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Forces affecting the grain movement in the working chamber of the rotary crusher

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Abstract. The article deals with the issue of reducing energy consumption by improving the design of the working bodies of the feed crusher.the equations of movement of grain particles, the impact of force on it and movement in structures made differently at the bottom of the rotor groove of the working chamber of the crusher are given. It is also implemented using one of the numerical methods on the PC using Matlab computing systems.

1. Introduction

Analysis of the world and domestic experience of animal husbandry shows that only in conditions of a high level of provision of farms with full-fledged feed and modern machines is it possible to realize the genetic potential of animals and poultry. Without the use of resource-saving machine technologies, highly efficient sets of machines and production lines, it is impossible to solve vital market problems [1, 2].

One of the main operations of feed preparation for feeding is the grinding of grain materials to the specified size. According to research, increasing the productivity of animals is provided both by the balance of feed for the necessary elements of nutrition, and by the equalization of the granulometric composition of the crushed grain.

The most responsible and time-consuming technological operation in agricultural production is the milling of feed grain, which is carried out mainly by hammer crushers with high energy and metal consumption, and the quality of the crushed product does not always meet the zootechnical requirements. Therefore, the creation of a feed grain shredder that allows you to get a finished product zootechnical of the required quality while reducing the specific energy and metal content is an urgent task [3-10].

Currently, a promising direction is the use of shredders in feed preparation lines that implement energy-efficient methods of grain destruction by cutting and chipping in impact-centrifugal and rotary crushers in their design and technological schemes.

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Grinding is the process of mechanical separation of a solid body into parts. In this case, the external forces acting on the body exceed the forces of molecular cohesion.

The theory of crushing or mass destruction of solids addresses two sets of basic questions. First, it studies the basic patterns in the distribution of particles by size in order to find simple methods for determining their average values and the degree of grinding. Second, it examines the functional relationship between the energy consumption of the grinding process and the degree of grinding, which allows you to evaluate the efficiency of the working process of the shredder according to the adopted technology, design and operating modes.

Research on the energy of grain grinding for food and feed purposes is mainly aimed at obtaining quantitative characteristics of processes, the interaction of working bodies of machines with the product in the form of forces, the equation of movement of grain particles, the impact of force on it and movement in structures made differently at the bottom of the rotor groove of the working chamber of the crusher [11-19].

2. Method

Pinching and destruction of particles occurs when moving the movable edge of the rotor groove relative to the fixed edge of the stator (Figure 1).

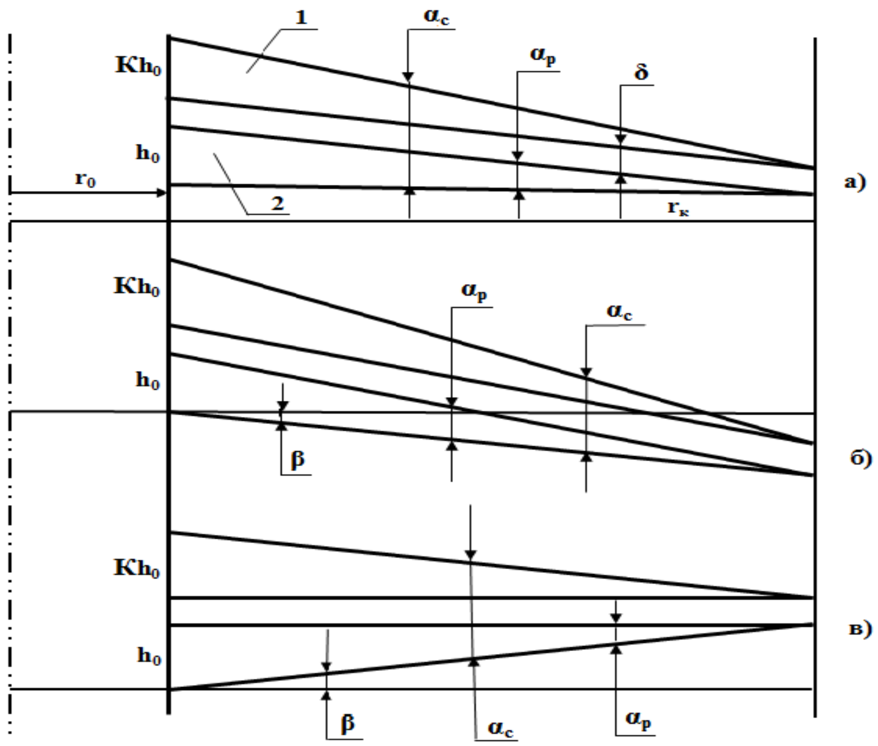

Figure 1. Rrotor groove locations: 1-stator; 2-rotor

Currently, reducing the relative energy intensity of crushers is one of the most pressing problems. When studying the energy capacity of the working chamber of the crusher, it is necessary to determine the forces acting on it when grain particles move along the rotor groove [20-24].

Consider the forces acting when the particle moves in the rotor groove at different values of the β angle when moving in the horizontal plane β=0, when the rotor groove is tilted down at the β angle, and when the rotor groove is tilted up at the β angle (Figure 2).

When a particle moves along the rotor groove, the following forces act on it (Figure 2, a): centrifugal force-– $F_{ц} = mr\omega^2$; Caryolis force (acts perpendicular to the plane in which the vectors lie $\bar{r}$ u $\bar{\omega}$).

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$F_\kappa = 2m\omega \cdot \dot{r} \cdot \sin\left(\bar{\omega} \cdot \bar{\dot{r}}\right)$ since the rotation of the rotor is clockwise, the angle between the vectors is $\bar{\dot{r}}$ u $\bar{\omega}$ equal to $\left(90^0 - \beta\right)$ -when the rotor groove is tilted down and $\left(90^0 + \beta\right)$ - when the rotor groove is tilted up, so

$$F_\kappa = 2m\omega \cdot \dot{r} \cdot \cos\beta$$

The friction force along the side face of the groove created by both the normal components of the Coriolis and centrifugal forces $F_1 = f\left(N_\kappa - N_ц^{'}\right)$, where is the coefficient of friction of the particle along the rotor groove; the friction force from the weight of the particle

$$F_2 = f\left(mg \cdot \cos\beta - N_ц\right)$$

Component of weight force

$$F_3 = mg \cdot \sin\beta$$

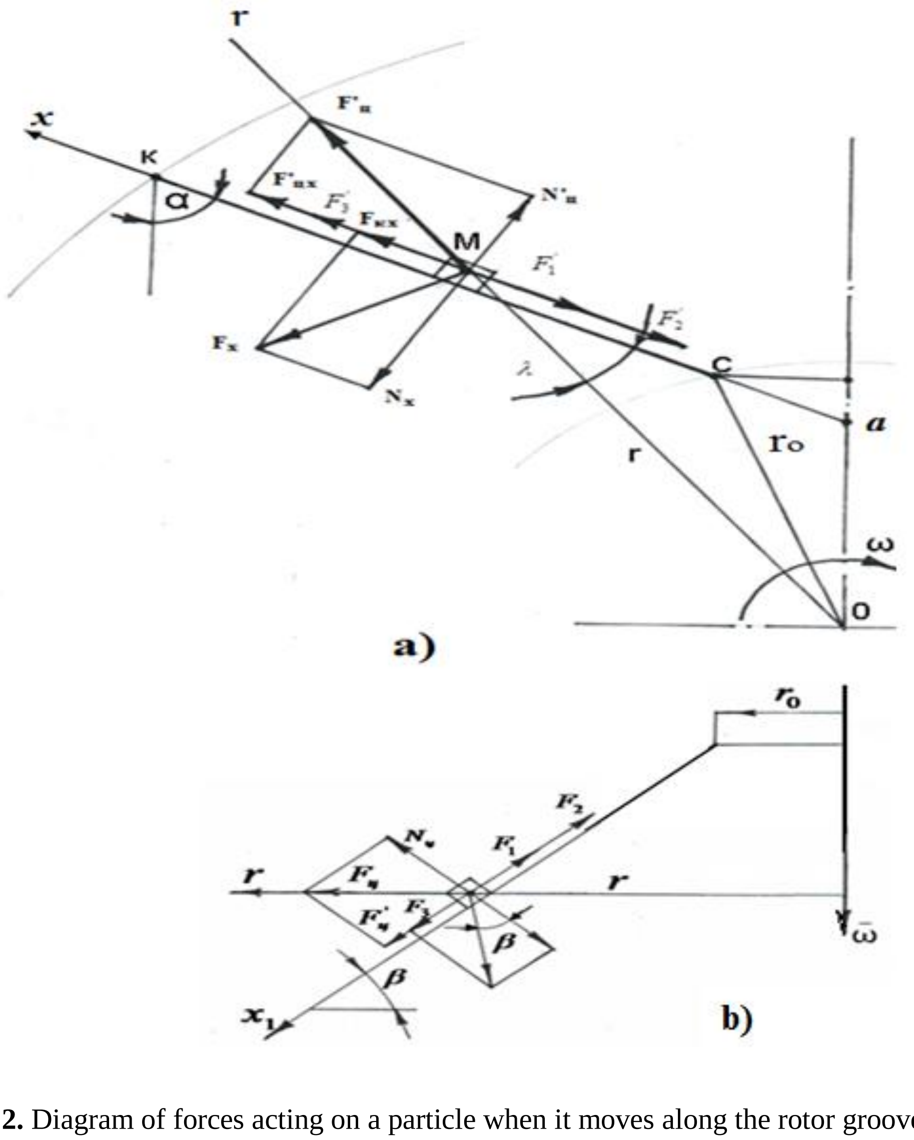

Figure 2. Diagram of forces acting on a particle when it moves along the rotor groove: a) in the horizontal plane; b) in a vertical plane passing through the axis of rotation.

If the movement occurs in a vertical plane along a groove inclined at an angle β, i.e. at $\lambda = 0$, then the equations of motion will have the form

$$m\ddot{x}_1 = F_{ц}^{'} + F_3 - F_1 - F_2,$$

Where is $F_{ц}^{'} \cdot \cos\beta = mr\omega^2 \cdot \cos\beta$ the projection of the centrifugal force on the axis x_1 (the bottom of the groove);

$F_3 = mg \cdot \sin\beta$ - projection of the weight force on the axis x_1;

$F_1 = fF_{к} = f2m\omega \cdot \dot{r} \cdot \cos\beta$ -the friction force on the side face of the rotor groove; resulting from the action of the Coriolis force on the particle;

$F_2 = f\left(mg \cdot \cos\beta - N_{ц}\right) = f\left(mg \cdot \cos\beta - F_{ц} \cdot \sin\beta\right) = f\left(mg\cos\beta - mr\omega^2 \cdot \sin\beta\right)$- the friction force of the particle on the bottom of the groove.

Considering that $r = x_1 \cdot \cos\beta$, we get after the reduction of m and the corresponding substitutions

$$\ddot{x}_1 = x_1\omega^2 \cdot \cos^2\beta + g \cdot \sin\beta - 2f\omega\dot{x}_1\cos^2\beta - f\left(g\cos\beta - x_1 \cdot \omega^2 \cdot \sin\beta \cdot \cos\beta\right)$$

or

$$\ddot{x}_1 + 2f\omega\cos^2\beta \cdot \dot{x}_1 + f\omega^2 \cdot \sin\beta \cdot \cos\beta \cdot x_1 - \omega^2\cos^2\beta \cdot x_1 + g\left(f\cos\beta - \sin\beta\right) = 0 \quad (1)$$

When moving in a horizontal plane, i.e. when $\beta=0$ end $x_1=r$ from equation (1) we get

$$\ddot{r} + 2f\omega\dot{r} - \omega^2 r + gf = 0 \quad (2)$$

A more complex equation is obtained if we take into account that the particle moves along a groove, along an axis x_1 that is deviated from the radial direction in the horizontal plane by an angle λ (Figure. 2, a):

$$\begin{aligned} m\ddot{x} &= F_{цx}^{'} + F_{кx} - F_1^{'} - F_2^{'} + F_3^{'} = F_{цx}^{'} + F_{кx} - f\left(N_{к} - N_{ц}^{'}\right) - f\cos\lambda\left(mg\cos\beta - N_{ц}^{'}\right) + F_3\cos\lambda = \\ &= mr\omega^2\cos\beta \cdot \cos\lambda + 2m\omega\dot{r} \cdot \cos\beta \cdot \sin\lambda - fm\omega\cos\beta\left(2\dot{r}\cos\lambda - r\omega \cdot \sin\lambda\right) - \\ &- fm\cos\lambda\left(g\cos\beta - r\omega^2\sin\beta\right) + mg\sin\beta \cdot \cos\lambda \end{aligned} \quad (3)$$

After the corresponding simplifications (3), we get

$$\ddot{x} + 2\omega\cos\beta\left(f \cdot \cos\lambda - \sin\lambda\right) \cdot \dot{r} - -\omega^2\left(\cos\beta \cdot \cos\lambda + f\left(\beta + \lambda\right)\right) \cdot r + g\cos\lambda\left(f\cos\beta - \sin\beta\right) = 0 \quad (4)$$

Of Δ OMC and Δ OMA on the go:

$$\sin\lambda = \frac{r_0}{r}\sin\left(\alpha - \frac{\gamma_{2p}}{2}\right); \quad x = r\frac{\sin\left(\alpha - \lambda\right)}{\sin\alpha};$$

From here

$$x = \frac{r}{\sin\alpha} \cdot \sin\left\{\alpha - \arcsin\left[\frac{r_0}{r}\sin\left(\alpha - \frac{\gamma_{2p}}{2}\right)\right]\right\} \quad (5)$$

As can be seen, the non-linearity and complexity of the obtained connection (5) creates certain difficulties when replacing r end $\dot{r}$ with values x and $\dot{x}$ in equation (4).Therefore it is much easier to consider the movement of the particle in the radial direction taking into account the angle of inclination of the rotor groove up or down by an angle β.

3. Results and Discussions

To simplify the resulting nonlinear relationship, consider the projection of the particle motion on the or axis and determine the corresponding values of x(t) from equation (5) and get (Figure 2, b)

$$m\ddot{r} = F_{ц} + F_3^{'} \cdot \cos\lambda - F_1^{'} \cos\lambda - F_2^{'} \cos\lambda = mr\omega^2 + mg\sin\beta \cdot \cos^2\lambda - 3fm\omega\dot{r}\cos^2\beta \cdot \cos\lambda +$$
$$+ fmr\omega^2 \cos^2\beta \cdot \sin\lambda \cdot \cos\lambda - fmg\cos\beta \cdot \cos^2\lambda + fmr\omega^2 \cdot \sin\beta \cdot \cos^2\lambda$$

or

$$\ddot{r} + 2f\omega\cos^2\beta \cdot \cos\lambda \cdot \dot{r} - \omega^2\left(1 + f\cos^2\beta \cdot \sin\lambda \cdot \cos\lambda + f\cos^2\lambda \cdot \sin\beta\right) \cdot r + $$
$$+ g\cos^2\lambda\left(f\cos\beta - \sin\beta\right) = 0 \tag{6}$$

Where

$$\lambda = \arcsin\left[\frac{r_0}{r}\sin\left(\alpha - \frac{\gamma_{2p}}{2}\right)\right] \tag{7}$$

Equation (6) is a second-order nonlinear differential equation that cannot be implemented analytically. When $\beta = \lambda = 0$, i.e., the radial movement of the particle in the horizontal plane, we get equation (2). If the movement occurs in the horizontal plane, but the line *CK* (Figure. 2, a) does not pass through the center of rotation, equation (6) will take the form

$$\ddot{r} + 2f\omega\cos\lambda \cdot \dot{r} - \omega^2\left(1 + f\sin\lambda \cdot \cos\lambda\right)r + fg\cos^2\lambda = 0 \tag{8}$$

In this case, the position of the line above the center of rotation O will $\alpha - \frac{\gamma_{1p}}{2} \prec 0$ give a positive value of the angle, and when the *CK* line is below the center O $\alpha - \frac{\gamma_{1p}}{2} \succ 0$, the angle λ will be negative. In the first case, the movement is accelerated due to the component of the Coriolis force directed $F_{к} \cdot \sin\lambda$ at the movement, and in the second it is $F_{к} \cdot \sin\lambda$ slowed down due to the anti-movement and increase in the friction force F1 due to a change in direction $N_{ц}^{'}$ (i.e. $F_1 = f\left(N_{к} + N_{ц}^{'}\right)$). When a particle moves radially with an angle of inclination to the horizontal plane, we get

$$\ddot{r} + 2f\omega \cdot \cos^2\beta \cdot r' - \omega^2\left(1 \pm f\sin\beta \cdot \cos\beta\right) \cdot r + tg\cos^2\beta. \tag{9}$$

When moving down, it has the sign (+) in parentheses, and when moving up, the sign (-).

If in equation (9)

$$A = 2f\omega\cos^2\beta; B = \omega^2\left(1 + f \cdot \sin\beta \cdot \cos\beta\right); C = f \cdot g \cdot \cos^2\beta.$$

Then we get a nonlinear inhomogeneous differential equation of the second orde

$$\ddot{r} + A \cdot r' - B \cdot r + C = 0 \tag{10}$$

The solution of which can be represented as

$$r = r_1 + r_2$$

where r1 is the solution of the corresponding homogeneous equation

$$\ddot{r} + Ar' - Br = 0 \tag{11}$$

Taking at the moment of entering the grain into the rotor groove (with some assumption) $\ddot{r} = r = 0$, receive $r_2 = \frac{C}{B}$

To solve (11), we will make the corresponding characteristic equation:

$$\lambda^2 + A\lambda - B = 0$$

We get various and real roots

$$\lambda_1 = -\frac{A}{2} + \sqrt{\left(\frac{A}{2}\right)^2 + B}; \qquad \lambda_2 = -\frac{A}{2} - \sqrt{\left(\frac{A}{2}\right)^2 + B}$$

From here we get the solution in General form:

$$r' = c_1 \cdot e^{\lambda_1 t} + c_2 e^{\lambda_2 t} + C/B \tag{12}$$

Accordingly the speed of movement

$$r' = c_1 \cdot \lambda_1 \cdot e^{\lambda_1 t} + c_2 \cdot \lambda_2 \cdot e^{\lambda_2 t} \tag{13}$$

To determine the coefficients c_1 and c_2, you must set the initial conditions. Let's assume for the initial moment of movement $t_0 = 0,\ r = r_0,\ r_0' = 0$. Substituting these data into equations (12) and (13), we get.

$$\left.\begin{aligned} r_0 &= c_1 + c_2 + \frac{C}{B} \\ 0 &= c_1\lambda_1 + c_2\lambda_2 \end{aligned}\right\} \tag{14}$$

From system (14) we get

$$c_1 = -\frac{\lambda_2}{\lambda_1 - \lambda_2}\left(r_0 - \frac{C}{B}\right), \quad c_2 = \frac{\lambda_1}{\lambda_1 - \lambda_2}\left(r_0 - \frac{C}{B}\right)$$

Substituting the obtained values c_1 and c_2 in (12) and (13), we get the final form:

$$r = \frac{1}{\lambda_1 - \lambda_2}\left(r_0 - \frac{C}{B}\right)\left(\lambda_i e^{\lambda_2 t} - \lambda_2 \cdot e^{\lambda_1 t}\right) + \frac{C}{B} \tag{15}$$

$$r = \frac{1}{\lambda_1 - \lambda_2}\left(r_0 - \frac{C}{B}\right)\left(\lambda_i e^{\lambda_2 t} - \lambda_2 \cdot e^{\lambda_1 t}\right) + \frac{C}{B} \tag{16}$$

As can be seen from equation (16), the movement of a particle in the radial direction is possible only if

$$r_0 - \frac{C}{B} \succ 0$$

That is, the angular speed of the rotor must be

$$\omega \succ \sqrt{\frac{f \cdot g \cdot \cos^2 \beta}{r_0 (1 \pm f \cdot \sin\beta \cdot \cos\beta)}}$$

Since equation (6) is nonlinear, it is very difficult to obtain the solution in analytical form and its implementation is easier using one of the numerical methods on the PVM using Matlab computing systems, etc. For the numerical implementation of equation (6), we present it in matrix form. To do this, enter the coefficients of the equation in a more convenient form. Take.

$$A = 2f \cdot \omega \cdot \cos^2\beta,\ B = g(f \cdot \cos\beta - \sin\beta), \quad C = f \cdot \cos^2\beta,$$

$$N = f \cdot \sin\beta$$

Then get

$$\ddot{r} + A \cdot \cos\lambda \cdot r' - \omega^2\left(1 + c \cdot \sin\lambda \cdot \cos\lambda + f \cdot N \cdot \cos^2\lambda\right) \cdot r + B \cdot \cos^2\lambda = 0$$

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Then we will represent the resulting equation in a simple system of two ordinary differential equations for this we will take

$$\left.\begin{array}{l} X(1) = r \\ X(2) = r' \end{array}\right\}$$

Then, from here we get a new system of equations

$$\begin{cases} \dot{X}(1) = X(2) \\ \dot{X}(2) = \omega^2 \left(1 + C \cdot \sin\lambda \cdot \cos\lambda + N \cdot \cos^2\lambda\right) X(1) - A \cdot \cos\lambda \cdot X(2) - B \cdot \cos^2\lambda \end{cases}$$

Or in matrix form

$$\begin{bmatrix} \ddot{X}(1) \\ \dot{X}(2) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ \omega^2\left(1 + C \cdot \sin\lambda \cdot \cos\lambda + N \cdot \cos^2\lambda\right) & -A \cdot \cos\lambda \end{bmatrix} x \begin{bmatrix} X(1) \\ X(2) \end{bmatrix} - \begin{bmatrix} 0 \\ \cos^2\lambda \end{bmatrix} \cdot B \qquad (17)$$

To use the PC and the solution in the Matlab shell (17), it is convenient to present it in vector form:
function yprime = udpol (t, r);

$$\text{yprime} = [0 \quad 1;\ \omega^2\left(1 + C \cdot \sin\lambda \cdot \cos\lambda + N \cdot \cos^2\lambda\right) - A \cdot \cos\lambda] \cdot [X(1) \qquad X(2)] \cdot B \qquad (18)$$

it is necessary to make

$$\lambda = \arcsin\left(F \cdot (X(1))^{-1}\right) \text{ where } \qquad F = r_0 \cdot \sin\left(\alpha - \frac{\gamma_{2p}}{2}\right)$$

4. Conclusions

Studies of the process of free movement of particles in the rotor slots at various operating and geometric parameters of the working chamber carried out. For this purpose, special files have been developed and used the MATLAB system on the PC. A decrease in the velocity of particles moving along inclined grooves, i.e. a decrease in the throughput capacity of the working chamber, was obtained.

References

[1] Sysuev V, Kryazhkov V, Syrovatka V 2002 Concept of development of mechanization, electrification and automation of agricultural production in the North-Eastern region of the European part of Russia for 2002-2010, Kirov.

[2] Thomas M, Hendriks W, van der Poel, AFB 2018 *Animal Feed Science and Technology* **240** 11-21

[3] Yalpachyk E, Budenko S 2013 *Praci Tavria State Agrotechnological University* **1** 218-226.

[4] Yalpachik O 2013 *Praci Tavria State Agrotechnological University* **7** 42-56.

[5] Gvozdev A, Yalpachik A 2012 *Praci Tavria State Agrotechnological University* **3** 102-108.

[6] Marczuk A, Blicharz-Kania A, Savinykh P, Isupov A, Palitsyn A, Ivanov I 2019 *Sustainability* **19** 5362.

[7] Tang C, Xu X, Kou S, Lindqvist P, Liu H 2001 *International Journal of Rock Mechanics and Mining Scienes* **8** 1147-1162.

[8] Savinyh P, Kazakov V, Moshonkin A, Ivanovs S 2019 *In the collection: Engineering for Rural Development* 123-128.

[9] Kazakov V 2013 *Bulletin of the NIIEIN* **12** (31) 36-42.

[10] Nanka O 2014 *Agrotechnics and Energy Supply* **1**(1) 204-209.

[11] Lopatin L 2018 *In the collection: Resource-saving technologies in the storage and processing of agricultural products materials of the XIV International Scientific and Practical Seminar* 177-181.

[12] Sivachenko L, Derman E 2016 In the collection: Scientific technologies and innovations electronic collection of scientific reports of the International scientific and practical conference 190-194

[13] Sabiev U, Sadbekov D, Roleder A, Akhmetov S 2020 *In the collection: The role of students' research work in the development of the agro-industrial complex. Collection of the All-Russian (national) scientific-practical conference* 249-255.
[14] Savinykh P, Isupov A, Ivanov I 2019 *Bulletin of the NIIEI* **8**(99) 18-33.
[15] Dyakonov V 1993 Spravochnik po RS MatLAB, Education, Moskov. (in Russian).
[16] Gurinenko L, Ivanov V, Semenikhin A 2012 *Bulletin of Agricultural Science* **4**(20) 10-16.
[17] Birkov S, Pilyugin K, Sabiev U Grinders corn grain. 2017 *New science: Theoretical and practical view*. **4**. 10-13.
[18] Bulatov S, Nechaev V, Shamin A 2020 *Bulletin of the NIIEI* **3**(106) 21-36.
[19] Rilley RV 2005 *Chemical and Process Engineering* **4** 189 - 195.
[20] Alijanov D, Abdurokhmonov Sh**,** Makhatov Sh 2018 *European Science Review* **5–6** 251-257.
[21] Alijanov D, Abdurokhmonov Sh**,** Amonov M 2016 *Journal European Applied Science* **11** 21-25.
[22] Alijanov D, Abdurokhmonov Sh, Jumatov Y and Bozorboev A 2020 *IOP Conf. Series: Materials Science and Engineering* **883** 012155
[23] Alijanov D, Abdurokhmonov Sh, Umirov N 2020 *IOP Conf. Series: Materials Science and Engineering* **883** 012117
[24] Alijanov D, Abdurokhmonov Sh, Umirov N, Ganiboeva E, Khudaykulov R, Bozorboyev A 2019 *International Journal of Innovative Technology and Exploring Engineering* **9** 436-438.