and speed of sliding of knives are received. It is investigated deformation by a component of factor of friction between sets. For reduction of a deformation component of factor of friction between sets (i.e. reductions of power consumption) at mill chips wood and weights of high concentration it is necessary to increase frequency of rotation of a rotor, and at mill weights of low concentration, on the contrary, to reduce it.

1. Introduction

Knife grinding machines are the basic process equipment for mill fibrous materials in a pulp and paper industry. At mill fibrous semi-finished products in mills the basic properties of let out production are pawned. These machines concern to the most power-intensive equipment by manufacture of a paper, a cardboard and wood plates [1-5]. An urgency of research mill in knife grinding machines is confirmed by publications with the analysis of various aspects in the field of hydrodynamics [4, 6, 7] and power interaction [5-8]. However, research of such problems is complicated with features of interaction of knives sets of mills and properties of fibrous semi-finished products. The efficiency of these machines does not exceed one percent [5]. The research of process of grind of fibrous materials taking into account wear of a font is executed in the work [9].

The purpose of the article is the research of results of the theory of contact interaction of knives developed in relation to the knife grinding machines [10] and development of new approaches to decrease in their energy consumption.

2. Object of researches

Modern representations about mill fibrous semi-finished products suggest to break this process on two basic stages:

1. Submission of a fibrous material in a zone mill and formation fibrous layers between knives of a rotor and stator.

2. Power and hydrodynamic influence on a fibrous material between a rotor and stator, removal of a material from a mill.

The developed theory of discrete contact of knives sets [10] describes a stage of power interaction of knives on a fibrous material. Power interaction of knives is a major factor mill fibrous semi-finished products especially chips and weights of high concentration [5]. Mill weights of high concentration and chips essentially differ from mill at low concentration. This distinction is caused by:

1. The smaller maintenance of water in weight creates conditions for primary formation of a structural component of the general pressure through inter-fiber contacts.

2. The backlash between a rotor and stator is much higher.

3. Can occur jamming internecine knife channels in the ground weight.

The analysis of the received expressions of contact pressure between knives [10] shows that contact characteristics depend on the following parameters:

1. Relative introduction of knives in a fibrous material $\frac{\delta}{a+b}$, where δ - rapprochement of knives of a rotor and stator as a result of action of loading on a knife of normal loading P (Figure 1); a + b - width of a knife.

2. The parameters describing loading $\hat{P} = \frac{2P}{(a+b)^3} \cdot h / E^*$, where h - thickness of a viscoelastic layer, E*- the resulted module of elasticity of a fibrous layer, $E^* = E_L / (1-\nu^2)$, where E_L - the long module of elasticity of a fibrous material, ν – factor Poisson.

3. Properties of a fibrous layer $c = T\varepsilon/T_\sigma$, where $T\varepsilon$, T_σ - time after-action and relaxations of a fibrous layer.

4. Deborah's numbers of a fibrous layer $\xi = T\sigma V/a_H$, where a_H - length of a platform of contact of knives of rotor and stator; T_σ - time of relaxation of a fibrous layer; V - speed of sliding of knives of a rotor on knives stator.

5. A relative step between knives sets l/(a+b), where l - step of knifes (Figure 1).

The circuit of the forces working on a knife at mill of fibrous weight is submitted in Figure 2.

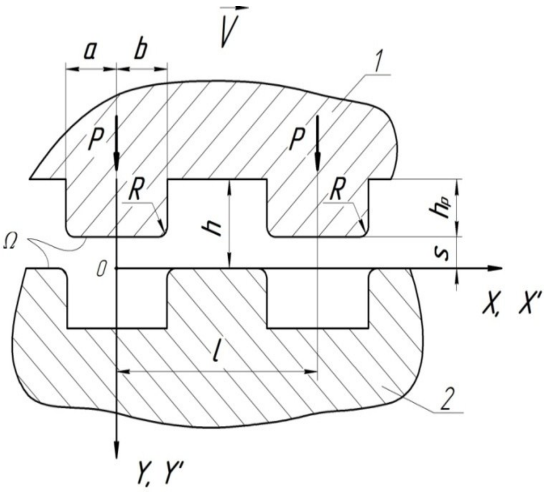

Figure 1. The circuit of contact interaction of knives: 1 - rotor; 2 – stator.

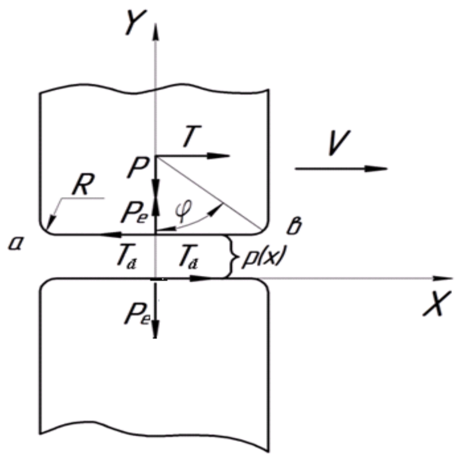

Figure 2. The circuit of the forces working on a knife at mill of fibrous weight.

3. Calculations

3.1 Time of a relaxation of fibrous materials

Wood and fibrous semi-finished products (including a paper) represents a viscoelastic material. For studying characteristics of such material, as a rule, it is used the phenomenological approach [11]. There are two methods of processing of the phenomenological data: integrated and analytical.

The integrated method is based on experimental data, receive dependence which reflects behavior of material under an action of variable factors. An example of integrated approach is equation Netting. This equation is successfully applied to the description of behavior of many materials [11].

The analytical method allows to find behavior of a fibrous material under the various conditions. Thus assumptions are done, that the material is structurally close to ideal elements which name rheological models.

Most widely for the description of properties of fibrous viscoelastic semi-finished products it is used the model of a standard body of Maxwell-Thomson [10, 11]. Parameters (rheological) of this model can be received constants by studying diagrams of dependence between a pressure and deformation at constant speed of deformation.

Authors of many uses aspire to proceed to more complex laws of deformation, increasing number of elements in mechanical models [12, 13]. It is necessary to note, that such approach allows to proceed to complex laws of deformation, however it does not always result in qualitative measurements of character of deformation. Therefore for practical purposes it is enough to use studying of standard model of a viscoelastic body [14].

Relaxation processes are of great importance, since at mill the fibrous material is exposed to the big frequencies of influence which can reach 30 kHz [9]. These processes cause hysteresis and the phenomena hysteresis loops frequently connect presence to process of plastic deformation [15, 16], however it can be also consequence relaxation character of grinding deformation. In connection with this major characteristic time of a relaxation of pressure which size is caused by reshuffled elements of structure of a fibrous material and kinetic deformations is served. Time of a relaxation depends on temperature and a mechanical pressure [17]. Many authors mark dependence of time of a relaxation of wood on its breed, humidity and speed of deformation. Time of a relaxation of wood makes from units up to tens seconds [18, 19]. Time of a relaxation of various fibrous materials is submitted in the Table 1.

Table 1. Time of a relaxation of fibrous materials.

Fibrous material, kind of deformation and charac-teristics	Wood, shift	Wood, compression	Cellulose Birch sulphitic, compression, concentration 1 - 6 %	Cellulose Pine sulphitic, compression, concentration 3 - 6 %	Cellulose sulphatic, compression, concentration 8-30 %	Cellulose air - dry sulphatic, compression
Time of a relaxation, s	37.5-41.9	4.6–4.7	$(2.8\text{-}5.6)10^{-4}$	$(2.8\text{-}4.0)10^{-4}$	$(1.5\text{-}4.2)10^{-4}$	9.4-11.7
Reference	[18]	[19]	[20]	[20]	[5]	[14], [17]

3.2 Pressure in zone of contact

The width of a platform of contact of knives sets is defined under the formula [10]

$$a_{í} = \sqrt[3]{\frac{3P(a+b)}{4E^{*}}},$$

where (a + b) - width of knife sets he long module of elasticity.

E_L depends on concentration and a kind of the ground weight, for sulphatic cellulose concentration from 3 up to 45 % E_L is in limits (1.3-13.4) $\cdot 10^5$ Pa, $\boldsymbol{\nu} = 0.5$ [5]. Graphically dependence $a_{í} = f(\lg P)$ is presented in Figure 3. The width of a platform of contact of knives a_H depends on properties of fibrous semi finished products P. Maximal enclosed loading width of a platform of knives

$$a_{í\ max} = \frac{a+b}{\cos\frac{\beta}{2}},$$

where β - a corner of a crossing of knifes of a rotor and stator.

At mill chips and weights of high concentration the width of a platform of contact can exceed maximal for the account jamming intestine channels sets.

Dependence of dimensionless pressure $\hat{p} = \frac{2ph}{(a+b)E^{*}}$ where p - pressure in a zone of contact between knives, from relative introduction of knives in a fibrous material $\frac{1}{a+b}$ it is submitted in Figure 4. Dependence is designed for sulphitic cellulose by concentration 40 - 45 %, speeds of sliding of knives V = 100 m/s and l / (a+b) = 2.

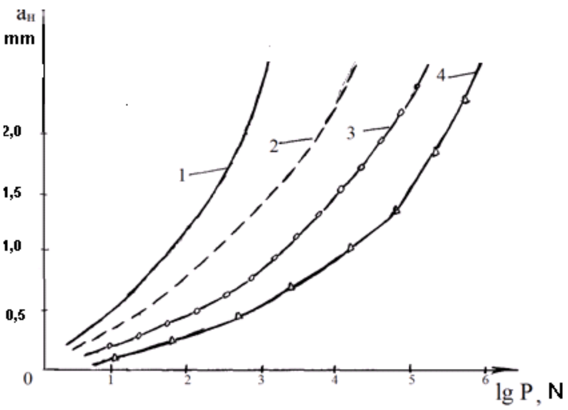

Figure 3. Dependence of width of a platform contact of knives sets from loading on a knife: 1,2 - E* = $1.0\cdot10^5$ Pa; 3,4 - E* = $10.1\cdot10^5$ Pa; 1,3 - (a+b) = 0.006 m; 2,4 - (a+b) =0.003 m.

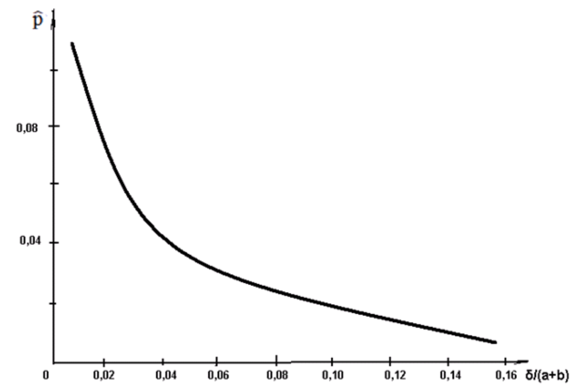

Figure 4. Dependence of the maximal amplitude of pressure $\hat{p}$ in a zone of contact between knifes from relative introduction of knives in a fibrous material.

Dependence of pressure $\hat{p}$ in a zone of contact between knives from displacement of a rotor is shown in Figure 5. The size of contact pressure paid off under formulas of contact pressure in j-strip of a zone of contact (the width of a strip was accepted on 1 mm) in view of characteristics and relative introduction of knives in a ground material. The width of a knife and intestine knife flutes at calculations was accepted on 3 mm, V = 100 m/s, P = 10^3 N.

In Figure 5 the pulses of pressure arising at interaction of knives of a rotor and stator are visible. The amplitude of pulses of contact pressure depends on characteristics of a ground material and influence on it of knives sets.

At mill weights of low concentration (cellulose sulphatic concentration of 3 %) pulses of contact pressure arise and at an output of a knife of a rotor from a zone of contact to a knife stator. And the amplitude of these pulses has negative value. At mill chips such pulses of pressure are absent.

Change of pressure at contact interaction of knives submits to laws of a viscoelastic body. At mill chips the amplitude of pulses of pressure is more, than at mill weights of low concentration. Results of theoretical research of pulse pressure are confirmed experimentally [5, 16, 21-23].

3.3 Deborah's number of a fibrous layer

In Figure 6 the schedule of change intestine knife backlash S from Deborah's number ξ is submitted. Deborah's number is in direct ratio speeds of sliding of knives of a rotor on knives stator. These dependences illustrate effect of "emersion" of knives at the big speeds of sliding, characteristic for viscoelastic materials. At small speeds of sliding ($V \to 0$, $\xi \to \infty$)) introduction of each knife is equal at the big and small density of contact.

It speaks that the fibrous layer has time to be restored completely in intestine knife to a flute. At increase in speed of sliding the density of contact of knives affects. At increase in a relative step of knives $\frac{1}{a+b}$ t intestine knife backlash at the same loading decreases. Intestine knife backlash decreases at increase in parameters $\hat{p}$.

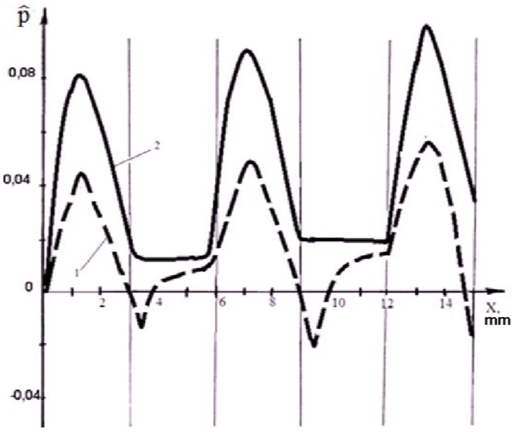

Figure 5. Dependence of pressure $\hat{p}$ in a zone of contact between knifes from displacement of a rotor: 1 – mill cellulose sulphatic concentration of 3 %; 2 – mill fur-tree chips concentration of 45 %.

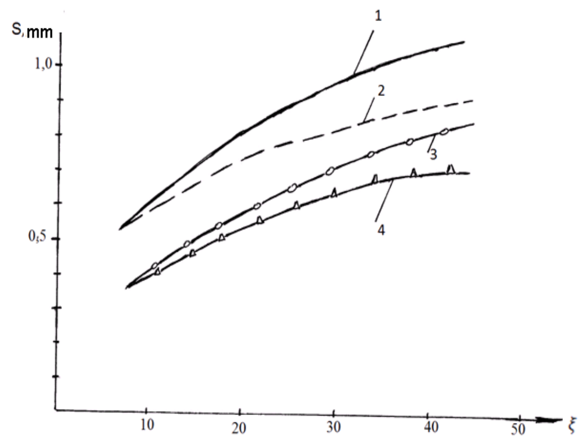

Figure 6. Dependence intestine knife backlash from Deborah's number: 1,2 - at $\hat{p}$= 0.032; 3,4 - at $\hat{p}$ = 0.08; 2,3 - at 1 / (a+b) = 4; 1,4 - at 1 / (a+b) = 2

Dependence of parameter $1/\xi$ (Deborah's inverse number) from speed of sliding of knives is submitted in Figure 7. This dependence is linear at constant width of a platform of contact of knives a_H. The corner of an inclination of a straight line to an axis abscissa (speeds of sliding V) depends on fluidity of semi-finished products. The less concentration of semi-finished products is the more corner of an inclination of parameter $1/\xi$ to an axis abscissa.

3.4 Factor of friction between sets of rotor and stator

The factor of friction will consist of two components: adhesive and deformation [22]. The deformation component of force of friction is equal to resistance to relative moving of rotor be relative stator for deformation of a fibrous layer. The adhesive component of force of friction is necessary for overcoming resistance for a cut of the communications arising in structure of adhesive interaction of rubbed surfaces.

Dependence of a deformation component of factor of friction between sets μ from Deborah's number, with reference to a wood pulp at $\hat{P} = \frac{2P}{(a+b)^3}\frac{h}{E^*} = 0.08$ is submitted in Figure 8. Two areas A and B are on the diagram. Area A is allocated and corresponds mill chips and weights of high concentration, and area B - weights of low concentration. Time of a relaxation of wood makes from units up to tens seconds and weights of low concentration make $(2.8 – 5.6) \cdot 10^{-4}$ s (see Table 1). Hence, analyzing the schedule and the formula of number of Deborah, it is possible to draw a conclusion - for reduction of a deformation component of factor of friction between sets (i.e. reductions of power consumption) at mill chips and weights of high concentration it is necessary to increase frequency of rotation of a rotor, and at mill weights of low concentration, on the contrary, to reduce it.

The density of contact of knives of a rotor and stator also influences a deformation component of factor of friction between sets. At high density of contact in the range $1 / \xi = 0.02 – 0.12$ this component of factor of friction is reduced, power consumption of process mill also decreases. Therefore it is recommended to use the sets with high density of contact. But thus, it is necessary to take into account throughput of sets [5].

In process mill chips and weights of high concentration there is an intensive steam formation [5], i.e. water in submitted semi-finished products evaporates, and concentration increases on radius sets [23]. This process causes "burning" semi-finished products in intestine knife flutes sets and increases their probability jamming [5, 23]. The resulted rigidity of a fibrous layer between knives $Cr = E^*/ h = E_L/ [h (1- \boldsymbol{\nu}^2)]$. For sulphitic cellulose concentration 40 - 45 % $Cr = (4.8 – 14.7)\ 10^8$ N/m^3. For wood $Cr = (11.0 – 16.5)\ 10^{12}$ N/m^3.

Increase of concentration of weight to radius sets causes increase in resulted rigidity Cr and according to researches [10] results in increase in factor of friction in a zone mill. And it increases power consumption of a mill. Therefore it is recommended to level concentration on radius sets by water delivery in a zone mill.

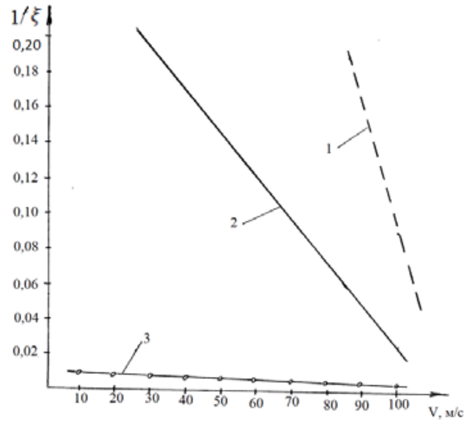

Figure 7. Dependence of parameter 1/ξ from speed of sliding of knifes: 1 - sulphitic cellulose concentration of 6 %; 2 - the same concentration of 20 %; 3 - fur-tree chips concentration 50 %.

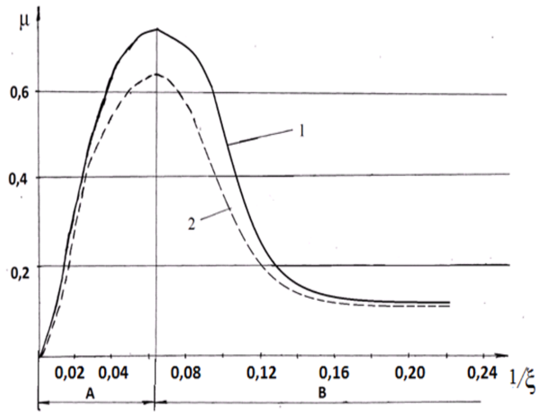

Figure 8. Dependence of a deformation component of factor of friction μ between sets from parameter 1/ξ: 1 - at low density of contact $\frac{1}{a+b} = 4$; 2 - at high density of contact $\frac{1}{a+b} = 2$; A - zone mill chips and weights of high concentration; B - zone mill weights of low concentration.

4. Conclusions

The theory of discrete contact of knives sets well describes a stage of power interaction of knives at mill fibrous semi-finished products. The received theoretical dependences are confirmed with experimental researches.

For reduction of a deformation component of factor of friction between sets and reductions of power consumption at mill chips and weights of high concentration it is necessary to increase frequency of rotation of a rotor, and at mill weights of low concentration, on the contrary, to reduce it.

At high density of contact of knives sets in a range 0.02 – 0.12 parameters $1/\xi$ the deformation component of factor of friction is reduced, also power consumption of process mill decreases. Therefore it is recommended to apply to set with high density of contact of knives of a rotor and stator.

For reduction of factor of friction and probability burning chips and weights of high concentration in intestine knife flutes it is recommended to submit water to a zone mill.

References

[1] Legotskij S S and Goncharov V N 1990 Potters the equipment and preparation of paper weight (M Wood industry) 224 p
[2] Ivanov S N 2006 *Technology of a paper* (M Forest industry) 696 p
[3] Byvshev A V and Savitsky E E 1991 *Mechanical of fibrous materials* (Krasnoyarsk Publishing house Krasnoyar. University) 216 p
[4] Alashkevich J D 1986 Bas of the theory of hydrodynamic processing of fibrous materials in mill machines (Auth. abstr. dis. compet. dr. sci. tech. Krasnoyarsk) p 36
[5] Goncharov V N 1990 Theoretician’s potters of a basis mill fibrous materials in knife grinding machines (Auth. abstr. dis. compet. dr. sci. tech. L) p 31
[6] Kang T, Somboon P and Paulapuro H 2006 Fibrillation of mechanical pulp fibers *Pap. Puu.* v **88** (7) 409-411
[7] Hafren J, Fernando D, Gorski D, Daniel G 2014 Fiber and fine fractions-derived effects on pulp quality as a result of mechanical pulp refining consistency *Wood Sci. Technol.* **48** (4) 737
[8] Karlstrom A and Eriksson K 2014 Fiber energy efficiency Part II: Forces acting on the refiner bars *Nord. Pulp Paper Res. J.* **29(2)** 332
[9] Vikharev S N, Alashkevich Yu D and Sivakov V P 2018 Study of fibrous materials grinding in knife machines taking into account the wear of the headset *System Methods Technologies* **3** (39) 108-115
[10] Vikharev S N 2013 Contact interaction sets of mills with a fibrous finished item *Wood magazine* **3** 133
[11] Komarov V I 2002 *Mosquitoes and destruction of pulp and paper materials* (Arkhangelsk Publishing house Arkhangelsk university) 440 p
[12] Baburim S V and Kyprianov A I 1983 *Rheological bases of processes of pulp-and-paper manufacture* (M Forest industry) 224 p
[13] Klencova N I 1976 *Structure and relaxation ability of cellulose* (L Science) 367 p
[14] Komarov V I and Kazakov I V 1993 Definition of time of a relaxation of a pressure in pulp-and-paper materials from static curves «σ - ε» at deformation and loading with constant speed *Wood magazine* **5-6** 130-133
[15] Germelis A A and Latyshenko V A 1967 Definition rheological characteristics from static curves «σ - ε», curves of creep and a relaxation *Mechanics of polymers* **6** 977-988
[16] Latyshenko V A 1968 *Diagnostics of rigidity and durability of materials* (Riga, Knowledge) 320 p
[17] Romanov V A 1988 *Technique's novels of an estimation elastic-plastic and deformation properties of a paper* (L LTU) 70 p
[18] Dvornik O R 2003 Modeling rheological behavior of wood during pressing *Engineering - physical magazine* **3** 150-155

[19] Bytulasov E O 2017 Perfection of a design of a milling rotor for crushing wood on the basis of raised damped abilities enclosure (Abstract thesis can. tech. sciences Orenburg) 16 p
[20] Terentyev O A 1980 *Hydrodynamic of fibrous suspensions in pulp-and-paper manufacture* (M Wood industry) 248 p
[21] Eriksen O 2013 *Mechanism in refining zone for development of physical properties of TMP fibers in low-consistency refiner* (Norwegian University of Science and Technology) 64 p
[22] Johnson K 1989 *Mechanic of contact interaction* (M. World) 509 p
[23] Olender D and Wild P 2007 Forces on Bars in High-Consistency Mill-Scale Refiners. Trends in Primary and Rejects Stage Refiners *J. Pulp Paper Sci.* **33** (3) 163