Statistical processing of the obtained data moment of inertia of the chopper soaked soybeans

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Abstract. The paper presents experimental studies to determine the moment of inertia of the moving disk of the grinding device. A method was used to determine the flywheel masses and moment of inertia from the «Vybega» curve. To determine the mechanical characteristics of the grinder, the method of a calibrated collector machine of alternating current was used. The mechanical characteristics of the grinder are obtained depending on the size of the abrasive, the value of the angle of curvature of the grooves and the size of the gap between the working bodies of the device being developed. Regression analysis made it possible to estimate the value of the resistance moment of the grinding device at a given value of the abrasive value and speed.

1. Introduction

The analysis of technological lines for the production of soy milk showed that the highest yield of protein during extraction occurs when using the ground dry soybean finer grinding (flour 0,35-0,5 mm). However, the energy intensity of the process is significantly higher. Therefore, the use of technologies based on the grinding of dry soybean grain into flour in small farms is unacceptable due to the high energy and metal content of the equipment at a relatively low consumption of feed product [1]. Based on the above, the most rational schemes of technological lines in the conditions of farms are those in which the grinding of soybean grain in a pre-soaked form is carried out, which allows to reduce energy costs due to the decrease in the strength of the latter.

Thus, there is a need to develop a universal constructive-technological scheme of technical equipment, combining the following technological operations: grinding, protein extraction, separation of the suspension into fractions.

2. Materials and methods

Because of a patent search for structures for preparing fodder for agricultural animals and poultry on a protein basis under the conditions of conducting personal subsidiary farming and peasant farming, we developed a device for obtaining a protein suspension from grain of leguminous crops (patent for invention of the Russian Federation No. 2614777, № 2621274).

3. Analytical studies to determine the design and operating parameters of the shredder of soaked soy grain

Because of the analysis of the working process of technical means for the preparation of high-protein feed, the main analytical dependences were obtained to justify the design and operating parameters of the shredder of soaked soy grain.
The productivity of the shredder was determined using the formula of V. P. Goryachkin, having previously determined the amount of product simultaneously covering the entire surface of the grinding disk $G$ and the exposure of the processing $T$:

$$Q_c = g_0 \frac{\pi R^2 (k^2 - 1)a_r}{k^3 S_r},$$  

(1)

where $g_0$ is the grain load, kg/m$^2$; 
$v_r$ – velocity of the particle along the groove, m/s; 
$R$ – radius of the rotating disk, m; 
k – disk constant, $k=R/r$; 
$S_r$ – the length of the arc along which the crushed particle moves, m.

The unknown in expression (1) is the speed of rotation of the lower disk $v_r$. After composing and solving the second-order Lagrange equation, as well as determining the forces applied in the plane of the disk and the elementary work applied in the direction of possible displacements, the rotation speed of the lower disk is defined as:

$$v_r = \sqrt{r^2 \omega^2 - 2 \left(g + \frac{G}{m}\right) S_r},$$

(2)

where $r$ – distance from the center of the disk to the grain, m; 
$\omega$ – angular velocity of the grain, rad/s; 
m – the mass of grain, kg; 
$Q$ – the pressure force of the upper disk grain; 
g – acceleration of gravity, m/s$^2$.

Since during the grinding process, the grain will start moving along a certain trajectory $S_r$ in relative motion with a relative speed $\vec{a}_r$, the expression describing the length of the arc $S_r$ is determined by

$$S_r = \frac{r}{a} \sqrt{1 + a^2} + C_2,$$

(3)

where $a=r/\varphi=\text{const}$; 
$C_2$ – arbitrary constant.

In the course of research, the relationship between the time $t$ and the arc length $S_r$ was determined which could be expressed as:

$$t = \frac{1}{n \sqrt{\gamma + nS_r + \sqrt{n\gamma + 2nS_r + nS_r^2}}} \times$$

$$\frac{\sqrt{n\gamma + 2nS_r + nS_r^2}}{n},$$

(4)

It is advisable to apply curved grooves to the lower rotating disk, since the possible trajectories of grain movement along the lower disk will be an Archimedean spiral or a circle sweep and it increase productivity and reduce energy consumption. For faster grain removal from the surface of the groove, the latter have a curved shape with a bulge directed in the direction of rotation [3]. Analysis of the working process of the soaked soy grain shredder allowed us to obtain an expression for determining the power required for grinding soaked soy grain:

$$N_u = g_0 \frac{\pi R^2 (k^2 - 1)a_r}{k^3 S_r} r$$

(5)
Analysis of expression (5) shows that the energy consumption for the process of grinding soaked soy grain depends on its design and processing parameters. With the known design parameters of the soaked soy grain shredder, the speed of rotation of the disk \( \omega \) and the time of grinding soy grain have a decisive influence on productivity and energy consumption \( t \).

The main element of the proposed technology for the preparation of high-protein feed based on soybean grain is a soybean grain chopper.

In previously published studies [1-3], a device was presented that allows the production of soymilk, tofu, and soy protein base for the preparation of feed for farm animals and poultry as a product of soybean grain processing.

A prototype was fabricated [4, 5] (Figure 1), on the basis of which a number of multifactorial experiments were carried out with the aim of experimentally substantiating the design-mode parameters of the shredder.

![General view of the shredder soaked soybean grain.](image1)

**Figure 1.** General view of the shredder soaked soybean grain.

Experimental installation in a proper measure allows varying in the required limits by the values of selected factors that affect the process of grinding soaked soybean grain, followed by extraction of soy protein. The frequency of rotation of the lower abrasive disc was changed by the switch frequency of the installation. The switch works in three modes [6, 7].

Replaceable abrasive discs with curved grooves were also made (Figure 2). Curved grooves are made in the form of grooves at different angle of intersection of the grooves (\( \alpha = 60^\circ, \alpha = 90^\circ, \alpha = 120^\circ \)). Overlaying washers between the upper abrasive cones exposed the gap between the abrasive discs and the cover of the chopper housing (thus, during the experiment, the gap between the abrasive discs 3, 4, and 5 mm was set.) The roughness of the abrasive surface of the discs was achieved by applying corundum on the abrasive stone, the roughness value was chosen \( Ra = 50, Ra = 250, Ra = 450 \) microns.

To determine the mechanical characteristics of the shredder, the method of calibrated collector AC machine was used. Be the first to experience the idle speed to the collector alternating current machine, then the motor connected to the chopper and carried out the grinding process with different direction of grooves, the roughness of the abrasive and over or between the disks, as these factors greatly affect the value of the mechanical moment. The result of the experiments is the mechanical characteristics of the shredder (figure 3). The full methodology of the experiments and the results are given in the article [1].
Figure 3. Mechanical characteristics of the grinder depending on the roughness of the abrasive.

Mechanical characteristics at start-up without load have a ventilating view [8, 9], and at receipt of a product at the increased frequencies of rotation leads to increase in the moment of resistance. Increasing the angle of direction of the grooves, abrasive roughness and reducing the gap between the discs can lead to an increase in the moment of resistance up to 20%.

Regression analysis allows us to estimate the value of the moment of resistance of the shredder at a given value of the abrasive roughness and speed [10]. To obtain the regression model the mechanical characteristics and verification of its adequacy to the identified dependent and independent variables: $x_1$ – engine speed, $-1C$; $x_2$ – roughness of abrasive material, $g/cm^3$; $U_1$ – the moment of disobedience, Nm.

Table 1. Data obtained from laboratory experiments.

| № п/п | $x_1$ | $x_2$ | $x_1^2$ | $x_2^2$ | $x_1x_2$ | $y_1$ |
|-------|-------|-------|---------|---------|----------|-------|
| 1     | 0     | 50    | 0       | 2500    | 0        | 0.30  |
| 2     | 141   | 50    | 19881   | 2500    | 7050     | 0.40  |
| 3     | 157   | 50    | 24649   | 2500    | 7850     | 0.73  |
| 4     | 172   | 50    | 29584   | 2500    | 8600     | 0.96  |
| 5     | 0     | 250   | 0       | 62500   | 0        | 0.30  |
| 6     | 141   | 250   | 19881   | 62500   | 35250    | 0.51  |
| 7     | 157   | 250   | 24649   | 62500   | 39250    | 0.96  |
| 8     | 172   | 250   | 29584   | 62500   | 43000    | 1.10  |
| 9     | 0     | 450   | 0       | 202500  | 0        | 0.30  |
| 10    | 141   | 450   | 19881   | 202500  | 63450    | 0.70  |
| 11    | 157   | 450   | 24649   | 202500  | 70650    | 1.01  |
| 12    | 172   | 450   | 29584   | 202500  | 77400    | 1.20  |
### Table 2. Regression analysis of the dependence of the voltage $U_1$ on the load $x_1$ and capacitance $x_2$.

The correlation coefficient $R = 0.98818000$; the coefficient of determination $R^2 = 0.97649970$; the Fisher criterion $F(5,6) = 49.863$; the value of the significance level of the model $p < 0.00008$; the standard error of estimate of the regression equation: 0.06984

| Shift and non-standardized coefficient of empirical formula | Student criterion $t$ (3) | $p$-significance level |
|-----------------------------------------------------------|---------------------------|------------------------|
| The regression coefficient in variable's                  | The standard error of estimate of the regression coefficients |                       |
| $x_1$           | -2.53539                  | 0.278270               | 0.082650               | 3.36684 | 0.015101 |
| $x_2$           | 0.11540                   | 0.428891               | -0.011885              | 0.002011 | -5.91150 | 0.001043 |
| $x_1^2$         | 3.16276                   | 0.298004               | 0.000228               | 0.000588 | 0.38723 | 0.711951 |
| $x_2^2$         | -0.10459                  | 0.418052               | 0.000091               | 0.000012 | 7.56548 | 0.000277 |
| $x_1x_2$        | 0.36318                   | 0.278128               | 0.000000               | 0.000001 | -0.37606 | 0.719809 |

The regression equation describing the effect of the abrasive speed and roughness now of resistance is obtained based on the regression analysis presented in table 2:

$$ y_1 = 0.278270 - 2.53539 x_1 + 0.11540 x_2 + 0.36318 x_1 x_2 + 3.16276 x_1^2 - 0.10459 x_2^2 $$ (1)

The coefficients of the equations adequately show that as the speed increases, the moment of resistance increases, and when the roughness of the abrasive decreases, it decreases.

**Figure 4.** Effect of speed ($x_1$) and the roughness of the abrasive ($x_2$) at the moment resistance of the shredder ($y$).

### 4. Findings

Thus, the mechanical characteristics at start-up without load have a fan-like appearance, and when the product arrives at increased rotational frequencies, it leads to an increase in the moment of resistance. Increasing the angle of the grooves, roughness of the abrasive and reducing the gap between the discs can lead to an increase in the moment of resistance to 20%. The chopper mechanism has a significant moment of inertia, which is confirmed by the overrun curve.
The coefficient of determination reflecting the General spread of sample points indicates that 99% of the variance of the dependent variable \(y_1\) is explained by the variation of the independent variables \(X_1, X_2\) and their combinations. The standard error of the standardized regression coefficient is 0.6984%. Regression coefficients are statistically significant and differ from 0 (\(p << 0.00008\)) and the constructed regression model describes the relationship between the roughness, speed and moment of resistance (\(R^2 = 99\%\)).

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