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INVESTIGATION ON THE DEPENDENCE OF A QUERN MILL OUTPUT ON THE SIZE OF GRINDING SLOT AND GRAIN MOISTURE

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A b s t r a c t. The present paper presents the results of investigations on the process of wheat grinding in a grinding machine in the aspect of a simultaneous determination of the influence of material moisture and grinding slot onto the output of the grinding machine. The model of the grinding process is described. The model allowed to develop the equation of the machine output in relation to the working slot and grain moisture content. An increase of the slot size increases also the output of the grinding process. An increase in material moisture level decreases the process output. Exceeding the moisture of 16% caused stucking of the mill.

K e y w o r d s: quern mill, grinding, wheat, moisture, grinding slot

INTRODUCTION

Material grinding is a process broadly applied in food industry and agriculture. It is a process, which consumes a lot of power. Annual energy consumption for grinding solid bodies reaches the value of about 1/3 of the total power production [6].

A detailed description of the course of grinding process is very complicated. Difficulties result from, among others, variability of physical and biological properties of food products and agricultural material as well as from various technological features and design of grinding machines and equipment.

The analysis of the existing theories on the grinding process proved that there is no consistent and universal theory describing the process comprehensively independent of the kind of ground material, design and operational features or technology of the machines and equipment used for grinding [5].

Development of the grinding theory in food industry and agriculture is mainly determined by the growing demand to lower the power consumption in the process maintaining at the same time high quality of the final product.

The aim of the present paper is to determine the influence of the material features and grinding machine parameters onto the output of a quern mill. An assumption has been made that the quern mill output is directly dependent on the physical features of the material being ground and on the design and operational parameters of a quern mill in use.

The paper contains the results of investigations obtained during wheat grain grinding. The investigations have been carried out using a quern mill in laboratory conditions. The analysis of results and conclusions constitute an attempt at such a selection of the size of the working slot of the mill and moisture of the material being ground that the output of the mill is increased to maximum, maintaining at the same time proper, high quality of the product.

ACCEPTANCE OF THE PROCESS MODE AND FORMULATION OF RESEARCH HYPOTHESIS

Before the investigations were started a hypothesis had been made that in a quern mill, there is a relation between the size of a working slot *S*, moisture of the material being ground W, and the mill output *Q*, and this dependence can be described by an equation.

Pursuant to the assumption, the model of the process under investigation has been approved (Fig. 1).

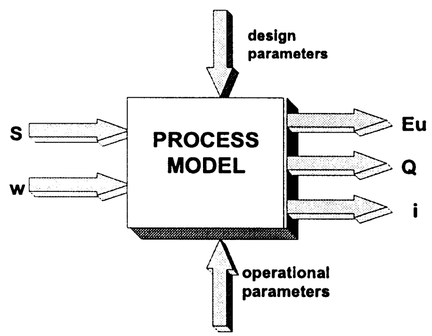

Fig. 1. The scheme of the process.

MATERIALS AND METHODS

Grinding of wheat grain has been carried out in the laboratory of the Department of Food Industry Machines, Mechanical Faculty, Lublin Technical University. Jana wheat grains have been used for this investigation. In order to determine the influence of material moisture content onto the course of the grinding process the material being investigated had been conditioned up to five different moisture levels. The moisture content of individual samples has been adjusted by drying or moistening. Levelling of the moisture content required in the entire mass of the samples was obtained by placing the samples in a cooling chamber at a constant temperature and by multiple shaking. In order to equalize the temperature of the samples with the ambient temperature they have been taken out of the chamber about one hour before taking measurements.

Moisture content of the raw materials has been determined using a drier method according to the PN-86/A-74011 standard. Moist samples were weighed on the analytical scales WA-35 with the accuracy of 0.01 g, and then the samples were dried in a drier of K 13 CG16/250 type at the temperature of 403 K till they reached a constant weight (for about 60 min). After cooling for about 30 min in a desiccator the samples were weighed on WA-35 scales with the accuracy of 0.01 g.

The moisture content of the samples of the material under investigation were checked every time before the execution of the investigation schedule.

A laboratory quern mill of ML-155 type, manufactured in the Mechanical School Group No. 1 in Warsaw and adjusted for grinding grain of four basic cereals has been used for grain grinding. The grinding element was replaced by the element capable of grinding pulse crops before the experiment.

The measuring system consisted of a PRL T103-type wattmeter, ZW-R-type feeder, and a TZ21S-type line recorder.

The investigated wheat has been divided into samples of 100 g each, weighed with the accuracy of 0.1 g on the WPE-300 scales. The measurements were taken for different associations of material moisture content and the size of grinding slot. The final result is an arithmetic mean of nine repetitions.

Contribution of particles with specific dimensions in the material was determined on the basis of sieve analysis before and after grinding. Three samples of 100 g were taken from all the portions of material subjected to the investigations. Afterwards they were sieved on a set of laboratory sieves with the following DIN numbers 4188 0.4; 0.5; 0.63; 0.8; 1.0; 1.25; 1.6; 2.0; 2.5; 3.15; 4.0; 5.0 and 6.3. Before and after grinding the sieves were shaken for 10 min on a WES-type shaker. The weight of individual wheat fractions was determined with the accuracy of 0.1 g on the WPE-300-type scales.

Study results showed that following factors exert the greatest influence onto the grinding process in a quern mill: size of the grinding slot and material moisture content. The present investigations were carried out for five levels of grain moisture content and five sizes of grinding slot. These values were changed according to the construction of the griding machine, as follows W: 8.1, 10.3, 11.8, 14.1 and 16.6%, and the S size was changed within the range from 1.15 to 5.74 mm (minimum and maximum slot size of the experimental equipment). The tests were repeated nine times for each of the 25 measuring points.

ANALYSIS OF RESULTS

In order to eliminate the measuring points with too big error, the following method was used:

- arithmetic mean and standard deviation of the readings approved for the analysis was calculated,
- value of t statistics for the significance level α=0.05 was calculated from t-Student distribution,
- relations were checked:

$$\frac{y_1 - y}{S} < t \tag{1}$$

where: y_i - measured value, y - arithmetic mean, S - standard deviation, t - value of t-Student statistics.

If one of the measurement points differed substantially from the others, it was eliminated.

While selecting equations describing relations between the variables, those regression equations that had the simplest possible form were selected. The method with the best properties from the view point of mathematical statistics was applied for the estimation of the unknown factors of this equation.

The general form of the regression equation is as follows:

$$F = f(x_1, x_2 \ldots x_p) \tag{2}$$

where: F - dependent variable, $x_1 \ldots x_p$ - independent variable.

Individual types of regression are expressed by the equations:

- linear regression:

$$F = \beta_0 + \beta_{1x1} + \beta_{pxp}, \tag{3}$$

- square regression:

$$F = \beta_0 + \beta_{1x1} + \beta_{pxp} + \beta_{1,2x1x2} + \beta_{p-1,pxp-1xp}. \tag{4}$$

In the present paper the regression equations of higher orders was not applied due to their complex form and very big number of equation coefficients.

In the regression equations, the searched coefficients β are calculated using the method of the smallest squares:

$$F = \sum_{i=1}^{n} (y_1 - y_i)^2 \tag{5}$$

where: n - number of measurement points, y_1 - measuremed value, y_i - approximated quantity.

For the functional F to reach a minimum value, the following condition must be met:

$$\frac{\delta F}{\delta \beta_k} = 0 \tag{6}$$

where: k = 1 ....n, n - the number of coefficients in a given equation.

After determination of the regression equation, the correlation coefficient r was calculated from the n-element test. This coefficient is an estimator of the correlation coefficient ρ only, hence it becomes a parameter for the entire examined population. Therefore, it is necessary to determine the confidence interval for the parameter being estimated.

The estimation was carried out using Z statistics:

$$Z = 1.151 \log \frac{1+r}{1-r} \tag{7}$$

for which standard deviation equals:

$$\sigma_z = \frac{1}{\sqrt[3]{n-3}}. \tag{8}$$

This statistics is described by normal distribution.

Then, a hypothesis $H_0(\rho=0)$ was made. According to this hypothesis the correlation is not significant. If this hypothesis is accepted, there is no cause-effect connection between the investigated variables. If this hypothesis is rejected, the correlation is significant. The investigation of the significance was carried out by the statistics described by the equation:

$$t = \frac{\sqrt{n-2}}{\sqrt{1-r^2}}. \qquad (9)$$

This statistics is described by the t-Student distribution for the degree of freedom $k = n - 2$. If the calculated t value is higher than the critical value $t_{\alpha/2,k}$, the hypthesis $H_0(\rho = 0)$ is rejected, which means that the correlation is significant.

IDENTIFICATION OF PROCESS PARAMETERS

According to the method adopted, the parameters of the grinding model assumed were described by the following relations:

– regression equation for the output of the process takes the form below:

$$Q = f(S, W) \qquad (10)$$

where: $f(W) = \beta_1 + \beta_2\ S$
$f(W) = \beta_3 + \beta_4\ W^{\beta_5}$.

RESULTS OF MODEL PARAMETER IDENTIFICATION

After calculation of the regression and correlation coefficients, the equations describing the investigated relations assume the following forms:

$$\beta_1 = 0.466; \beta_2 = 0.317; \beta_3 = 1.226;$$
$$\beta_4 = -2.290.10^{-4}; \beta_5 = 2.955$$
$$r = 0.9292;\ \text{error} = 8.326\%. \qquad (11)$$

Relation between machine output and the working slot combined with grain moisture content is described by the following equation:

$$Q = (0.466 + 0.317\,S)(1.226 - 2.290\ 10^{-4}\ W^{2.955}) \quad \text{(kg s)} \ (12)$$

In the Figs 2 and 3, three types of relations obtained during wheat grain grinding are presented. Figure 2a illustrates the influence of the quern mill slot size onto its output. This relation is very clear. With the increase of slot size, the output of the machine increases linearly. In Fig. 2b the influence of the moisture content of the ground material on the output of the mill is presented. It was confirmed that together with the increase of grain moisture content, the output of the mill decreases. At the level of about 18%, grain in the quern mill is practically not ground. The correctness of the mathematical model adopted is presented in Fig. 3.

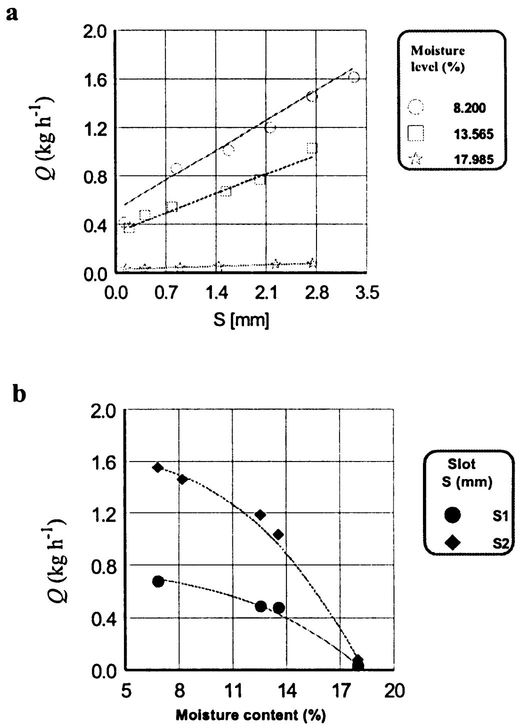

Fig. 2. Relation $Q = f(S)$ (a) and $Q = f(W)$ (b).

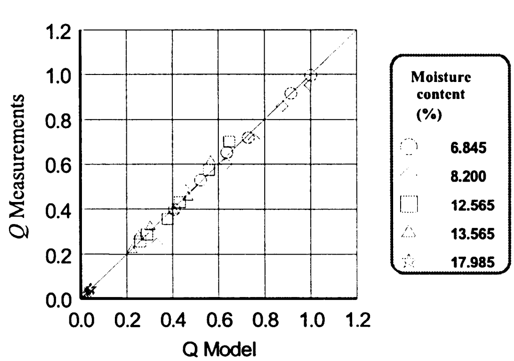

Fig. 3. Comparison of the model adopted with the measured results.

CONCLUSIONS

1. The investigations carried out proved the correctness of the research hypothesis put forward.

2. During the investigation of a quern mill it has been found out that:
- an increase of a grinding slot S size causes an increase in the output of grinding process;
- after the moisture content in the grain exceeds the level of 16%, a decrease in the output was observed up to the point when the mill is blocked.

3. In the case of the mathematical model of the grinding process that has been worked out, there is a significant qualitative and quantitative agreement between the influence of the construction and operation quantities onto the output of the grinding process - the correlation coefficient is close to one.

4. The mathematical model of the grinding process worked out may constitute the basis for further research on the following aspects:
- use of alternative grinding facilities,
- grinding process of other granular agricultural and food materials.

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