Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Automatic balancing devices of rotors of the knife refiners

To cite this article: S N Vikharev 2020 *J. Phys.: Conf. Ser.* **1515** 042002

Automatic balancing devices of rotors of the knife refiners

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 paper considers automatic balancing devices for knife refiner rotors which rotate in a two-phase or three-phase medium. The total imbalance of the mill rotor consists of mechanical, hydraulic and hydrodynamic components. The main component is mechanical imbalance, which changes during operation due to uneven wear of the headset. It is recommended to use automatic rotor balancing devices in the designs of these machines. These devices allow compensating for the mechanical component of the rotor imbalance without stopping the mill. A mathematical model and designs of automatic balancing devices for mill rotors have been developed. The proposed calculation method and design of automatic rotor balancing devices can be used in other machines, for example, in centrifugal pumps.

1. Introduction

Knife refiners represent the main technological equipment for grinding fibrous materials in the pulp and paper industry [1]. Mills are machines with increased dynamism. The main source of oscillation of knife refiners is rotor imbalance [1-3]. Increased dynamic loads reduce the reliability of the nodes of the mills and worsen the working conditions of the staff [3]. Dynamic forces arising from the operation of mills are a source of vibration and noise. Vibration and noise negatively affect service personnel. An attempt to standardize and monitor the vibration of these machines was made in the publication [3].

The purpose of the article is to research and develop auto-balancing devices (hereinafter ABD) of rotors of knife refiners.

2. Rotor imbalance

The total imbalance of the mill rotor consists of mechanical, hydraulic and hydrodynamic components [2]. The mechanical component of the imbalance is fundamental and depends on the balancing and runout of the mill rotor. The mill rotor refers to rotors with variable mass due to the headset installed on it. The imbalance of the knife refiner rotors changes during its operation due to uneven wear of the headset. In this case, the dynamic loads on the rotor bearings and supporting structures also change [2].

Hydrodynamic imbalance occurs due to uneven filling of the inter-knife channels of the rotor with a fibrous suspension, which leads to a mismatch of the center of mass of this suspension with the axis of rotation of the rotor. Hydrodynamic and mechanical imbalances occur at the rotor speed [4]. The mill rotor rotates in a two-phase (fiber and water) or three-phase (fiber, water and steam) medium. This leads to the appearance of hydraulic and hydrodynamic imbalance of the rotor.

The hydrodynamic imbalance of the rotor is clearly manifested when grinding wood chips in the production of thermomechanical pulp. When grinding chips, steam is formed, which unevenly fills the inter-knife grooves of the headset. This leads to a displacement of the center of mass of the rotating semi-finished product in the rotor headset relative to the axis of rotation of the mill. On temporary implementations of mill vibration in the production of thermomechanical pulses, beats with increased amplitudes are clearly visible. The period of these beats is unstable.

The source of these beats, in my opinion, is the steam that forms when the chips are ground.

The hydrodynamic and mechanical components of the mill rotor imbalance are manifested at the rotor speed and its harmonics [4]. Hydraulic imbalance of the rotor manifests itself at frequencies lower than the rotor speed [5,6].

3. Dynamic and mathematical models of a rotor with an auto-balancing device

The mechanical component of the mill rotor imbalance can be compensated with the help of the automatic control device with the machine running. These devices are active and passive [7, 8]. We investigate the passive ABD as applied to the mill rotor (figure 1). We will introduce the following notations: K as the center of mass of the mill rotor, M as the mass of the rotor without taking into account the corrective masses. The axis of rotation of the rotor passes through point O. At a distance e from the axis of rotation there is a center of the rotor mass. The rotor rotates at a constant angular velocity ω.

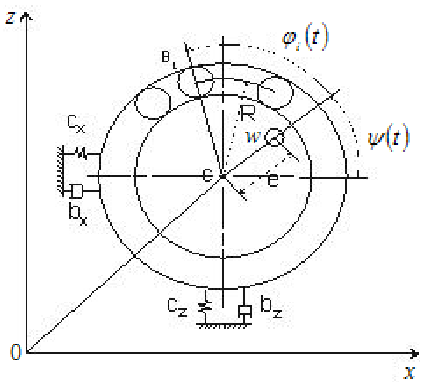

Figure 1. Dynamic model of rotor of a knife grinding machine with ABD.

Based on the Lagrange equations, a mathematical model of a knife refiner rotor with a passive ABD is obtained:

$$M\ddot{X} - Me\dot{\psi}^2\cos\psi - Me\ddot{\psi}\sin\psi + \sum_{i=1}^{n} m_i\left\{\ddot{X} - R(\ddot{\psi}+\ddot{\varphi}_i)\sin(\psi+\varphi_i) - R(\dot{\psi}+\dot{\varphi}_i)^2\cos(\psi+\varphi_i)\right\} +$$
$$+ C_x X = -B_x\dot{X}$$

$$M\ddot{Z} - Me\dot{\psi}^2\sin\psi + Me\ddot{\psi}\cos\psi + \sum_{i=1}^{n} m_i\left\{\ddot{Z} + R(\ddot{\psi}+\ddot{\varphi}_i)\cos(\psi+\varphi_i) - R(\dot{\psi}+\dot{\varphi}_i)^2\sin(\psi+\varphi_i)\right\} +$$
$$+ C_z Z + Mg + \sum_{i=1}^{n} m_i g = -b_z\dot{Z}$$

$$I_y\ddot{\psi} - Me\ddot{X}\sin\psi + Me\ddot{Z}\cos\psi + Me^2\ddot{\psi} - \sum_{i=1}^{n} m_i\left\{R\left[\ddot{X}\sin(\psi+\varphi_i) - \ddot{Z}\cos(\psi+\varphi_i)\right] + R^2(\ddot{\psi}+\ddot{\varphi}_i)\right\} +$$
$$+ \sum_{i=1}^{n} m_i g R\cos(\psi+\varphi_i) = \widetilde{M}$$

The equation of motion of the i-th balancing ball looks like:

$$-m_i R\left[\ddot{X}\sin(\psi+\varphi_i)-\ddot{Z}\cos(\psi+\varphi_i)\right]+m_i R^2(\ddot{\psi}+\ddot{\varphi}_i)+m_i gR\cos(\psi+\varphi_i)=-D_i\dot{\varphi}_i,$$

where: $i = 1\ldots n$ – the number of ABD balls; m_i, D_i – mass and viscous resistance to movement of the i-th ball; C_x, C_z, b_x, b_z – stiffness and damping coefficients of the rotor bearings in the horizontal and vertical directions, respectively; $\widetilde{M}$ – system movement moment; g – acceleration of gravity.

Analyzing the obtained mathematical model, we can conclude that with a flexible mill rotor, i.e. operating in the off-resonance mode, the corrective masses of the ABD will compensate for the operational imbalance. For a balanced rotor, the condition $m \geq eM/(iR)$ i.e. the mass of the balancing balls must be large enough to compensate for the imbalance of the rotor.

However, mill rotors operate in the pre-resonance mode [4]. For ABD to work, it is necessary that the rotor of the knife grinding machine operates in the resonant mode. In order to ensure such a mode, a path to reduce the rigidity of the mill supports has been chosen.

4. Designs of knife refiners with automatic balancing device of the rotor

A single-disk mill with a cantilever rotor [10] contains a grinding chamber 1 (figure 2), a bed 8 and a rotor, which contains a shaft 3 and a disk 2. The rotor shaft 3 is fixed in two supports (only one support is shown in figure 2). The support contains radial 4 and thrust 5 bearings, which are mounted on the rotor shaft 3 and in the glass 6. The glass 6 is located in the bearing housing 7. The bearing housing 7 is mounted on the bed 8. A cover 9 is fixed to the bearing housing 7. A sleeve 10 and a spring 11 are located on the rotor shaft 3. Balancing balls 14 are located between the sleeve 10, the ring 12 and the rotor disk 2.

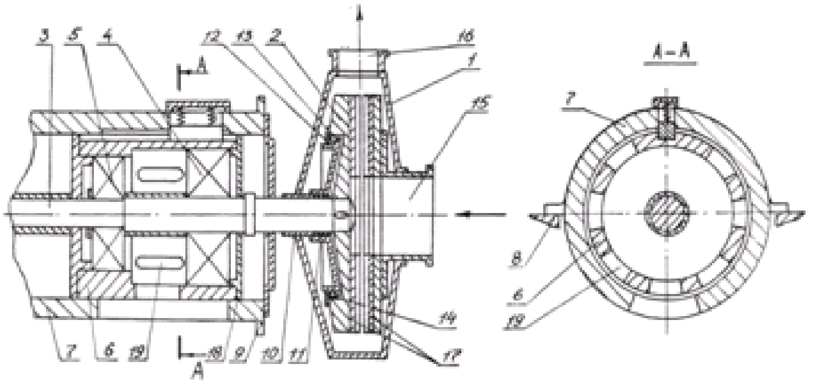

Figure 2. Mill with a passive rotor ABD: 1 - grinding chamber; 2 - rotary disk; 3 - shaft; 4 - radial bearing; 5 - thrust bearing; 6 - a glass; 7 - case; 8 - bed; 9 - a cover; 10 - sleeve; 11 - spring; 12 - ring; 13 - conical surface; 14 - balls; 15.16 - nozzles; 17 - headset; 18 - surface of the housing; 19 - cutouts of the glass.

The "auto balancing" mode has been added to the mill. In this mode, the mill is jigged in such a way that the cup 6 comes out of contact with the surface 18. As a result, the cup 6 will occupy a cantilever position in which the stiffness of the mounting of the radial bearing will decrease significantly and the rotor will go into the out-of-resonance mode of operation. If the rotor of the mill is shifted further to the left, then the sleeve 10 will abut against the cover 9, as a result of which the sleeve 10 will not move to the left. Spring 11 will compress. The balls 14 come out of contact with the conical surface 13, as a result of which they can roll in the channel formed by the disk 2, the sleeve 10 and the ring 12. Due to the inertial forces, the balls 14 are self-mounted in the "easy" place of the rotating rotor. After that, the mill jigging is stopped and the rotor is moved to the right using the additive mechanism. Under the action of the spring 11, the sleeve 10 will be pressed against the cover

9 until the balls 14 are fixed. Then, with further movement of the rotor to the right, the cup 6 comes into contact with the surface 18, as a result of which the support becomes rigid again, and the automatic balancing of the rotor is completed.

A design of a mill with active ABD has been proposed [11]. The mill rotor is constantly operating in the pre-resonance mode. The forced movement of corrective masses occurs due to the additive mechanism. A sleeve with grooves is installed on the rotor shaft, on which corrective masses interacting with each other are installed. Corrective masses interact with the thrust sleeve. Moving the rotor of the mill using the additive mechanism, control the location of the corrective masses. In this way, the rotor is automatically balanced.

A dual disc mill design with a passive ABD has also been proposed [12]. In this mill, balancing balls are mounted between the rotor disk and the screw on each side of the disk. Changing the stiffness of the bearing supports occurs using the additive mechanism.

The Wood alloy has been proposed for ABD mill rotor in the patent [13]. Wood's alloy is a low-melting alloy that goes into a liquid state at elevated temperature in the grinding chamber of the knife refiner. In this case, due to inertial forces, this alloy moves to the "easy" place of the rotating rotor to compensate for the operational imbalance of the rotor.

Automatic balancing of the knife refiner rotor should be done when replacing the headset and with an increase in the imbalance of the rotor. This reduces the dynamic load on the supporting elements of the rotor and supporting structures.

It should be noted that the automatic balancing of the rotor should be carried out when the vibration amplitude exceeds the standard values. Management of the ABD is advisable to carry out in automatic mode. Such a device should work together with the automatic process control system of the mill.

5. Conclusions

The imbalance of the mill rotor is the main source of increased dynamic loads on the rotor bearings and supporting structures. Rotor imbalance consists of mechanical, hydraulic and hydrodynamic components. The main component is mechanical imbalance, which changes during operation due to uneven wear of the headset.

It is recommended to use automatic rotor balancing devices in the designs of these machines. These devices allow you to compensate for the mechanical component of the rotor imbalance without stopping the mill.

The mathematical model and design of the auto-balancing devices of the mill rotor are developed. Automatic balancing of the rotor of the mill should be done when replacing the headset and with an increase in the imbalance of the rotor.

The proposed methods of ABD calculation and design of mill rotors can be used in other machines, for example, in centrifugal pumps.

References

[1] Legotsky S S and Goncharov V I 1990 *Grinding equipment and pulp preparation* (Moscow: Forest Industry)
[2] Vikharev S N 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **537** 032015
[3] Vikharev S N 2019 *IOP Conf. Ser.: Journal of Physics* **1399** 044005
[4] Vikharev S N and Sivakov V P 2012 The dynamics of the rotors of disk refiners *Bulletin of Kazan State Technical University* **6** 4
[5] Goncharov V N 1990 *Theoretical foundation of refining fibrous materials in knife refiners: Abstract of dissertation for the degree of Doctor of Technical Sciences* (Leningrad)
[6] Berg D and Karlstrom A 2005 Dynamic pressure measurements in full-scale thermomechanical pulp refiners *Proceedings of 2005 International Mechanical Pulping Conference, Oslo, Norway* pp 42-9
[7] Frolov K V 1981 *Vibrations in the technique* (Moscow: Machinebuilding)

[8] Kuindgi A A 1974 *Automatic balancing of rotors of high-speed machines* (Moscow: Machinebuilding)
[9] Gusarov A A, Susanin V I and Shatalov L N 1979 *Automatic balancing of machine rotors* (Moscow: Nauka)
[10] Vikharev S N, Trenkin A I and Dobrynin A A 1991 *Disc refiners for refining fibrous materials* (Moscow: Rospatent) **34** 4674892
[11] Vikharev S N, Kuchumov E G, Malygin V N and Rogozhnikova I T 2001 Disc refiner for refining fibrous materials (Moscow: Rospatent) **29** 108125
[12] Vikharev S N 2014 *Vibration protection of knife refining machines* (Ekaterinburg: UGLTU)
[13] Vikharev S N and Nasykova G T 2007 Disc refiner (Moscow: Rospatent) **7** 2007 133276