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# Vibration diagnostics of plates of knife refiners

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**Abstract.** The subject of the research is the diagnosis of the technical condition of the plate of knife refiners. The technical diagnosis of a knife plate consists of determining the stability of the inter-knife gap and the degree of the plate wear. The paper explores the dynamic effects of a plate on a fibrous material. It is shown that the main source of high-frequency vibration of the stator is pressure pulses that occur when the rotor and stator knives cross. The influence of the rotor speed and the number and angle of intersection of the plate knives on the nature of the stator vibration spectrum is studied. It is concluded that the intensity of the effect of the plate on the fibrous material increases from the centre to the periphery. A formula is proposed for determining plate frequencies taking into account the Doppler effect. The vibration diagnostics of the rotor beats is based on the resonance-demodulation method. Estimating the depth of the amplitude modulation of vibrational acceleration of the stator at the maximum plate frequency with harmonics of the working frequency, it is possible to judge the amount of beating of the rotor plate. A device was developed for vibration diagnostics of the beats of a rotor plate of a disk mill. The developed methods and tools can be used in other industries, for example, in mining and metallurgy.

## 1. Introduction

Knife refiners are the main technological machines for grinding fibrous materials in pulp and paper industry. When grinding fibrous materials in mills, the basic properties of the products are laid [1-2]. The most unreliable element of refiners is a knife plate [1-4]. The relevance of developing methods and means of technical diagnostics of the plate of knife refiners is confirmed by many publications [1, 3, 5-7].

The diameter of the mill disc reaches up to 1600 mm and above. The manufacturing accuracy of the refining unit should be the same for all mill sizes. This is due to the fact that an effective impact on the semi-finished product is possible with a gap not exceeding a few tenths of a millimeter [1-3]. This implies stringent requirements for tolerance on the gap between the rotor and stator. The gap depends on the concentration of the mass, the peripheral speed of the rotor, the deformation of the mill elements under the action of the additive force, backlash in the bearings [8-9]. Diagnosis of the technical condition of the knife plate consists of determining the stability of the inter-knife gap and the degree of the plate wear [10]. The stability of the inter-knife gap is understood to mean the parallelism of the plate of the rotor and stator.

The reasons for the non-parallelism of the rotor and stator are divided into static, dynamic and technological [11]. Static reasons include end runout of the rotor and improper stator installation.



Dynamic reasons are insufficient mill rigidity, uneven temperature distribution on the body and refining chamber. Technological reasons are caused by the uneven release of steam along the periphery of the gap between the disks when grinding wood chips and high concentration substances. It was proposed in [12] to reduce technological causes by supplying raw materials to the mill from two sides. In [13] it is proposed to eliminate the effect of uneven temperature distribution on disk parallelism. However, the developed tools do not respond to static and technological causes.

The methods of determining the degree of the plate wear by changing the increase in the quality of the semi-finished product [15] and by metal inclusions in the semi-finished product at the outlet of the mill [16] are well known. The disadvantage of these methods is low accuracy and high complexity. Also a method for determining the degree of the plate wear by changing the idle power [9] is known.

Diagnostics of the metal contact of the rotor and stator is possible with the help of a vibration transducer fixed to the stator [17]. If the signal from the vibration transducer of the set value is exceeded, it is possible to identify the metal contact of the rotor and stator. Integrated control systems for the operation of mills, including gap sensors, a control device for metal contact, the general technical condition of the vibration level [17] are known. The most informative methods for the technical diagnosis of knife refiners are vibration diagnostic methods [18].

Operational and design engineering of the plate is considered in [10, 19-20]. The purpose of the study is the development of methods and means of technical diagnostics of a plate of knife refiners.

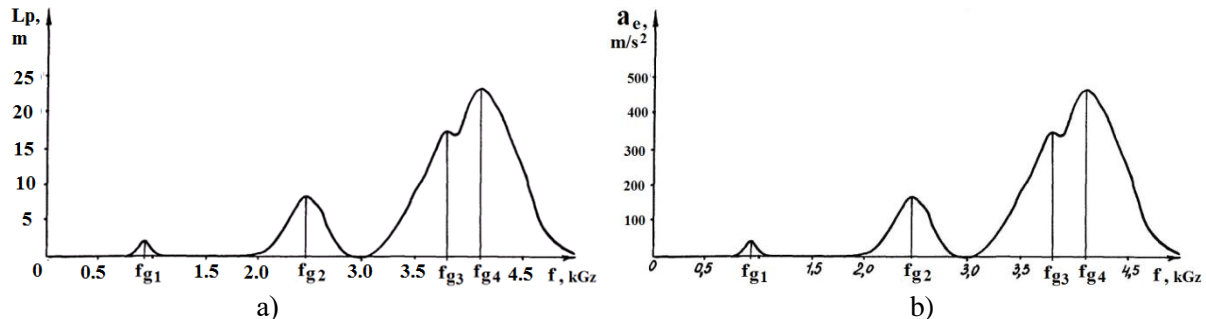
## 2. Dynamic effects of the plate on the grinded material

The dynamic impact of the plate is understood to mean pressure impulses that occur when the knives of the plate cross and act on the fibrous semi-finished product [1, 3]. The spectra of changes in the cutting length of the plate are determined using the fast Fourier transform method according to temporary realizations obtained by combining exact copies of the rotor and stator knife patterns. An example of the spectrum is presented in figure 1 a. As it is known [1, 3], when passing through the rotor blades relative to the stator blades, pressure pulses arise that affect the fibrous semi-finished product, and the amplitude of which is actually a characteristic of the expected grinding result. The amplitudes of the pressure pulses depend on the properties of the fibrous layer and on the gap between the rotor and stator. Pressure pulses act on the semi-finished product, thereby causing it to grind [9, 21-24], and on the stator and rotor, causing them to vibrate.

The spectra of vibration acceleration of the stator of mills of various grades are studied. An example of the spectrum is presented in figure 1 b. Comparing the corresponding spectra of changes in the cutting length of the plate and vibration acceleration of the stator, we can conclude that they correspond to each other. Consequently, the main source of high-frequency vibration of the stator is the pressure pulses that occur when the rotor and stator knives cross. The impact of the plate on the fibrous material is high frequency, which is up to 30 kHz.

On the spectra obtained, characteristic peaks are clearly visible, corresponding to different belts of crossed knives. The  $f_{gi}$  center frequencies of these peaks are plate ones. Moreover, the peak with a lower plate frequency corresponds to the knife belt closest to the centre of the disk, with the least number of knives. The peak with the maximum plate frequency corresponds to the knife belt on the periphery of the disk with a large number of knives (figure 1).

The amplitude of the vibrational acceleration of the stator is proportional to the amplitude of the pressure pulses that occur when the knives cross. Consequently, the amplitude of vibration acceleration at head frequencies is a diagnostic sign of the intensity of the grinding process on the knife belts of the plate.



**Figure 1.** Spectra of the cutting length of the plate (a) and vibration acceleration of the mill stator (b).

As a rule, the amplitude of vibration acceleration at plate frequencies increases with increasing frequency. This suggests that the intensity of the impact of the plate on the fibrous material increases from the centre to the periphery.

### 3. Methods and materials

With the end beating of the rotor plate, the intensity of the impact of the plate knives on the fibrous material changes with frequencies that are multiples of the reverse frequency. Amplitude modulation of the plate frequencies occurs with harmonics of the reverse frequency. Therefore, the maximum plate frequency is selected as the carrier one. Vibration acceleration at maximum plate frequency can be expressed as (1):

$$a_{gmax} = a_a [1 + mb(t)] \cos(\omega_{gmax}t + \varphi_0), \quad (1)$$

where:  $a_a$  - amplitude of vibration acceleration at the maximum plate frequency;  $m$  - amplitude modulation depth,  $b(t)$  - modulation time function;  $\omega_{gmax}$  - maximum plate frequency.

The  $b(t)$  function can be represented as:

$$b(t) = \sum_{k=1}^n a_{ak} \cos(k\omega t + \varphi_k), \quad (2)$$

where:  $a_{ak}$  - the amplitude of the  $k$ -th reverse frequency harmonics.

Substituting expression (1) in (2), we obtain:

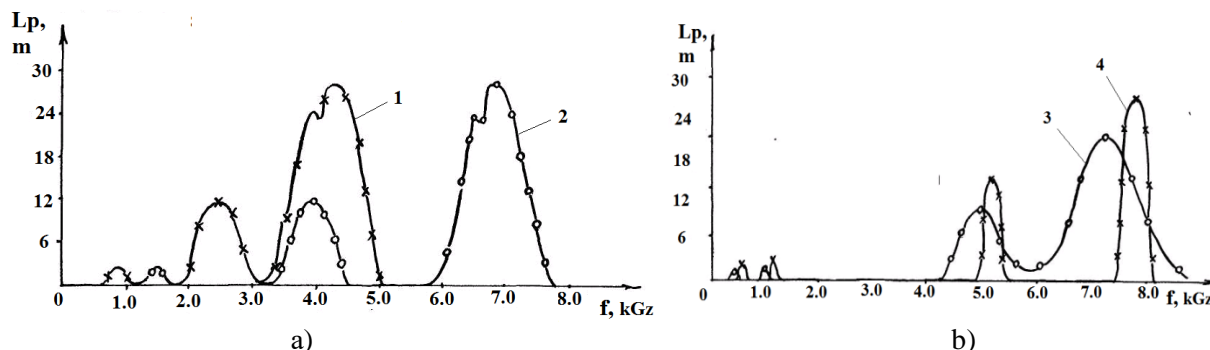
$$a_{gmax} = a_a \left[ 1 + \sum_{k=1}^n m_k a_{ak} \cos(k\omega t + \varphi_k) \right] \cos(\omega_{gmax}t + \varphi_0), \quad (3)$$

where:  $m_k$  - partial modulation factor;  $\varphi_k, \varphi_0$  - phase shifts;  $\omega = 2\pi f_r$  - rotor speed.

Estimating the depth of amplitude modulation of vibration acceleration at the maximum plate frequency with harmonics of the reverse frequency, it is possible to judge about the amount of beating of the rotor plate.

### 4. Experimental part and results

We studied the influence of the following factors on the spectrum of the cutting length of the plate: the rotor speed, the number and angle of intersection of the knives. An increase in the rotor speed and the number of knives leads to a shift of the peaks corresponding to the various knife belts of the plate towards an increase in plate frequencies. A decrease in the angle of intersection of the rotor and stator knives leads to a decrease in the width of the peaks, to an increase in plate frequencies and their amplitudes. Conversely, an increase in this angle leads to an increase in the width of the peaks and a decrease in plate frequencies and their amplitudes (figure 2).



**Figure 2.** Spectra of the cutting length of the plate with changes in the rotor speed (a) and the angles of intersection of the knives (b): 1-  $n = 10 \text{ s}^{-1}$ ; 2 -  $n = 16.7 \text{ s}^{-1}$ ; 3-  $\beta = 20^\circ$ ; 4 -  $\beta = 5^\circ$ .

Plate frequencies are determined by the formula:

$$f_{gi} = (j \cdot n \cdot z_i / 60) \cdot \cos \beta_i, \tag{4}$$

where:  $j$  - number of rotating rotors;  $n$  - rotor speed,  $\text{min}^{-1}$ ;  $z_i, \beta_i$  - the number of knives and the angle of intersection of the rotor and stator knives on the  $i$ -th knife belt of the plate.

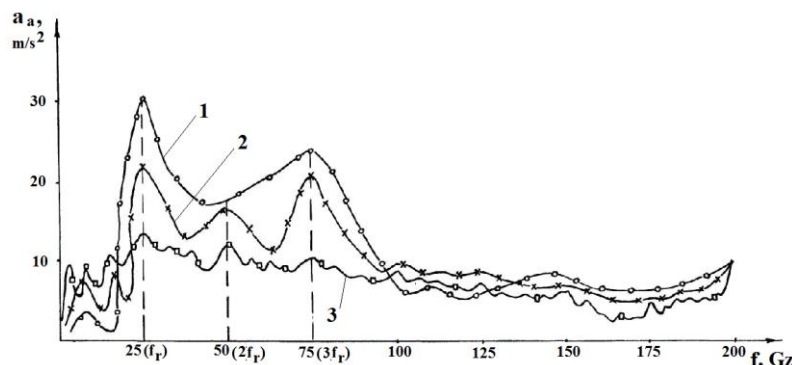
The sliding speed of the rotor knives over the stator knives depends on the plate pattern and rotor speed. The speed vector can be directed towards the centre of the disk (pulp retention mode) or to the periphery of the disk (pumping mode). The sliding speed of the knives can be comparable to the speed of sound in a metal. Therefore, when studying the vibration of mills, it is necessary to take into account the Doppler effect [6], i.e. the frequencies recorded by the stationary vibration transducer on the stator are calculated by the formula:

$$f_{gi}^* = f_{gi} / (1 \pm V/C), \tag{5}$$

where:  $C$  - sound speed in plate material;  $V$  - sliding speed of the rotor knives over the stator knives.

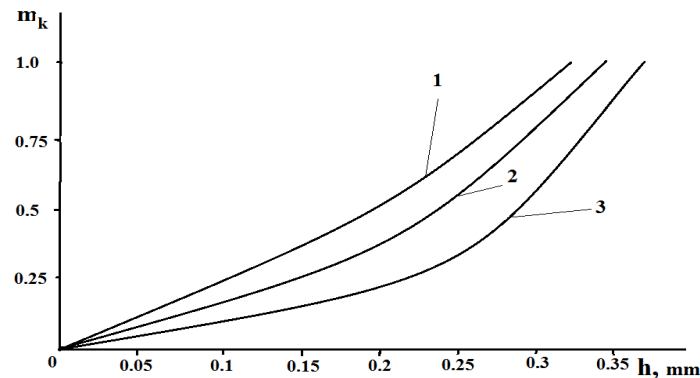
In equation (5), “+” is put if the sliding speed of the knives is directed to the vibration transducer and “-” appears if the sliding speed of the knives is directed from the vibration transducer. The vibration frequencies recorded by the vibration transducer, largely depend on the place of its fastening, i.e. some frequencies will be determined by the formula (5) with a “+” sign, others with a “-” one. The received wavelength is defined as  $\lambda = (C - V) / f_{gi}^*$ .

Spectra of the amplitude envelope of vibration acceleration at the maximum plate frequency were obtained for various values of the end beat of the rotor plate when grinding fibrous materials on a knife refiner (figure 3).



**Figure 3.** Envelope acceleration spectra of the stator at the highest headset frequency for various values of the face runout of the rotor plate: 1 - 0.15 mm; 2 - 0.1 mm; 3 - plate is clipped.

The spectra obtained show that with an increase in the beating value, the amplitudes of the envelope of vibration acceleration at harmonics of the reverse frequency increase, i.e. the depth of the amplitude modulation of the envelope increases with the above harmonics (figure 4).

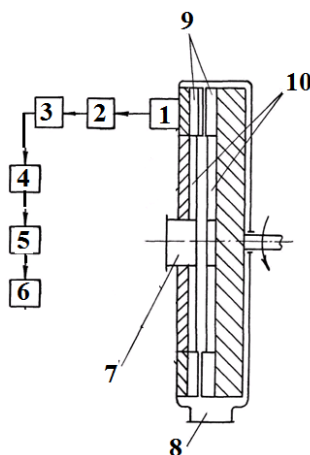


**Figure 4.** The dependence of the partial coefficient of amplitude modulation on the amount of runout of the rotor plate: 1 - reverse frequency; 2 - second harmonic of the reverse frequency; 3 - third harmonic of the reverse frequency.

Analysing the results, we can conclude that to determine the end runout of the rotor, one can use the resonant-demodulation method of vibration diagnostics.

### 5. Device for diagnosing beats of the rotor plate

A device was developed that implements a resonant-demodulation method for diagnosing beats of a rotor plate (figure 5). The device consists of a vibration transducer 1, preamplifier 2, narrow-band filters 3 and 5, a demodulator 4 and indicator 6.



**Figure 5.** Scheme of the device for vibration diagnostics of the beats of a plate of a rotor of a disk mill: 1-vibration transducer; 2-preamplifier; 3-narrowband filter tuned to the maximum plate frequency; 4-demodulator; 5-band filter tuned to the reverse frequency; 6-indicator; 7, 8-nozzles; 9,10-plate.

The fibrous material is fed into the mill through the pipe 7 and is grinded using a plate 9 and 10. Pressure pulses act on the fibrous material, which cause the stator to vibrate. A vibration transducer 1 is mounted on the stator using a waveguide, which converts vibration into an electrical signal. Further, the signal is amplified, with the help of a narrow-band filter 3, a signal is allocated with a maximum plate frequency. Then the signal is fed to the demodulator 4. From the obtained envelope with the help of the filter 5, the harmonic components of the reverse frequency are extracted. Estimating the amplitude of these components using indicator 6, the magnitude of the end runout of the rotor is determined.

## 6. Conclusion

Vibration diagnostics of the technical condition of the knife plate consists of determining the degree of wear and stability of the inter-knife gap. The main source of high-frequency vibration of the stator includes pressure pulses that occur when the rotor and stator knives cross. This follows from the correspondence of the spectra of changes in the cutting length of the plate and vibration acceleration of the stator. The impact of the plate on the fibrous material is high-frequency that is up to 30 kHz. The spectra show the characteristic peaks of the set frequencies. Moreover, the peak with a lower plate frequency corresponds to the knife belt closest to the centre of the blade disk of the mill, with the least number of knives. The peak with the maximum plate frequency corresponds to the knife belt on the periphery of the disk with a large number of knives. The amplitude of vibration acceleration at plate frequencies increases with increasing frequency. This suggests that the intensity of the impact of the plate on the fibrous material increases from the centre to the periphery of the blade disc. An increase in the rotor speed and the number of knives leads to a shift of the peaks corresponding to the various knife belts of the plate towards an increase in plate frequencies. Reducing the angle of intersection of the rotor and stator knives leads to a decrease in the width of the peaks, to an increase in plate frequencies and their amplitudes. Conversely, an increase in this angle leads to an increase in the width of the peaks and a decrease in headset frequencies and their amplitudes.

The sliding speed of the knives of the plate can be comparable with the speed of sound in the metal. Therefore, when studying the vibration of mills, it is necessary to take into account the Doppler effect. A formula is proposed for determining plate frequencies taking into account this effect.

The vibration diagnostics of the rotor beats is based on the resonance-demodulation method. Estimating the depth of the amplitude modulation of vibrational acceleration of the stator at the maximum plate frequency with harmonics of the working frequency, it is possible to judge about the amount of beating of the rotor plate. A device was developed for vibration diagnostics of the beats of a plate of a rotor of a disk mill. The developed methods and tools can be used in other industries, for example, in mining and metallurgy.

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