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Vibration calculation of the plate knives in refining machines

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Vibration calculation of the plate knives in refining machines

S N Vikharev

Ural State Forest Engineering University, Siberian tract, 36, Ekaterinburg, 620100, Russia

E-mail: cbp200558@mail.ru

Abstract. The subject of research is the method of vibration calculation of the plate knives. The study of the shapes and frequencies of free oscillations of knives was carried out using the finite element method and analytics. The error between theoretical and experimental studies does not exceed 9%. A diagram is proposed for determining the resonant modes of the plate knives. The proposed measures to reduce oscillations and dynamic stresses of the plate knives are as follows: change of the frequency of the rotor rotation; change of the length of the knives; change of the crossing angle of the rotor and stator knives; the choice of material for knives; use of damping devices in the plate design. The plate with interchangeable working elements and a headset with damping devices of knives are proposed and protected by patents for useful models. The developed method of vibration calculation can be used in other industries, for example, in mining and metallurgical industries.

1. Introduction

Knife refining machines are the main technological equipment for refining fibrous materials in the pulp and paper industry. The most unreliable element in this equipment is the knife plate [1-3]. Plate knives are worn due to abrasive and other types of semi-finished product [1,3]. However, when knives are operated in resonant zones, increased additional stresses are created, which cause fatigue phenomena in the material. The vibration strength of the headset knives largely determines the durability, life and reliability of the headset as a whole. The task from the point of view of dynamics is to reliably assess its performance and reliability.

2. Dynamic and mathematical models of the plate knives

The knife is considered as a beam on an elastic base (figure 1). The study of oscillations is carried out in a linear formulation, the inertia of the knife section is not taken into account, the rigidity of the knife attachment to the base of the plate is constant, the centrifugal force acting on the rotor head knife blade is not taken into account.

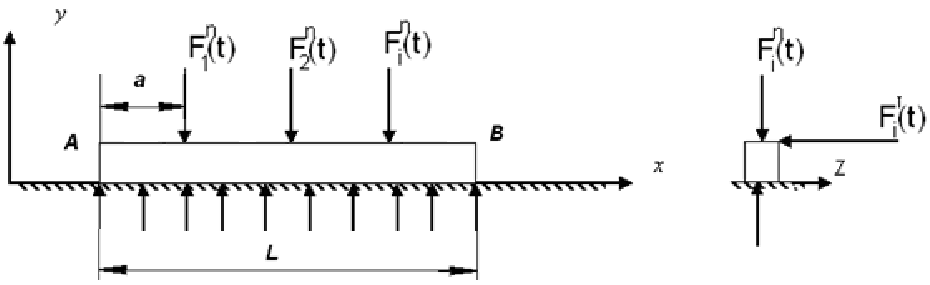


Figure 1. Dynamic model of the plate knife.

The mathematical model of this dynamic system was obtained on the basis of the Lagrange equations in [4]. Frequency of free oscillations for a knife of finite length:

$$\omega_{\Gamma 0} = \sqrt{\frac{n^4 EI\pi^4 g}{mL^4} + \frac{C_k g}{m}}, \tag{1}$$

where m – knife length unit weight; L – knife length; EI – knife bending stiffness; g – acceleration of gravity; C_k – the coefficient characterizing the rigidity of the attachment of the knife to the base of the plate, n=1,2,3…

The forced vibration of the plate was studied in [5–8]. The frequencies of intersection of the rotor and stator blades are called plate frequencies. When calculating the plate frequencies, it is necessary to take into account the Doppler effect that occurs during the operation of knife refining machines [8]. Hydrodynamic processes and engineering of these machines are considered in [9, 10].

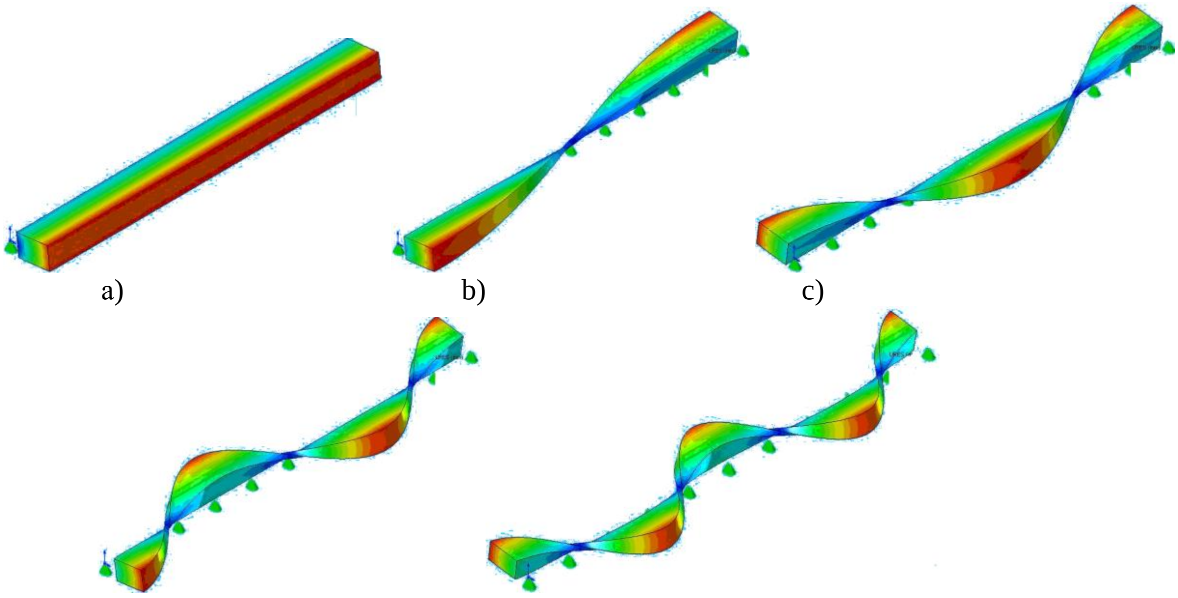
3. Investigation of the natural frequencies and oscillation patterns of knives

The study of natural frequencies and forms of bending oscillations of knives was carried out using the finite element method by means of the “CosmosWorks” software package [11]. Baseline data for the calculation are presented in table 1.

Table 1. Initial data for calculation.

Grid type	Grid on solid body
Jacobi check	16 points
Item size	0.8361 mm
Tolerance	0.041805 mm
Number of items	11658
Number of nodes	21507
Dimensions of knife	3×8×120 mm
Lateral stiffness	$9.48\cdot 10^7$ h/m
Mounting stiffness	$3.78\cdot 10^8$ h/m

The results of the calculation of the first five forms and frequencies of the natural oscillations of the knife are presented in figure 2 and table 2.



a) b) c) d) e)

Figure 2. Forms and frequencies of free oscillations of the plate knife: a) first 2320 Hz; b) the second 3540 Hz; c) the third 4870 Hz; d) fourth 5610 Hz; e) fifth 7010 Hz.

Table 2. The natural frequencies of the bending vibrations of the plate knife.

Oscillation shape	Frequency, Hz			Relative error, %	
	Finite element method	According to formula (1)	Experiment	Finite element method	According to formula (1)
First	2320	2195	2410	3.7	8.9
Second	3540	3408	3615	2.1	5.7
Third	4870	4821	5080	4.1	5.1
Fourth	5610	5543	5845	4.0	5.2
Fifth	7010	6932	7370	4.9	5.9

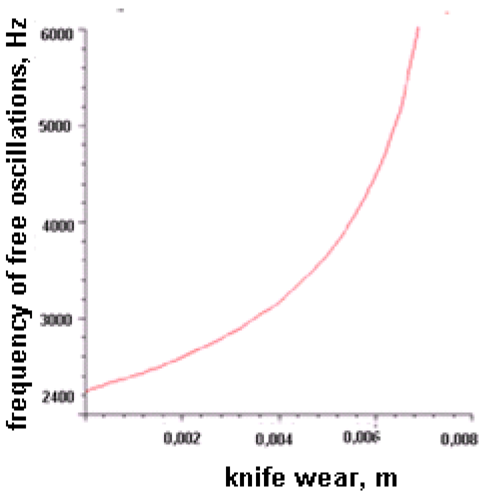
The relative error in determining the free oscillations of the plate knife according to the finite element method does not exceed 5%, and analytically by the formula (1) does not exceed 9%.

The dependences of the lower frequency of free oscillations on the amount of wear of the knife and the rigidity of attaching the knife to the base of the plate are shown in figure 3. The frequencies of free bending vibrations of the knives increase during the plate knives wear and decrease with the decrease of the rigidity of the plate knife. To reduce the rigidity of the mount, one can use the typesetting set [12-14] or the hydraulic additive of the knives [15].

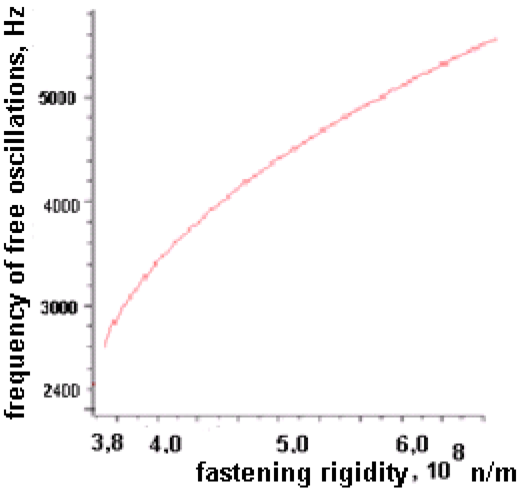
4. Vibrating refiner plate design

The first task in the vibration design of the plate is to calculate the free oscillation frequencies of the knives. The second task is to calculate the forced plate frequencies. Theoretical studies do not allow to accurately determine the magnitude of the disturbing forces and calculate the amplitudes of the oscillations of the knives.

The oscillations of the plate knives occur when the knives of the rotor and the stator cross at plate frequencies. The dynamic system of the rotor knife - the stator knife is nonlinear due to the properties of the fibrous layer between the knives [16]. Therefore, oscillations of this system are excited at the harmonics and subharmonics of the plate frequencies. If the free oscillations of the knives coincide with the plate frequencies, then resonant oscillations arise with increased amplitudes and dynamic voltages. Resonant modes of the plate increase the likelihood of knives breakage.



a)



b)

Figure 3. The dependence of the lower frequency of free oscillations of the knife from wear (a) and fastening rigidity (b).

Due to the large number of perturbing harmonics and the frequencies of the natural oscillations of the blades, the determination of the resonant modes is performed using the resonance diagram (Campbell diagram). An example of such a chart is presented in figure 4.

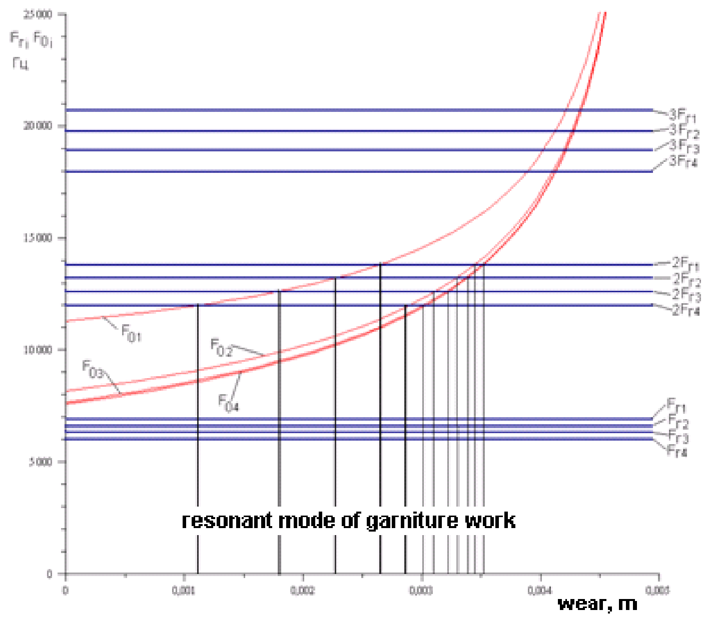


Figure 4. Resonance diagram of the headset knives: $F_{01}...F_{04}$ -frequency of free oscillations of the knives; $F_{\Gamma1}...F_{\Gamma4}...3F_{\Gamma1}...3F_{\Gamma4}$ - forced plate frequencies and their harmonics.

When using the plate, it is possible that the forced and natural frequencies coincide. To prevent resonant modes, the vibration protection condition $|F_{\Gamma i} - F_{0i}| \geq 0.3F_{0i}$ must be met.

Analysing the diagram in figure 4, we can conclude that the wear of knives of more than 1 mm leads to the appearance of resonant oscillations. The most dangerous is the operation of the plate when the wear of knives reaches 3 mm. The resonant diagram provides the necessary information, both in the design process and in the operation of the plate. In the process of designing, using the resonance diagram, the resonant frequencies of the knives are predicted and timely measures are taken to prevent them. During operation, the resonance diagram helps to identify the source of oscillations.

There are three types of measures to eliminate the resonant oscillations of the plate knives. First, change the plate frequencies in such a way that the vibration protection condition is fulfilled. This can be achieved in the following ways: by changing the rotor speed; by changing the length of the knives; by changing the angle of crossing of the rotor and stator knives. Secondly, by changing the natural frequencies of oscillations of the knives: by changing the design parameters of the knives; by changing the material of knives. All these activities should be accompanied by calculations to assess their effectiveness. The listed activities relate to changes in the plate pattern, which is associated with great technological difficulties, and in some cases it is simply impossible [17]. The third type of event is the creation and use of damping devices in plate designs. Plate designs with damping devices are protected by patents of the Russian Federation [12-15]. Damping devices can significantly reduce the oscillations of knives in resonant modes, reduce stresses in the material of knives and increase the reliability of the plate.

5. Conclusions

The methodology for the vibration calculation of the plate knives has been developed and successfully tested, which includes the determination of free and forced oscillation frequencies of the knives. The error between theoretical and experimental studies does not exceed 9%.

A diagram is proposed for determining the resonant modes of the plate knives. Developed measures to reduce vibrations and dynamic stresses of the plate knives are as follows: change of the frequency of rotation of the rotor; change of the length of the knives; changing of the angle of crossing the rotor and stator knives; the choice of material of knives; use of damping devices in the design of the plate. A plate with interchangeable working elements and a plate with damping devices of knives are proposed and protected by patents for useful models. The developed method of vibration calculation can be used in other industries, for example, in the mining and metallurgical industries.

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