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Hudrodynamic vibration of knife refiner

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Hudrodynamic vibration of knife refiner

S N Vikharev

Department of technical mechanics and the equipment of pulp and paper industry, Ural State Forest Engineering University, Siberian tract, 37, Ekaterinburg, 620100, Russia

E-mail: cbp200558@mail.ru

Abstract. The aim of this article is to study the hydrodynamic vibration of knife refiners. Such vibration occurs due to hydrodynamic processes during the operation of the mill. A mathematical model is proposed that describes hydrodynamic vibration. The hydrodynamic force that excites the mill oscillations consists of the following main components: impact of the semi-finished product on the auger blades and headset knives; forward and reverse flow interactions; pressure on the knives of the headset. These forces depend on the design and operation of the mill. The error between theoretical and experimental studies does not exceed 20%. Vibration processes of hydrodynamic origin are mainly determined by the impact of the semi-finished product flow on the auger blades at the entrance to the mill. The proposed research technique can be used in other machines, for example, in centrifugal pumps.

1. Introduction

Knife refiners play the role of the main technological equipment for grinding fibrous semi-finished products in the pulp and paper industry [1,2]. These machines have increased dynamism [3]. The dynamics of mills are considered in articles [4-6]. The vibration caused by the operation of the mill headset consists of the pulsed vibration [7–9] that occurs when the rotor and stator knives cross, and the vibration of hydrodynamic origin caused by the interaction of the fibrous semi-finished product with the mill headset and screw [8]. The article considers only hydrodynamic vibration which is a consequence of hydrodynamic processes that occur during the operation of the mill. A study of the dynamics of the flows of fibrous prefabricated in mills was carried out in [10-16].

There are frequent cases when mills excite intense vibrations at blade and head frequencies. An attempt to standardize and monitor the vibration of knife grinding machines was made in [17].

The purpose of the article is to study the hydrodynamic vibration of knife refiners.

2. Mathematical model

We will consider a knife refiner as a linear system with viscous friction proportional to the speed of oscillation. The oscillations of such a system are described by the following equation [18]:

$$\ddot{S} + 2\beta \dot{S} + \omega_0^2 S = \frac{1}{M} F_c \sin(z\,\omega t + \varphi) \qquad (1)$$

where $\beta = \frac{h'}{2M}$, S is the transition of the system in *X, Y, Z* directions, ω – rotor rotation speed, h', *M, C* - damping coefficient, system mass and stiffness, $\omega_0^2 = \frac{C}{M}$, F_c –hydrodynamic force amplitude, z, φ - number of knives and phase angle.

3. Hydrodynamic forces

The hydrodynamic force F_c consists of the following main components: impact of the semi-finished product on the auger blades F_1 and the knives of the headset F_2; interactions of forward and reverse flows F_3; pressure on the knives of the headset F_4. These forces depend on the design and operation of the mill and have axial y, transverse x, and vertical z components. Therefore, the mathematical model (1) can be written for each coordinate.

The presence of a screw in mills for grinding wood chips and a high concentration mass determines the hydrodynamic flows of the semi-finished product. Dynamic forces can arise due to hydrostatic mismatch of the flows of fibrous semi-finished product with the inlet part of the screw and (or) with the inlet part of the headset.

The impact of the semi-finished product on the auger blades of radius r is exerted by the component V_n^s of the relative velocity vector V_1^s directed normal to the surface of the blade (figure 1, a).

a)   b)
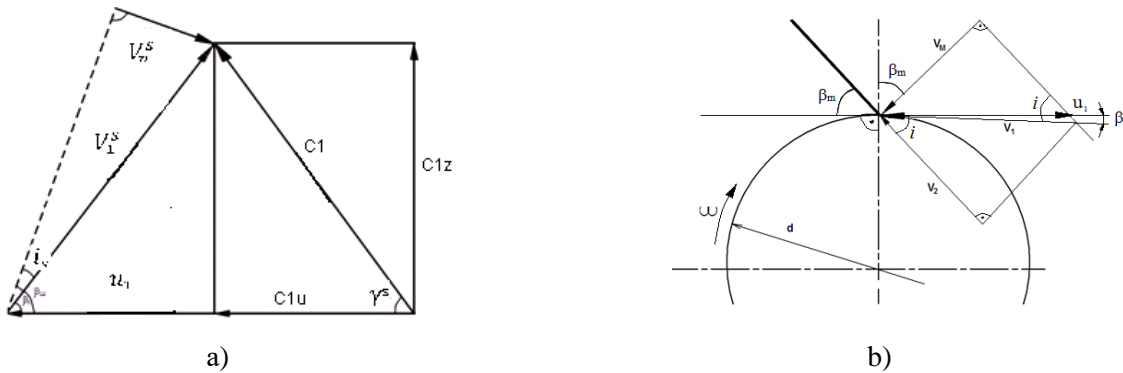
Figure 1. Semi-finished product velocity vectors: a) at the entrance to the mill auger; b) at the entrance to the knife headset mill.

Semi-finished product impact force on mill auger blades

$$F_1 = \rho Q_s (\mu^2 + 1)^{0,5} \left(\frac{8Q_s}{\pi D_s^2 - 4 z_s F_s - \pi d_s^2} \sin i_s \right) / j z_s \tag{2}$$

$$\mu = \frac{\pi n_s r}{120} \frac{\pi D_s^2 - 4 z_s F_s - \pi d_s^2}{Q_s} - \text{tg} \, \gamma^s.$$

where n_s, z_s - rotational speed and number of blades of the auger of the mill, Q_s, D_s, d_s - productivity, external and internal diameter of the screw, F_s - the cross-sectional area of the auger blades in the plane normal to its axis, γ^s, i_s - angle of the flow spin and attack.

The flow pattern of the semi-finished product at the entrance to the grinding headset is shown in figure 1, b. Semi-finished product impact force on headset knives is as follows:

$$F_2 = \frac{2\rho}{jz} \sin \beta_m Q \left\{ \frac{\pi n d}{60} - \frac{2\,(\text{ctg}\,\beta_m + \text{ctg}\,\gamma)}{j[\pi l(D+d) - 2zbl]} Q \right\} \cos \beta_H \tag{3}$$

,

where ρ - the density of the grinded semi-finished product, n, z - rotational speed and number of mill blades, D, d - outer and inner diameter of the headset, b, l - number, width and length of knives on a knife belt, Q, j - mill productivity and number of grinding zones, γ - semi-finished product inlet swirl angle, β_H - the angle of inclination of the knives to the plane of the disc, which is as a rule $\beta_H = 90°$.

The motion scheme of the semi-finished product in the mill is shown in figure 2. The moment of force arising from the interaction of the forward and reverse flows relative to the axis of the mill M_0 can be written as the difference between the moments of the forces of the forward and reverse flows of the semi-finished product M_1, M_2. The force of impact from the moment M_0 on the mill rotor equals to $F_3 = 4M_0 / (D + d)$.

a)   b)
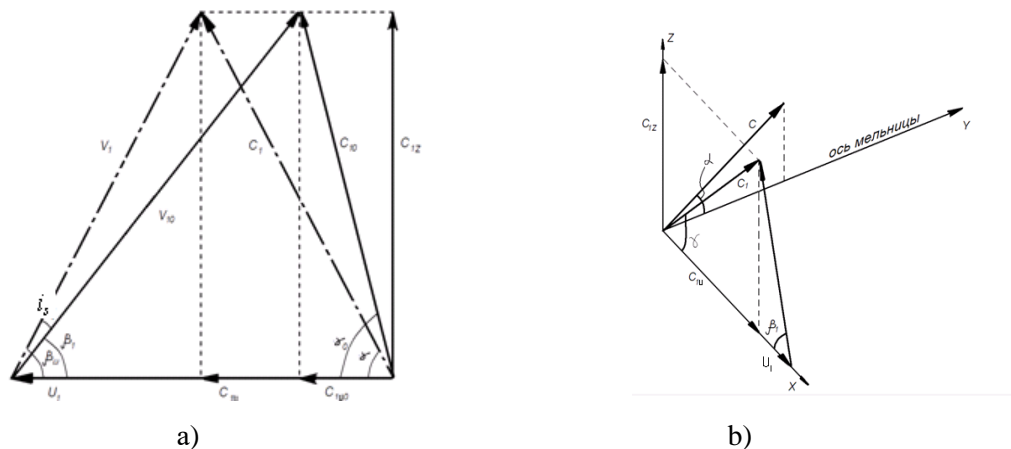
Figure 2. The scheme of movement of the semi-finished product: a) in the screw; b) in the mill headset.

The moment of forces of the direct flow of the semi-finished product:

$$M_1 = \frac{\omega}{t}\left[\left(\sum_{i=1}^{k} r_i^2 m_i\right)\Big/2 + \left(\sum_{i=1}^{k} e_i^2 m_i\right)\right].$$

Semi-finished product reverse flow moment:

$$M_2 = \frac{m_0}{t}\left[\left(c_{2u}\frac{D}{2}\right) - \left(c_{1u}\frac{d}{2}\right)\right],$$

where m_0 - the mass of fibrous semi-finished product involved in the return flow, c_{2u}, c_{1u} - circumferential components of the absolute speed of the return flow at the output and input of the headset, r_i, m_i - the radius of rotation and the mass of the semi-finished product in the inter-knife grooves on the i-th knife belt of the headset, e_i - distance between the center of rotation of the semi-finished product on the i-th knife belt and the axis of rotation of the mill rotor, k – number of the headset knife belts.

The hydrodynamic effect on the knife occurs due to the difference in pressure acting on the side faces of the knife. Moreover, the maximum hydrodynamic pressure occurs when the knife is against the inter-knife groove (area 1), and the minimum when the headset knives are opposite each other (area 2).

Knife pressure:

$$F_4 = \int_0^S (p_n - p_b)_1 \, ds - \int_0^S (p_n - p_b)_2 \, ds, \tag{4}$$

where p_n, p_b - pressure on the side faces of the knife, 1,2 –interaction areas of knives.

4. Comparison of theoretical and experimental studies

Using the Ansys fluent software package, spruce wood pulp flows were studied in an MD-3Sh7 mill [11]. The amplitude of the hydrodynamic vibration of this mill was calculated according to the developed method using the Matlab program. The results of theoretical and experimental studies of vibration are presented in figure 3.

The nature of the obtained theoretical and experimental dependences coincides. The error between theoretical and experimental studies does not exceed 20%. The vibrational processes of hydrodynamic origin are mainly determined by the impact of the semi-finished product flow on the auger blades at the inlet, i.e., by force F_1. The main component of this error, in our opinion, is caused by the error in the simulation of the semi-finished product. The conducted studies confirm the reliability of the considered models.
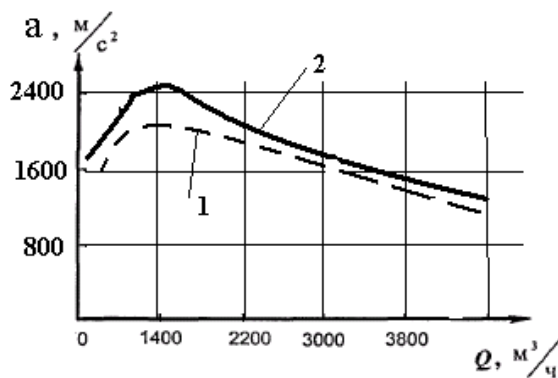
Figure 3. The amplitude of the hydrodynamic vibration of the mill MD-3Sh7 when grinding spruce wood with a change in productivity: 1- theory, 2- experiment.

5. Conclusions

A mathematical model that describes hydrodynamic vibration in knife refiners is proposed. The hydrodynamic force that excites the mill oscillations is made up of the following main components: impact of the semi-finished product on the auger blades and headset knives; forward and reverse flow interactions; pressure on the knives of the headset. These forces depend on the design and operation of the mill. Formulas for calculating these forces are proposed.

The screw in mills for grinding wood chips and a high concentration mass determines the hydrodynamic flows of the semi-finished product. Dynamic forces can arise due to hydrostatic mismatch of the flows of fibrous semi-finished product with the inlet part of the screw and (or) with the inlet part of the headset.

The error between theoretical and experimental studies does not exceed 20%. Vibration processes of hydrodynamic origin are mainly determined by the impact of the semi-finished product flow on the auger blades at the entrance to the mill.

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