



DETERMINATION OF SPEED RANGE OF HAMMER MILL GRINDER

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ABSTRACT

In Russia 2017 was declared the Year of ecology. Enormous amounts of wastes resulted from scouring of agricultural crops (husks of sunflower, buckwheat, panicum etc.) impair environmental situation. Nevertheless, such wastes are widely applied in various industries. In order to use the wastes after processing of agricultural products it is necessary to grind them and to mix with various components in certain ratios. Hammer mill grinders are the most widely applied machines. However, their design and workflow are characterized by certain disadvantages leading to quality impairment of final products and significant energy consumption. Thus, we developed new designs of hammer mill grinder and hammer which allow to reduce grinding energy consumption and to increase yield. This article is devoted to theoretical study of optimum angular speed of rotor shaft with the hammers of the proposed grinder design.

Keywords: husks of agricultural crops, hammer mill grinder, hammer deviation angle, angular speed of rotor shaft.

INTRODUCTION

In order to draw attention of society to environmental issues, in Russia 2017 was declared the Year of ecology.

In Russia there are more than 14 000 large garbage dumps occupying surface area in excess of 4 million ha. In addition to legal dumps there are about 60 000 unauthorized dumps. According to information by Ministry of natural resources and ecology of Russia, surface area of such sites is at least 20 000 ha. [1].

In addition to industrial and domestic wastes there are large amounts of dumps with wastes obtained upon scouring of cereals and sunflower (husks).

The issues related with disposal of husk are caused by its low bulk density as well as by its flammability and afterglow accompanied by unpleasant odors and, hence, negative impact on environment. Due to low bulk density the companies bear expenses for loading and transportation of husk to disposal sites.

Nowadays numerous researchers proved that agricultural husk is sufficiently valuable raw stock used in various industries [2-5].

While using agricultural husks in various industries it is required to grind it to required particle size distribution and mix with various components in certain ratios.

Hammer mill grinders are the most promising devices for agriculture. However, their design and workflow are characterized by certain disadvantages leading to quality impairment of final products and significant energy consumption [6].

Hence, an urgent task is to increase efficiency of grinding of agricultural husks by hammer grinders on the basis of improved design of working members.

METHODS

According to researches by Makarov, grinding in hammer grinder results from hammer impacts on particles, impingement of particles upon sieve surfaces and upon other particles [7].

Grain grinding by hammer grinders was studied by numerous researchers: Aleshkin, Mel'nikov, Roshchin, Syrovatka *et al.* However, grinding of agricultural husks by hammer grinders has not been studied yet.

RESULTS

The essence of operation of hammer grinder is comprised of adjusted supply of feed material to working chamber of grinder, grinding of the material to required particle size distribution and unloading of final product.

Since the considered feed material is characterized by high sailing capacity, then the existing grinders will operate with low and high energy intensity. The absence of a single procedure as well as influence of various factors on grinding promoted development of innovative promising design of hammer grinder [8] allowing grinding more efficiently the considered material.

Taking into consideration that in hammer grinder the material is processed by hammer impacts, we also proposed a promising design of working member [9] which increased hammer grinder yield and decreased energy intensity of grinding.

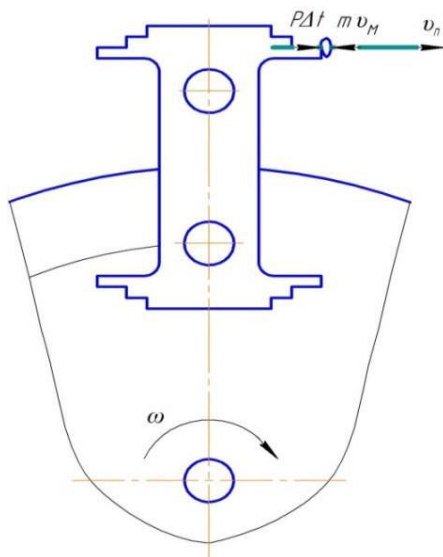
On the basis of experimental data by Plokhov, average circular speed of air and product layer inside the grinder chamber depends on speed of rotor with hammers and equals to:

$$v_l = (0.4 \dots 0.5)v_h,$$

where v_l is the circular speed of air and product layer, m/s; v_h is the circular speed of hammers, m/s.

Thus, it is possible to believe that hammers move in certain environment of air and product layer.

Let us consider the interaction between radially positioned hammer and feed material particle (see Figure-1). Since the rotor rotation frequency is low in comparison with material feed rate to grinding chamber, that is, $v_{f.m.} = 0$, then the hammer exerts pulse impact on particle.


Figure-1. Hammer impact on material.

Using the theorem of impulse forces, it is possible to write the equation of impact as follows [6, 7]:

$$P\Delta t = mv_h, \quad (1)$$

$$P = \frac{mv_h}{\Delta t},$$

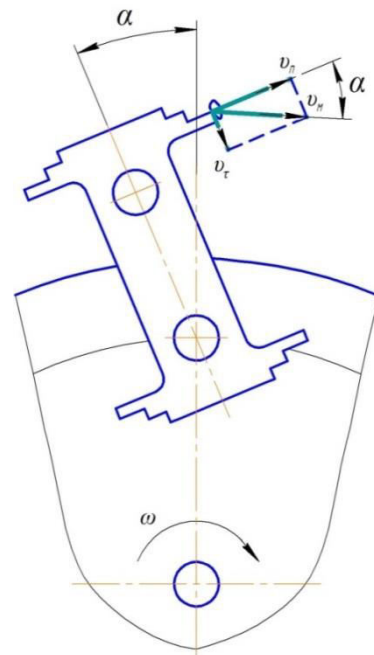
where P is the hammer impact force, N; Δt is the infinitely short time of interaction between hammer and particle, s; m is the particle weight, kg; v_h is the hammer circular speed, m/s.

Analysis of Equation. (1) demonstrates that impact force can vary upon variation of weight of impinged particle or rotation frequency of hammer rotor.

In the case of hammer deviation from radial position due to impacts on particles of feed material by the angle α (Figure-2), Equation (1) will be as follows:

$$P = \frac{mv_p}{\Delta t} \text{ or } P = \frac{mv_m \cos \alpha}{\Delta t}, \quad (2)$$

where α is the angle of hammer deviation from radial position.


Figure-2. Oblique impact.

Herewith, the absolute value of vector of circular speed of feed material particle v_m interacting with hammer upon impact equals to the speed of point of their interaction. Thus, the impulse impact will equal to the product of particle weight and normal constituent v_p of circular speed v_m , in its turn v_p equals to:

$$v_p = v_m \cos \alpha. \quad (3)$$

It follows from Equation (2) that upon hammer deviation from radial position the impact force will be lower and the feed particle will tend to slide along the hammer edge due to generated speed v_r . Hence, hammer deviation from radial position upon material grinding decreases efficiency of grinder operation.

It can be concluded that hammers, pivotally mounted on rotor, should be in radial position during operation. This can be provided by action of centrifugal forces at appropriate rotor rotation frequency. Hence, while selecting speed of hammer grinder, let us consider the condition when the hammer is not deviated from radial position. Let us present the hammer in position deviated from radial and summarize all forces interacting with it during operation (Figure-3).

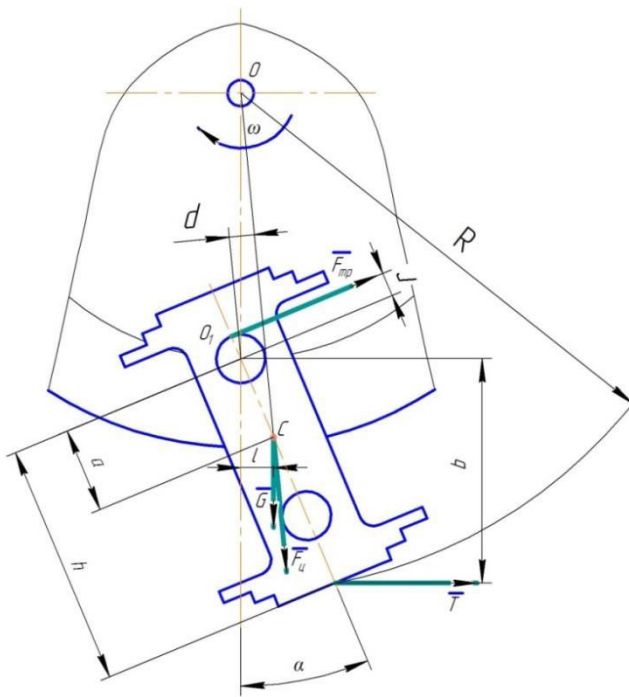


Figure-3. Impacts on hammer upon its operation.

It is obvious that the hammer will be equalized by moment of the mentioned forces acting with regard to axis of hammer pivot O_1 . Let us write the equation of moments for this diagram:

$$Tb = Gl + F_{fr}r + F_c d, \quad (4)$$

where T is the resistant force of air and product layer interacting with hammer; b is the arm of resistant force; G is the hammer gravity force; l is the arm of gravity force; F_{fr} is the hammer friction force with regard to pivot surface; r is the pivot radius; F_c is the centrifugal force; d is the arm of centrifugal force.

Applying all necessary transformations Equation (4) can be rewritten as follows:

$$\frac{Nh \cos \alpha}{R \omega z} = mg \sin \alpha + f m \omega^2 R r + m \omega^2 R \alpha \tan \alpha, \quad (5)$$

where N is the required power of rotor shaft drive, kW; h is the distance from pivot axis to the point of force T , m; α is the angle of hammer deviation; R is the distance from hammer pivot axis to the point of force T , m; ω is the angular speed of rotor, s^{-1} ; z is the number of hammers; m is the hammer weight, kg; g is the acceleration of gravity, m/s^2 ; f is the coefficient of friction in pivot, $f = 0.15$.

When hammer is not deviated from radial position, that is, $\alpha = 0$, then Equation (5) is as follows:

$$\frac{Nh}{R \omega z} = f m \omega^2 R r. \quad (6)$$

For steady operation of hammer, when it is not deviated from radial position, the following condition is required:

$$\frac{Nh}{R \omega z} < f m \omega^2 R r. \quad (7)$$

whence:

$$\omega \geq \sqrt[3]{\frac{Nh}{f R^2 z m r}}. \quad (8)$$

Satisfaction of this condition would allow providing optimum operation speed of hammer grinder.

Taking into consideration that grinding hammer speed v_h plays the main role for breaking of material, these speeds should be coordinated as follows:

$$v_m \approx v_{break} + v_l, \quad (9)$$

where v_{break} is the breaking speed upon material grinding, m/s; v_l is the speed of air and product layer, m/s.

Taking into consideration that the feed material in grinding chamber is destroyed upon multiple hammer impacts of particles, the breaking speed of agricultural husks can be written as follows:

$$v_{break} = \sqrt{\frac{k_s \sigma_{st} r_{boss}}{\rho} (0.81 + 2.3 l g \lambda)}, \quad (10)$$

where k_s is the coefficient of sailing capacity, for sunflower husk $k_s = 3.16-4.13 \text{ m}^{-1}$, for buckwheat husk $k_s = 3.69-5.8 \text{ m}^{-1}$, for panicum husk $k_s = 2.45-8.1 \text{ M}^{-1}$; σ_{st} is the static limit of husk strength, MPa; r_{boss} is the distance from hammer pivot to bosses, m; ρ is the material density, kg/m^3 ; λ is the extent of grinding.

On the basis of experimental data by Mel'nikov and Plokhov the breaking speeds of grains were determined in the range of 60 ... 80 m/s [6].

In order to determine the yield of hammer grinder upon grinding of loose materials the following equation can be applied:

$$Q = \frac{3.6 k_e \rho D^2 L n}{60}, \quad (11)$$

where k_e is the empirical coefficient depending on type and sizes of sieve meshes, for flat sieves with mesh diameter of 3 mm $k_e = (1.3 \dots 1.7) \cdot 10^{-4}$; ρ is the density of feed material, kg/m^3 ; D is the rotor diameter around the hammer ends in working position, m; L is the rotor length, m; n is the rotor rotation frequency, min^{-1} .

Full power required for hammer grinder drive can be described as follows:

$$N = N_{gr} + N_{cir} + N_{idle}, \quad (12)$$

where N_{gr} is the power consumed directly for material grinding, kW; N_{cir} is the power consumed for circulation of air and product layer, kW; N_{idle} is the power consumed for idle run of rotor with hammers, kW.



Power consumption for grinding is determined as follows:

$$N_{gr} = QA_{gr},$$

where A_{gr} is the work consumed for grinding of 1 kg of material, J/kg.

Sum of powers for circulation N_c and idle run N_{idle} is selected on the basis of experimental data in the range of 15 ... 20% of power for grinding N_{gr} :

$$N_{cir} + N_{idle} = (0.15 \dots 0.2)N_{gr}.$$

DISCUSSIONS

Further theoretical and experimental studies of this topic will be devoted to development of hammer grinder prototype and its working members decreasing energy intensity of grinding and increasing yield and quality of final product. The developed hammer grinder can be applied for husk grinding by companies related with production of cereal crops.

In order to increase yield and to decrease energy intensity of grinding using our developed hammers with working edge in the form of external three-step rectangular bosses, additional researches will be carried out. It is necessary to determine amount of hammers on rotor which should provide its uniform rotation. In addition, the researches should take into account the influence of flow rate of air and product layer, as well as the influence of the gap between hammer edges and surface of grinder sieve.

Engineering and operation parameters of hammer grinder should be experimentally studied in order to increase efficiency of grinding of agricultural husks.

CONCLUSIONS

Grinding of agricultural husks by hammer grinder differs significantly from grain grinding. We believe that the main grinding element, hammer, can most efficiently influence on grinding of the considered agricultural husks. Thus, reasonable optimum speed for the developed hammers will allow increasing the yield of hammer grinder by 15 ... 20%.

Moreover, energy intensity of grinding of agricultural husks in comparison with grain grinding using the proposed hammers will decrease by 5.8 times due to its geometric and kinematic parameters.

This article presents equations for determination of kinematic parameters of operation of hammer grinder.

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