MOTION OF GRAIN PARTICLE ALONG BLADE OF ROTOR FAN OF HAMMER CRUSHER

Peter Savinyh[1], Vladimir Nechaev[2], Marina Nechaeva[2], Semjons Ivanovs[3]
[1]North-East Agricultural Research Institute, Russia; [2]Vyatka State University, Russia;
[3]Latvia University of Agriculture; [3]Nizhegorod State Engineering Economic University, Russia
semjons@apollo.lv

Abstract. A design and technological scheme has been developed for the hammer crusher of grain with a rotor fan. Experimental and theoretical investigations have been carried out in order to determine dependencies describing the relative motion of a grain particle along the blade of the rotor fan and which allow at preset parameters prognostication of the force of a normal reaction of the particle and the time of its being on the blade.The conducted investigations allow optimisation of the design and technological parameters of the rotor fan at the stage of its designing in order to increase its throughput capacity, to reduce metal and energy intensity, to raise the quality of the final product, to reduce the overall dimensions of the crusher.

Keywords: grain crushing, hammer crusher, rotor fan, radius of curvature.

Introduction

One of the most labour intensive processes in animal husbandry is feed preparation, namely: disintegration operations of the feed to be fed to the animals. An essential part in the structure of the feed ration of animals is concentrated forage; therefore, a technology of its preparation for feeding is of great importance. The technological processes of the grain loading and disintegration determine, in many aspects, the quality of the produced feed and the cost of its selling. Considering a possibility to reduce the number of operations and labour, the producers are giving increased preference to hammer crushers with pneumatic self-loading of the forage grain from clamps and piles, in contrast to similar crushers with forced delivery of the material to be disintegrated. Theoretical investigations of the grain motion and transformation parameters have been conducted in the technological process of the crushed forage production [1; 2].

In spite of the wide distribution of the hammer crushers with pneumatic self-loading of the material, certain peculiarities of their working procedure have not been studied sufficiently completely, which is the reason to conduct investigations in this direction. A hammer crusher has been developed with a rotor fan the advantage of which is that the rotor and the fan are combined in a single unit [3-5]. Installation of the blades of an optimal shape inside the rotor allows creation of the necessary pressure despite the small dimensions of the blades, reduction of the dimensions of the fan and the body of the crusher, as a whole, an increase in its throughput capacity and the quality of the ready product. Alongside with this, a mathematical description of the interaction of grain with the hammers and blades of the rotor fan provides a possibility to optimise to a considerable degree the technological process of crushing grain at the stage of designing.

Method of the research

The object of the research was an experimental hammer crusher (Fig. 1) consisting of a frame 1 with an electric motor 2 installed on it, body 3 implemented in the form of an Archimedean spiral with a rotor fan 4 mounted inside it.

The rotor fan 4 is executed in the form of a hub 5 with the internal 6 and external 7 disks between which the axes of suspension 8 are arranged; each with a set of hammers 9. The external disk 7 is a ring. For the purpose of investigations the design of the crusher allows installation of rings with various internal diameters. The internal disk 6 has blades of the fan 10 fixed on it. A sieve 11 is fixed to the internal side of the casing.

The technological process in the crusher proceeds in the following way.

When the electric motor 2 is switched on, vacuum is created inside the crushing chamber by the action of the blades of the fan 10, due to which through the suction connection (inlet duct) 12 the grain is delivered into the crushing chamber. Crushing of the grain takes place as a result of multiple interactions of the operating tools of the rotor fan 10 and the sieve 11. The crushed material is screened through holes in the sieve 11, and through the discharge connection (duct) 13 it is supplied to the bunker or another container.

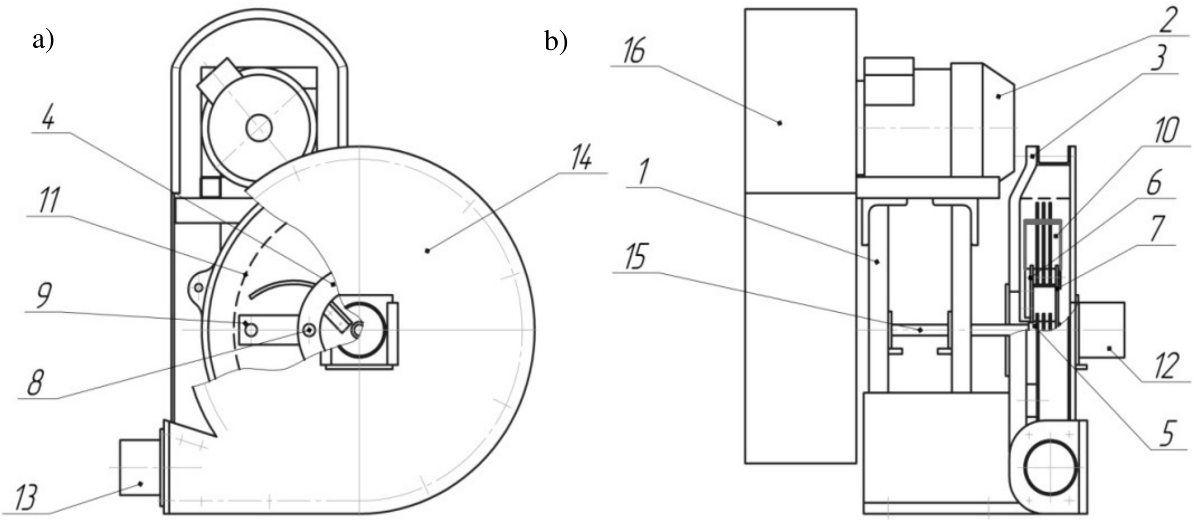

Fig. 1. **Structural embodiment of the experimental hammer crusher with a rotor fan:** a – general view; b – lateral view; 1 – frame; 2 – electric motor; 3 – body; 4 – rotor fan; 5 – hub; 6, 7 – respective internal and external disks; 8 –axis of the suspension; 9 – set of hammers; 10 – blades of the fan; 11 – sieve; 12 – suction connection (inlet duct); 13 – discharge connection (duct); 14 – cover; 15 – shaft; 16 – casing

Interaction of grain with the hammers and blades of the rotor fan proceeds at a peripheral velocity of about 67.5 m·s^{-1} [6], therefore we carried out experimental and theoretical investigations of the motion process of the particle along the blade of the rotor fan, which made it possible to prognosticate at the preset parameters: the force of a normal reaction, the time when the particle is on the blade, as well as to obtain an equation in relation to motion of a point.

The motion process of the particle along the blade of the rotor fan is described by a differential equation of the relative motion which, considering the forces acting upon it (Fig. 2), has the appearance:

$$m\vec{W}_r = m\vec{g} + \vec{N} + \vec{F}_{tp} + \vec{F}_k + \vec{F}_u, \tag{1}$$

where m – mass of the particle;

$\vec{W}_r$ – reltive acceleration of the grain particle;

$m\vec{g}$ – gravity force acting upon the grain particle:

$\vec{g}$ – acceleration of free fall,

$\vec{N}$ – force of a normal surface reaction of the blade;

$\vec{F}_{tp} = f \cdot \vec{N}$ – friction force of the particle against the blade, where f – coefficient of sliding friction;

$\vec{F}_k = -2 \cdot m \cdot \vec{\omega} \times \vec{v}_r$ – Coriolis force of inertia;

$\omega = \varphi$ – angular velocity of the rotor fan, rad·s^{-1};

$\vec{v}_r$ – relative speed of the particle along the blade, equal to $\dot{\varphi} \cdot \rho$, where ρ – the curvature radius of the blade, m;

$\vec{F}_u = m \cdot \omega^2 \cdot \vec{r} = m \cdot \omega^2 \cdot (\vec{r}_A + \vec{\rho})$ – transportation force of inertia , where

$\vec{r} = \vec{r}_A + \vec{\rho}$ – vector, by its length equal to the distance from the rotation centre of the rotor fan to the particle, m.

Let us write equation (1) in the projections on the moving axes τ and n:

$$\begin{cases} m \cdot \ddot{\varphi} \cdot \rho = -m \cdot g \cdot \cos\beta - F_{tp} + F_{u\tau} \\ m \cdot \dot{\varphi}^2 \cdot \rho = m \cdot g \cdot \sin\beta - N + F_k + F_{un} \end{cases}, \tag{2}$$

where $\beta = \omega \cdot t + \varphi$ – angle of the change of the position of the particle during time *t*, degree;

$F_{u\tau}$, F_{un} – projections of the transportation force of inertia correspondingly on the tangent and the normal, N.

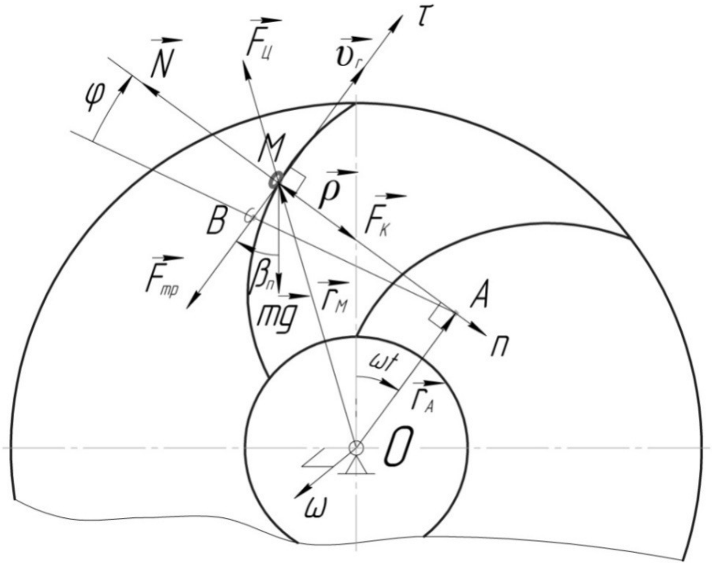

Fig. 2. **Sliding of the particle along the external side of the blade of the rotor fan**

The tangent and the normal, which are the constituent forces of inertia, are determined by expressions:

$$F_{u\tau} = m \cdot \omega^2 \cdot r_A \cdot \cos\varphi, \tag{3}$$

$$F_{un} = -m \cdot \omega^2 \cdot r_A \cdot \sin\varphi - m \cdot \omega^2 \cdot \rho \tag{4}$$

Substituting the obtained expressions (3, 4) into the system of equations (2), we will obtain:

$$\begin{cases} m \cdot \ddot{\varphi} \cdot \rho = -m \cdot g \cdot \cos(\omega t + \varphi) - N \cdot f + m \cdot \omega^2 \cdot r_A \cdot \cos\varphi \\ m \cdot \dot{\varphi}^2 \cdot \rho = m \cdot g \cdot \sin(\omega t + \varphi) - N + 2m \cdot \dot{\varphi} \cdot \rho \cdot \omega - \\ - m \cdot \omega^2 \cdot r_A \cdot \sin\varphi - m \cdot \omega^2 \cdot \rho. \end{cases} \tag{5}$$

From the first equation of the system (5) we define the angular acceleration $\ddot{\varphi}$:

$$\ddot{\varphi} = \frac{1}{\rho}\left(- g \cdot \cos(\omega t + \varphi) - \frac{N}{m} \cdot f + \omega^2 \cdot r_A \cdot \cos\varphi \right), \tag{6}$$

where

$$\frac{N}{m} = -\dot{\varphi}^2 \cdot \rho + g \cdot \sin(\omega t + \varphi) + 2\dot{\varphi} \cdot \rho \cdot \omega - \omega^2 \cdot r_A \cdot \sin\varphi - \omega^2 \cdot \rho. \tag{7}$$

Results of the investigations

Solution of equation (6), after substitution of expression (7) into it, can be executed by a numerical method preliminarily indicating: the angular velocity of the rotor fan, the curvature radius of the blade, the position of the particle on the blade defined by the angle φ, the friction coefficient and time.

In our case computing of the parameters of the motion of a particle along the blade was executed on the personal computer by means of a developed software in "Visual Studio 2008" with a time interval $\Delta t = 0.0001$ s. For comparison, the curvature radius of the blade was changed within the limits

ρ = 50 ± 10 mm [7], angle φ = 0 ± 10° depending on the geometry of the blade, the other parameters remaining unchanged: angular velocity ω = 314 s^{-1} and the friction coefficient f = 0.1.

The programme for computing the motion parameters of a particle was worked out in such a way that it allows conducting analysis of any indicator affecting its motion as a constituent part of these equations.

The conducted investigations showed that at angles φ = – 9° (except the blades with a curvature radius ρ = 60 mm), – 8°, – 7°,– 2°, – 1°, 4°, 5°, 10° the force of a normal reaction has a positive value, at other angles it is negative; that is, when interacting with a convex blade, the particle is sliding only until its movement acquires transportation velocity but after that it separates under the impact of the centrifugal force, which manifests itself in a negative value of the force of a normal reaction N (Fig. 3). In the other cases the sliding movement is possible only along the concave side of the blade.

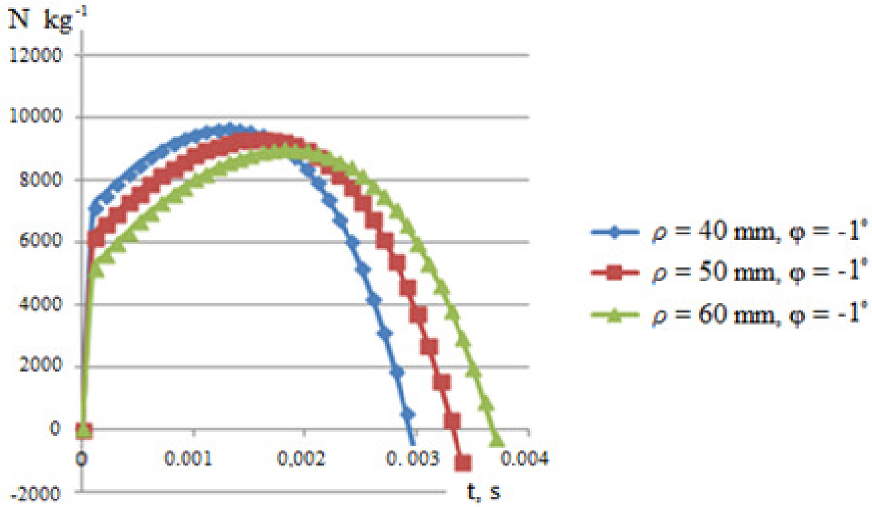

Fig. 3. **Graph of the change of the force of normal reaction depending on the sliding time of the particle along the blade**

Analysis of the graphs (Fig. 3, 4) showed that in the moment as the particle occurs on the blade the force of a normal reaction sharply increases reaching an extreme value, then it starts decreasing smoothly, and, reaching zero, the particle separates from the blade. The particle slides the longest time t = 0.0037 s and the path along the blade with the curvature radius ρ =60 mm, the speed of the movement having a lesser value than when moving along a blade with ρ = 40 mm, which, in its turn, leads to accelerated wear-and-tear of the working surface of the blade.

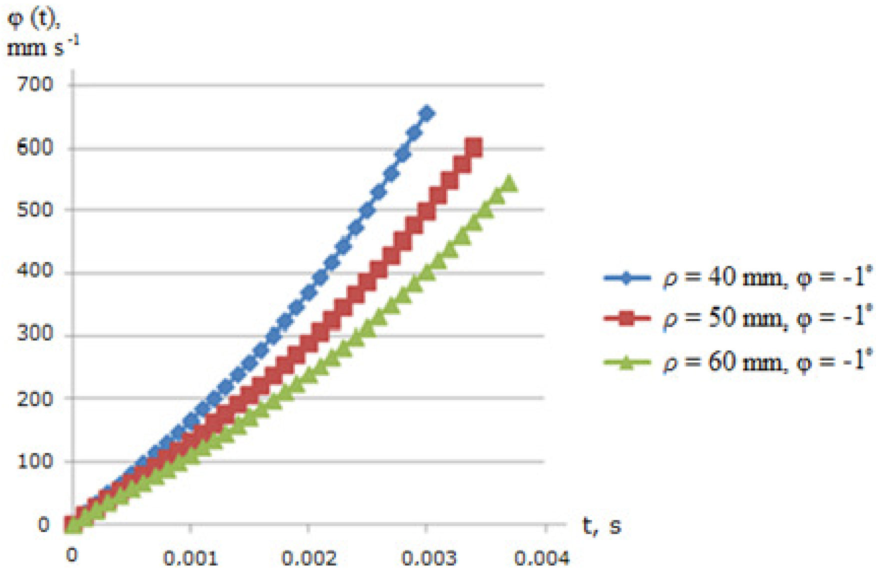

Fig. 4. **Graph of the change of the sliding velocity of the particle along the blade depending on time**

The conducted laboratory tests of the crusher with a rotor fan crushing grain confirmed the correctness of the conclusions about the motion of a particle along the blade: the wear-and-tear of the working surface of the blade is proportional to the force of a normal reaction and the sliding velocity. The greater the force of normal reaction and lower the sliding velocity, the greater should be the wear-and-tear of the working surface of the blade, and, vice versa. In Figure 5 there are presented blades after crushing 150 kg of barley (with each set). It is evident that the greatest wear-and-tear is using the blades with a great curvature radius (Fig. 5c). Optimal are the blades with a curvature radius $\rho = 40$ mm.

a) b) c)

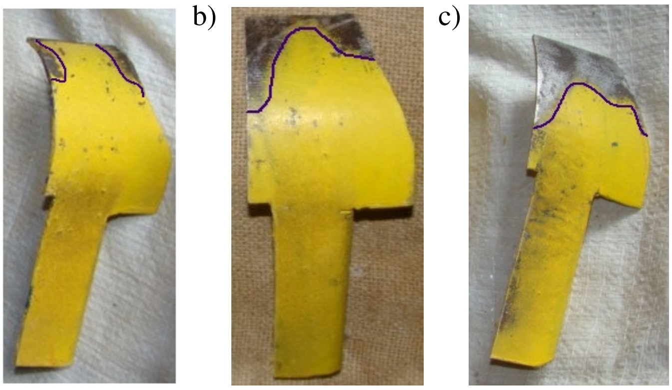

Fig. 5. **General view of a blade of the rotor fan with a curvature radii:**
a – $\rho = 40$ mm; b – $\rho = 50$ mm; c – $\rho = 60$ mm

Conclusions

1. As a result of the conducted experimental and theoretical investigations dependencies have been determined, which describe relative motion of a grain particle along the blade of the rotor fan, and the value of the force of a normal reaction at preset values of the angular velocity of the rotor fan, the curvature radius of the blade, the position of the particle on the blade, the friction coefficient and time.
2. It has been established that the smaller the curvature radius of the blades, the smaller the wear-and-tear zone and the greater the sliding velocity of the particle along the blade. Besides, the initial motion velocity of the particle has no effect upon the character of its movement but only leads to the change of the force of a normal reaction.

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