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Vibration processes in the knife refining machines

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Vibration processes in the knife refining machines

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Abstract. An object of research is a vibration of the stator of the knife refining machines and its interrelation with the factors which influences the course of refining among them are technical condition of a plate and change of characteristics of the ground material. The diagnostic model of process of refining is developed and positively approved. The new method of determination of degree of wear of the refining plate of refiners is offered. The new method of management of functioning of the knife refining machines is developed. It is shown that management of work on this indirect indicator is not worse, than the management based on the earlier known diagnostic signs of refiners functioning. The developed method of management is indispensible for the refiners with stepwise regulation of a gap, in a disk-conic refiners and in a dual refiners. Realization of this method under production conditions showed stable characteristics of a gain in degree of refining of a semi-finished fibrous product and decrease in specific power consumption during refining. The developed methods can be used in other branches of industry, for example, mining and metallurgy.

1. Introduction

The knife refining machines – 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 developed [1, 2]. These machines belong to the most power consuming equipment in production of paper, cardboard and wood plates [2, 3]. The relevance of the researches of processes in the knife refining machines is confirmed by a set of publications with the analysis of various aspects in the field of properties of fibrous semi-finished products [4-6] and energy saving technologies [7-10]. It is necessary to distinguish refining of fibrous mass of low and high concentration [3, 8]. In their investigations of functioning of the knife refining machines some authors [2, 3] give preference to the mechanical action transferred by bars to fiber by direct force contact, while others [4, 7] explain refining process by the action of hydrodynamic factors in a gap between knives, assuming that pulp fibers are affected by gradient forces and pulsations of hydrodynamic pressure. V.N. Goncharov [3] has proved that the mechanical action has the defining value for fibers refining. In the knife refining machines the following physical processes were investigated: pressure [11], forces [8], temperature [3] and vibration of the stator [12]. From the researches of vibration the conclusion was drawn that vibration is a consequence of pulse pressure in a refining zone [12]. Usually the correctness of functioning of refiners is evaluated on two diagnostic signs: the specific load of edges of knives and specific expense of useful energy [1, 3]. The set of the controlling and operating systems of the knife refining machines which are based on these diagnostic indication is known [1-3]. Management of work is made by an additive, by a change of rotor rotation frequencies a and by regulation of an expense of a semi-finished product [1, 3, 11]. Dynamics of management of process of refining was studied in work [13]. The objective of this research is to reveal the influence on vibration of the stator the structural parameters of a plate, technology and regime factors of refining and to develop a method of management of functioning of the knife refining machines.

2. Methods and Materials

Vibromovement mill stator *k* points with polar coordinates of R_0, Q_0 and taking into account the principle of superposition (1)

$$S_{ak} = \sum_{i=1}^{n} F_i G_i \left(R_{0,} Q_{0,} R_{i,} \omega_i\right), \quad (1)$$

$G_i \left(R_{0,} Q_{0,} R_{i,} \omega_i\right)$ - Green harmonious function [14] for dynamic force, F_i, ω_i, R_i – amplitude, frequency and radius of application of *i* dynamic force.

The main source of fluctuations appears at plate frequencies which reach tens of kHz [12] therefore it is better to use not the amplitude of vibromovement, but vibration acceleration amplitude (2)

$$a_{ak} = \sum_{i=1}^{n} F_i G_i \left(R_{0,} Q_{0,} R_{i,} \omega_i\right) \omega_i^2. \quad (2)$$

Let's note that at uniform influence of the distributed loading on knife belts of the stator vibration acceleration amplitude *k* point will not depend on coordinate Q_0 (3)

$$a_{ak} = \sum_{i=1}^{n} F_i G_i \left(R_{0,} R_{i,} \omega_i\right) \omega_i^2. \quad (3)$$

Dynamic reaction F_i depends on parameters of a fibrous layer between a rotor and the stator and intensity of impact on it of a knife plate [15]. Amplitude of impulses of pressure, i.e. dynamic reaction of a fibrous layer, depends on the factors influencing the course of refining and is actually the characteristic of the expected result of refining [3]. In works [1,3] it is shown that results of refining depend on technical condition of a plate. Therefore it is possible to write down(4)

$$F_i = f_i \left(K_i, \delta_i, \omega_i\right) = f_i^* \left(W_i, \Delta M_i\right), \quad (4)$$

K_i, δ_i - parameters and size of impact on a fibrous layer, W_i – parameters of the factors influencing the course of refining, ΔM_i – change of characteristics of the ground material.

Substituting (4) in (5) we will receive

$$a_{ak} = \sum_{i=1}^{n} f_i^* \left(W_i, \Delta M_i\right) G_i \left(R_{0,} Q_{0,} R_{i,} \omega_i\right) \omega_i^2. \quad (5)$$

Expression (4) represents diagnostic model which connects parameters of vibration of the stator of a mill with factors, influencing the refining course, including technical condition of a plate and change of characteristics of the ground material. $G_i \left(R_{0,} Q_{0,} R_{i,} \omega_i\right) \omega_i^2$ is a transfer function which characterizes system response *i* to influence of dynamic force of $F_{i..}$

3. Experimental Part and Results

The vibration spectra of refiners stators of various brands (Figure 1) were investigated. On the received spectra the characteristic peaks corresponding to various belts of the crossing plate knives are clearly visible. The central frequencies of these peaks belongs to plate [16]. To peak with a smaller plate frequency corresponds the knife belt, the next to the center of a disk, with the smallest quantity of knives. To peak with the maximum plate frequency corresponds the knife belt on the periphery of a disk with a large number of knives [16]. At a research of plate frequencies it is necessary to take into account the Dopler's effect [17].

Amplitude of vibration acceleration of the stator in the longitudinal direction is proportional to amplitude of impulses of pressure which arise at knives crossing [12,17]. Therefore, vibration acceleration amplitude at plate frequencies are diagnostic sign of intensity of process of refining on knife belts of a plate. As a rule, vibration acceleration amplitude at plate frequencies increases with increase in frequency. It means that the intensity of impact of a plate on fibrous material increases from the center to the periphery. Influence on character of a range of vibration of the following factors is investigated: frequencies of rotation of rotor, number and angle of crossing of knives. Increase in frequency of rotation of rotor and number of knives leads to the shift of the peaks corresponding to various knife belts of a plate towards increase in plate frequencies. Reduction of an angle of crossing of knives of rotor and the stator leads to reduction of peaks width, to increase in plate frequencies and their amplitudes. To the contrary, increase in this angle leads to increase in peaks width and reduction of plate frequencies and their amplitudes.

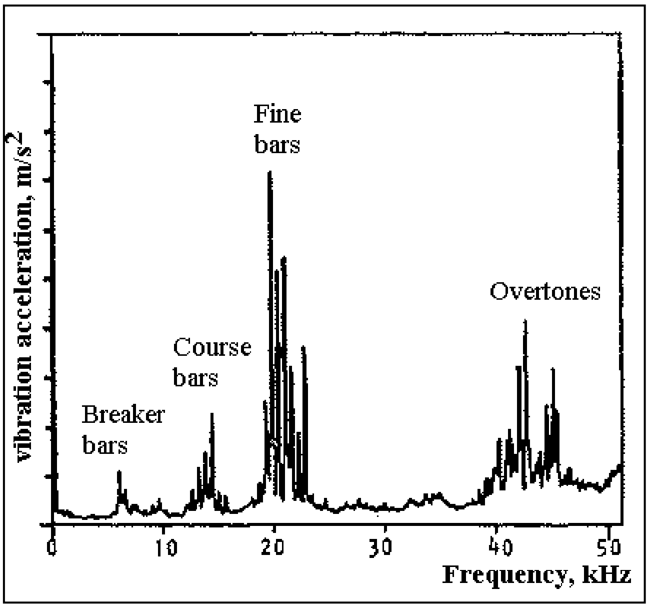

Figure 1. Spectrum of vibration acceleration of the stator of refiner.

3.1. Influence of variable factors of refining on vibration of the stator

The regression equations which define amplitude of vibration acceleration of the stator are received at refining of mass of low concentration (up to 3%) coniferous cellulose E-92 and deciduous cellulose OB-I at experimental installation (6, 7):

$$Y_1 = 32.9 + 6.4X_1 - 18.7X_2 + 2.6X_3 - 0.9X_4 \quad (6)$$

$$Y_2 = 19.9 + 2.0X_1 - 4.9X_2 + 0.8X_3 - 0.3X_4, \quad (7)$$

X_1 - specific load of edges of knives, W·s/km; X_2 - grinding degree on an entrance, °SR; X_3 - pulp concentration, %; X_4 - volume consumption of pulp, l/s.

By the same manner the regression equation which characterizes the amplitude of vibration acceleration of the stator was received for refining the wastes of sorting under production conditions the high concentrations (up to 15%) spruce pulp

$$Y_3 = 279 + 213X_7 + 89X_3 - 60X_5, \tag{8}$$

X_5 - consumption of absolutely dry fiber, kg/h, X_7 - expense of useful energy, kW.

The greatest influence on amplitude of vibration acceleration of the stator technological characteristics of the pulp at the entrance. And with increase in degree of a refining and reduction of length of fiber amplitude of vibration acceleration of the stator decreases. The second by importance indicator is a specific load of edges of knives or an expense of useful energy. At the increase of this factor the amplitude of vibration acceleration of the stator increases. The third by importance indicator is a concentration of pulp. At its increase the amplitude of vibration acceleration of the stator increases. And, at last, the fourth by the importance indicator, is the pulp expense. At its increase the amplitude of vibration acceleration of the stator decreases.

3.2. Correlation between change of characteristics of the ground material and vibration of the stator

The following regression equations were received which characterize a gain in degree of a refining of Y_4, Y_5 and reduction of length of fiber Y_6, Y_7 at refining of pulp of low concentration (up to 3%) of cellulose E-92 and OB-I (9-11)

$$Y_4 = 2.4 + 1.7X_6 - 0.9X_3 - 1.1X_4 \tag{9}$$

$$Y_6 = 4.7 + 3.2X_6 - 1.7X_3 - 2.4X_4 \tag{10}$$

$$Y_7 = 2.9 + 1.9X_6 - 0.6X_3 - 1.7X_4, \tag{11}$$

where X_6 – amplitude of vibration acceleration of the stator in the longitudinal direction, m /s^2.

The regression equations were received which characterize a gain in a degree of a refining of Y_8 and breaking length of Y_9 at refining of waste of sorting of spruce pulp of high concentrations (up to 15%) (12, 13)

$$Y_8 = 23.1 + 11.7X_6 - 1.6X_3 - 3.4X_5 \tag{12}$$

$$Y_9 = 449 + 204X_6 - 84X_3 - 86X_5 \tag{13}$$

Coefficients of linear correlation between diagnostic signs and characteristics of paper pulp are presented in the Table1.

Table1. Correlation coefficients between diagnostic signs and characteristics of paper pulp.

	Changes of characteristics of paper pulp		
Diagnostic signs	Degree of refining, °SR	Breaking length, m	Average length of fiber, dg
1. Specific load of edges of knives, W·s/km	0.74 ± 0.16	0.77 ± 0.14	0.71 ± 0.18
2. Growth of pulp temperature,°C	0.71 ± 0.18	0.69 ± 0.19	0.73 ± 0.16
3. Amplitude of vibration acceleration of stator, m/s^2	0.79 ± 0.13	0.78 ± 0.14	0.82 ± 0.12

The received results show that by estimating amplitude of vibration acceleration of the stator, it is possible to operate functioning of refiners. Adjustment of work on this indirect indicator is not worse, than on earlier known diagnostic signs of functioning of the knife refining machines. High-frequency vibration of the stator as it was shown above, is a consequence of pulse pressure on forward edges of knives. For management of a mill by this diagnostic sign it is not necessary to determine idling power. The small lag effect, high speed of distribution of acoustic waves on elements of the stator design causes fast reaction of a vibroacoustic signal to a change of technological state. By estimating vibration at plate frequencies, it is possible to evaluate the intensity of refining on each knife belt of a plate. Also the advantage of the proposed method is a simplicity of measurement of vibration of the stator by serially produced facilities.

3.3. Influence of plate technical conditions on stator vibration

During the plate wear the geometrical dimentionals of the refining elements are subjected to change and, as a rule, this wear occurs unevently [18] that worsens the refining ability of a plate [3, 19, 20] and reduces dynamic impacts on a semi-finished product and, therefore, reduces the level of vibration of the stator when other factors of refining are constant. For the proof of dependence between the level of vibration of the stator and degree of wear of a plate the researches on spruce sulfite cellulose refining on refiners under production conditions were performed. Concentration of weight at refining of 6±1%, productivity is 50±5 t/day. Vibration of the stator was measured periodically during the period of operation of a plate at the constant engine capacity of 0.35 MW. Researches of refining of wastesorting of spruce wood pulp are also conducted. Concentration of the pulp at refining is 16±5%, and productivity is 76±30 t/day. In a course of researches the engine capacity of 0.75 MW was maintained. Vibration of the stator was measured periodically during all time of operation of a plate. As the productivity of a mill changes over a wide range, the relationship of amplitude of vibration acceleration of the stator to mill productivity was analyzed. Amplitude of vibration acceleration of the stator (or its relationship to productivity) decreases during the time of operation of a plate at the constant engine capacity of a mill [20, 21]. This happens because of wear of a plate. In quality diagnostic sign of wear of a plate it is recommended to use stator vibration amplitude (or its relationship to mill productivity) at the constant engine capacity.

3.4. Realization of methods of diagnostics of structural parameters of technical condition of a plate and management of functioning of refiners

The method of determination of wear of a plate of a mill at which measurement of amplitude of vibration of the stator at the constant engine capacity [21] is offered. Wear degree at the same time is determined by a formula (14)

$$K_w = \frac{a_{eo} - a_e}{a_{eo} - a_k}, \quad (14)$$

where, a_{eo}, a_k - amplitude of vibration of the stator at the beginning and the end of operation of a plate, m/s^2, a_e - amplitude of vibration of the stator at the current moment, m/s^2.

The method is implemented as follows. From exploitation experience of a similar plate vibration amplitude at the beginning of term and at the end of operation term at the constant engine capacity is known. At the same engine capacity the vibration level at the moment is determined and, having substituted the values of these indicators in the formula (13), a degree of wear of a plate at the moment is defined. In the case of necessity the plate is replaced. At large fluctuations of productivity of a mill the relationship of amplitude of vibration of the stator to productivity is analyzed, i.e. determine coefficient of wear of a plate by a formula (15)

$$K_w = \frac{(a_{eo}/Q_o - a_e/Q)}{(a_{eo}/Q_o - a_k/Q_k)}, \quad (15)$$

where, Q_o, Q_k, Q - mill productivity in the beginning, at the end and at the current moment of operation, respectively.

In comparison with the known method [1,3] of determination of wear of a plate the offered method is less labor-consuming since it does not demand at the time of measurement the jigging of a mill and its "switching off" from a technological stream for measurement. The scheme of the device realizing the developed method of regulation of process of refining (Figure 2,a), include the vibroconverter 1 which is connected to the regulating block 5 which connects to the control point adjustment 7 and the mechanism of additive 9. The system allows to control and maintain automatically constant the set level of dynamic impacts (pressure impulses) on fibrous material in a gap between rotor and stator. Under production conditions, when productivity of refiners changes in a wide range, the management of a mill is recommended to be made on the relationship of amplitude of vibration of stator to a consumption of fibrous material. The developed method of regulation of process of refining is irreplaceable in the refiners with step regulation of a gap, disk and conic refiners and in dual refiners (Figure 2, b).

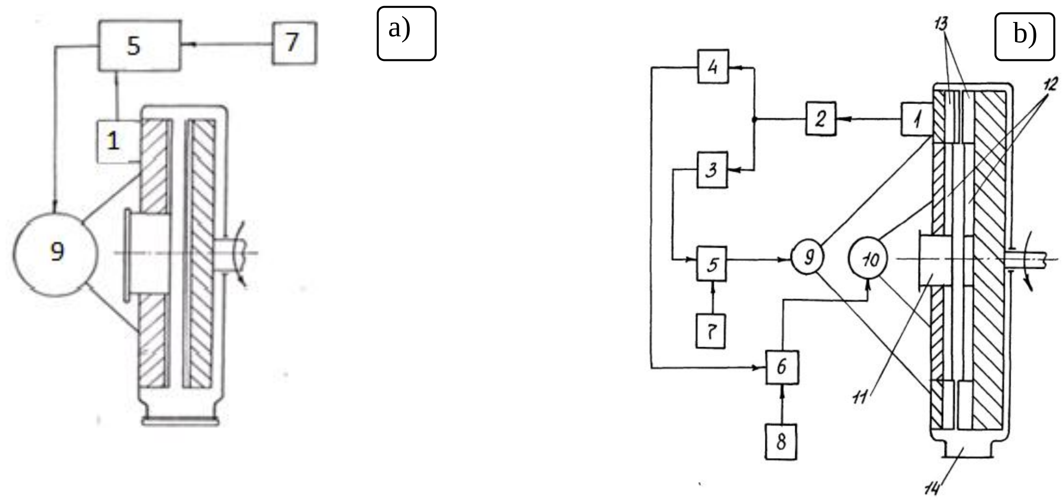

Figure 2. Schemes of devices for regulation of process of refining of the knife refining machines:- with one zone of refining; b) - with step regulation of a gap: 1 - vibroconverter; 2 - preamplifier; 3, 4 - filters; 5, 6 - regulating blocks; 7, 8 - control point adjustments; 9, 10 - additive mechanisms; 11, 14 - branch pipes; 12, 13 - refining zones

The scheme includes the vibroconverter 1 which is connected to the preamplifier 2 connected with the filters 3 and 4 which are adjusted on plate frequencies, and connected to the regulating blocks 5 and 6 respectively. The regulating blocks 5 and 6 are also connected to control point adjustments 7,8 and mechanisms of additive of a mill 9 and 10. The developed devices also protect a plate from metal contact and destruction at a hit in a gap from foreign matters. The control system of functioning is mounted and underwent positive approbation on a mill of refining of waste of sorting of wood pulp on JSC «Solikamskbumprom». Realization of this method under production conditions showed stable characteristics of a gain of degree of a refining and decrease in specific power consumption on refining.

4. Conclusion

The diagnostic model which connects the parameters of vibration of the stator of a mill with the factors influencing the course of refining is developed and positively approved. Among those factors are also a technical condition of a plate and changes of characteristics of the ground material. Amplitude of vibration of the stator increases with increase in plate frequencies. It means that the intensity of impact of a plate on fibrous material increases from the center to the periphery. Increase in frequency of rotation of rotor and number of knives leads to the shift of the peaks corresponding to different knife belts of a plate towards increase in the plate frequencies. Reduction of an angle of crossing of knives of rotor and the stator leads to reduction of width of peaks, to increase in plate frequencies and their amplitudes. To the contrary, increase of this angle leads to increase in width of peaks and reduction of plate frequencies and their amplitudes.

The greatest influence on amplitude of vibration of the stator is rendered by technical characteristics of pulp on entrance. And with increase in degree of a refining and reduction of length of fiber amplitude of vibration acceleration of the stator decreases. The second by the importance indicator is specific load of edges of knives and an expense of useful energy. At increase of this factor the amplitude of vibration acceleration of the stator increases. The third by importance indicator is the concentration of the pulp. As it increases the amplitude of vibration acceleration of the stator increases. And, at last, the fourth by importance indicator is the pulp expense. As it increases the amplitude of vibration acceleration of the stator decreases. The new method of determination of degree of wear of the refining plate of refiners is offered. The new method of management of functioning of the knife refining machines is developed. It is shown that management on this indirect indicator is not worse, than management based on earlier known diagnostic signs of functioning of refiners. The developed method of management is irreplaceable in refiners with stepwise regulation of a gap, disk and conic and in a dual refiners. Realization of this way under production conditions showed stable characteristics of a gain of degree of a refining of a semi-finished product and decrease in specific power consumption on refining. The developed methods and means can be used in other branches of industry, for example, mining and metallurgy.

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