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Modeling of the Stress-Deformed State of Working Bodies of Technological Equipment

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Abstract. This paper considers modeling of the stress-deformed state of the process of mechanical crushing of rubber during its recycling, in the form of a mechanical system consisting of a rotor, a feeding device and an unloading grid-sieve. In practice, this model makes it possible to grind recyclable rubber products and sort them when sifting through grids and sieves, together with dividing the crumb into size classes. As the object of research of equipment used for the recycling of raw materials, we have considered a rotor, which is a shaft on which are mounted plates of a circular contour with a cutting surface. For an analytical study of the processes arising from the rotor movement, we have proposed a dynamic model, consisting of a rotor with blades and a device that feeds the material. The processed product is fed from above and moves along with the tray, reaching the surface of the rotor with knives. The grinding process makes it possible to obtain particles of various sizes, or crumbs, which, by sifting and sorting, can then be reused in order to obtain bitumen mastic, raw materials for the production of noise insulation materials, rubber seamless coatings and other materials. We have also considered power loads applied to the blade surfaces. The stress-deformed state of the blade plates has been investigated. Dependencies have been obtained that make it possible to determine geometric parameters of the blade plates, as well as optimal characteristics of the cutting tool, so to minimize the likelihood of deformations.

Keywords: Modeling · Rotor · Blade · Stress · Deformation

1 Introduction

Grinding is one of the oldest mechanical processes used by humans in everyday life. This operation is currently widely used in various industries, such as food industry, processing industry, agriculture. Blades are the main working tools for the grinding process. Depending on the shape, sharpening angle, material and manufacturing technology, modern cutting tools can crush almost any material, both on a domestic and industrial scale. Practice shows that crushers are the most effective in industrial conditions. The rotor crusher is one of the most popular types of equipment for the implementation of the grinding process both in equipment for oil and gas processing, and in the food and processing industry, as well as in the agricultural production [1–8]. As you know,

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the main cutting tools of crushers are blades, which can be mounted on the stator and rotor. Rotor crushers are one of the main types of equipment in the processing of tires into rubber crumb, as they carry out the last stage of crushing the raw material before its separation and sorting. The quality and size of crumb rubber, the durability of all technological equipment depend on the rotor crusher blades, namely, on their optimal design and sharpening angle [9–16].

In addition, in the process of crushing, it is possible to provide for the simultaneous separation of the resulting product according to size classes when sifting them through grids and sieves, which can be installed directly in the crusher body. The bulk product is fed from above and transported over sieves, moving through several grids or sieves with different mesh diameters. Under the influence of gravity and vibration of the working table, the product is divided into several fractions, with different particle sizes.

This article analyzes the stress-deformed state of the rotor blades.

2 Materials and Methods

For the analytical study of the processes arising during the movement of the considered mechanical system, it is necessary to draw up a calculation scheme, a mathematical modeling of the movement process. In this paper, we have proposed a dynamic model, consisting of a rotor 1 rotating around a fixed horizontal axis with an angular velocity ω in a steady state of operation of the rotor, of a tray 3, moving in guides and transporting the previously coarsely crushed rubber crumb 2 to the rotor 1 blades (Fig. 1).

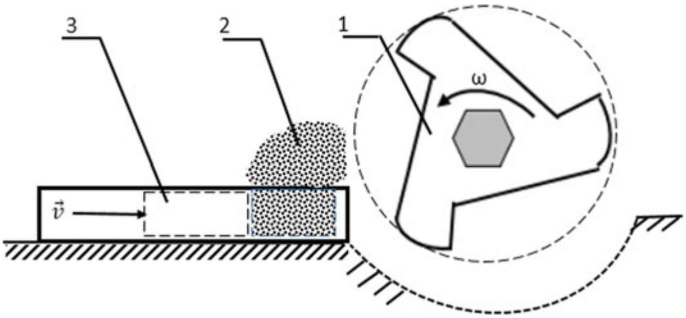

Fig. 1 Model of the process of grinding of rubber crumb

The rotor is a set of round plates and blade plates alternately and rigidly mounted on a horizontal shaft (Fig. 2).

3 Results and Discussion

In this paper, in order to study the mechanical processes arising during the operation of technological equipment intended for crushing rubber crumb, we have considered a rotor, fixed on the shaft of an electric motor and rotating with an angular velocity ω. The

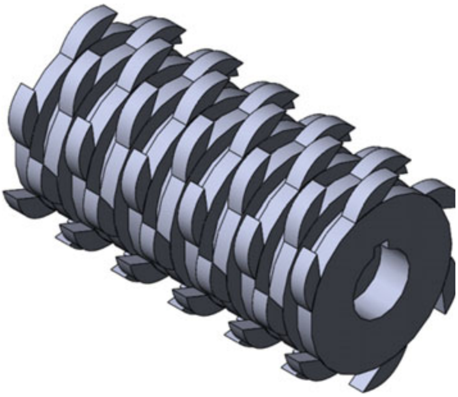

Fig. 2 Model of the rotor shaft with blades

rotor is presented in the form of a structure consisting of round plates, between which plates with blades are installed for cutting the crumb. The material for cutting is fed to the blades by a tray moving at a speed *v* along the fixed guides, and it is fed periodically as it is grinded. In practice, the movement of the tray can be carried out, for example, by a screwdriver or a crank-slide mechanism. The calculation of the parameters of the tray movement has not been considered in this paper.

Grinding of the crumb into smaller particles occurs when they fall between the rotor blades and the fixed base of the feeding tray. The fixed base of the feeding tray in this case acts as a fixed blade. Further, the material, crushed to the required size, passes through the openings of the grids-sieves installed below the rotor shaft with blades into a receiving container or cavity.

Investigation of the stress-deformed state of the crusher should start by the determination of the cutting forces arising on the blades of the rotor plates. We will assume that the cutting force is evenly distributed over the cutting edge of the blade. The 2-component cutting force $\overrightarrow{F}$ composed of $\overrightarrow{F_1}$ and $\overrightarrow{F_2}$ will act on the blade following the formula (Fig. 3), [1, 17, 18]:

$$F_1 = F \cdot \cos\alpha, F_2 = F \cdot \sin\alpha, \tag{1}$$

α is the angle of the blade installation.

Let us consider the deformation of the blade bending, which, with some assumptions, can be considered as a cantilever beam with a rigidly terminated end [1, 17–20], having a rectangular section of the constant width *l* and variable height *y* (Fig. 4).

The bending moment due to the vertical component of the cutting force along the blade length is the following:

$$M_x = F_1 \cdot z, \tag{2}$$

The axial moment of resistance of the rectangular section of the blade is the following:

$$W_x = \frac{y \cdot \ell^2}{6}, \tag{3}$$

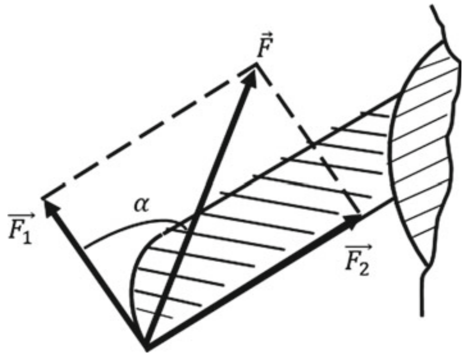

Fig. 3 Scheme of forces acting on the blade

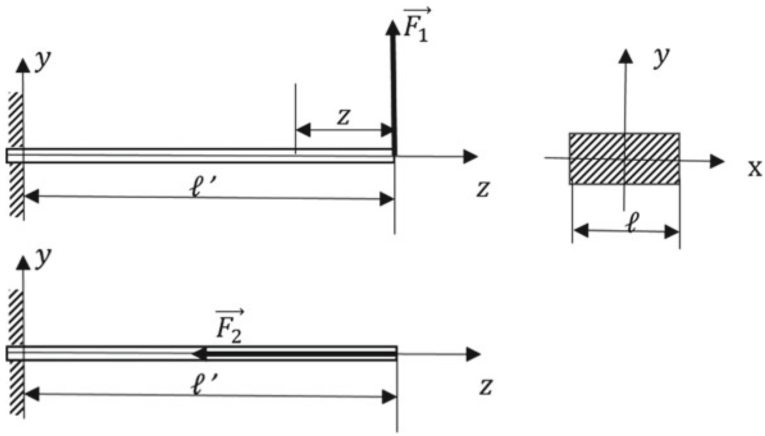

Fig. 4 The blade design scheme

where y depends on the sharpening angle of the blade, ℓ is the blade length. The stress in each section during bending deformation is determined by formula [19, 21–23]:

$$\sigma = \frac{M_x}{W_x} = \frac{6 \cdot F_1 \cdot y \cdot z}{y \cdot \ell^2} = \frac{6 \cdot F_1 \cdot z}{y \cdot \ell^2} = \frac{6 \cdot F \cdot \cos\alpha \cdot z}{y \cdot \ell^2}, \tag{4}$$

where $M_x = M_{x\max}$ is determined using the bending moment diagram.

$$M_{x\max} = \frac{6 \cdot F \cdot \cos\alpha \cdot \ell'}{h \cdot l^2}. \tag{5}$$

Based on the obtained expression, we can determine the blade parameters by writing down the following strength condition:

$$\sigma_{\max} \leq [\sigma],$$

$$\frac{6 \cdot F \cdot \cos\alpha \cdot \ell'}{h \cdot \ell^2} \leq [\sigma]. \tag{6}$$

Let us consider the compression deformation of the blade, where y is the variable. Let us determine the critical value of the rectangular cross section rod. The rod flexibility is determined as follows:

$$\lambda = \frac{\mu \cdot \ell'}{i_{\min}}. \tag{7}$$

Let us calculate the radius of gyration following the formula below:

$$i_{\min} = \sqrt{\frac{J_{\min}}{A}}, \tag{8}$$

where

$$J_{\min} = \frac{\ell \cdot y^3}{12}, \quad A = \ell \cdot y. \tag{9}$$

Thus,

$$i_{\min} = \sqrt{\frac{\ell \cdot y^3}{12 \cdot \ell \cdot y}} = \frac{y}{\sqrt{12}}. \tag{10}$$

The considered blade model assumes the length reduction factor $\mu = 1$. Thus, we get:

$$\lambda = \frac{1 \cdot \ell' \cdot \sqrt{12}}{y} = \frac{\ell' \cdot \sqrt{12}}{y}. \tag{11}$$

Let us calculate the ultimate flexibility using the formula:

$$\lambda_{\text{ult}} = \sqrt{\frac{\pi^2 \cdot E}{\sigma_{\text{prop}}}}. \tag{12}$$

Knowing the material from which the blade is made and the sharpening angle, we determine the possibility of applying the Euler formula:

$$\lambda \geq \lambda_{\text{ult}} = \pi \cdot \sqrt{\frac{E}{\sigma_{\text{prop}}}}. \tag{13}$$

If the condition is met, then the Euler formula is used in order to calculate the critical force:

$$F_{\text{cr}} = F_2 = F \cdot \sin\alpha = \frac{\pi^2 \cdot E \cdot J_{\min}}{(\mu \cdot \ell')^2}, \tag{14}$$

otherwise, the Yasinsky formula should be applied.

Thus, analytical expressions have been obtained, with the help of which it is possible to determine the force components for the cutting force of the rotor crusher blades.

4 Findings

1. This paper considers a model of a single-shaft rotor crusher for grinding rubber crumb. The crusher consists of a shaft with alternately mounted circular contour plates with a cutting surface and circular plates fixed on the rotating shaft. The material for cutting is periodically fed to the rotor by translational movement of the chute along the fixed guides. Crumbling crumbs into smaller particles occur when they fall between the rotor blades and the fixed base of the feeder tray. The fixed base is used as the fixed knife.
2. Assuming the cutting force as uniformly distributed along the edge of the knife blade, its stress–strain state is considered as a set of deformations of the transverse and longitudinal bends of a cantilever beam with a rigidly fixed end.
3. Analytical expressions have been obtained, with the help of which it is possible to determine the knife geometric parameters, select the material for its manufacture and the components of the critical value of the cutting force of the crusher knives.
4. The use of the proposed model will make it possible to find out optimal operating conditions for the cutting technological equipment in order to ensure stability of its movement, as well as to select rational technological characteristics of the cutting tool as a whole.
5. The developed model can be used to solve the problems of grinding and fractionation of the product in the equipment of the mining, processing and food industries, as well as in the agricultural industry. Particles of sorted crumb rubber, depending on its size, serve as the basis for various materials, including building ones. The practical implementation of the model will make it possible to obtain crumb rubber for industrial use.

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