

# Development of a software-hardware complex for studying the process of grinding by a pendulum deformer

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**Abstract.** The article is devoted to the development of a software and hardware complex for investigating the grinding process on a pendulum deformer. The hardware part of this complex is the Raspberry Pi model 2B platform, to which a contactless angle sensor is connected, which allows to obtain data on the angle of deviation of the pendulum surface, usb-cameras, which allow to obtain grain images before and after grinding, and stepping motors allowing lifting of the pendulum surface and adjust the clearance between the pendulum and the supporting surfaces. The program part of the complex is written in C # and allows receiving data from the sensor and usb-cameras, processing the received data, and also controlling the synchronous-step motors in manual and automatic mode. The conducted studies show that the rational mode is the deviation of the pendulum surface by an angle of  $40^\circ$ , and the location of the grain in the central zone of the support surface, regardless of the orientation of the grain in space. Also, due to the non-contact angle sensor, energy consumption for grinding, speed and acceleration of the pendulum surface, as well as vitreousness of grain and the energy consumption are calculated. With the help of photographs obtained from usb cameras, the work of a pendulum deformer based on the Rebinder formula and calculation of the grain area before and after grinding is determined.

## 1. Introduction

Having conducted a study of the state of the food industry in Russia, it can be concluded that the level of development of technical production to the world level does not correspond. Based on the results of the research, 19% of the active part of production assets correspond to the declared level, 20% need modernization, and 42% should be replaced [1].

At present, flour production is developing in two directions:

1. Shorter work schedules are inherent in small agricultural mills and small farms.
2. Full technology, which includes advanced modes of screen separation, grinding, and hydrothermal processing.

In both cases, the fundamental process is the grinding of grain materials, which determines the quality of flour, issuance and energy consumption.

## 2. Relevance

The technology of multiple grinding of grain operates and the production of intermediate products with their further delivery to flour of various grades, and bran at present time.

As the main equipment of grain processing enterprises for the production of flour, roller machines are used, the main working part of which is a pair of rolls, making rotational movement with different speeds towards each other. This process is partially automated and lasts continuously, but also such production has its drawbacks, namely the high power consumption (up to tens of millions of kWh per



year). Also, roller machines have other disadvantages, such as: complex technology; large costs for the production of a rolling mill bed, re-grinding grain, and so on.

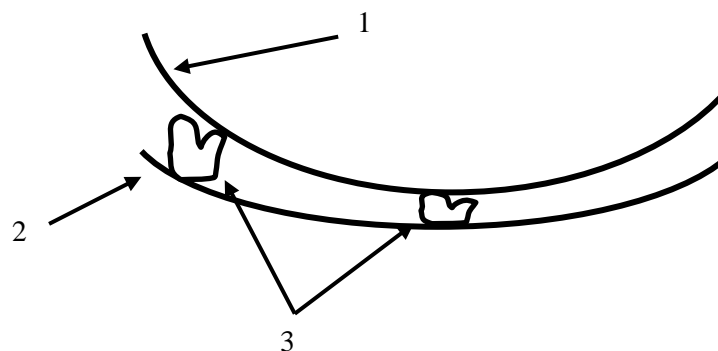
Despite the sufficient complexity of the process for obtaining flour in mill production, the production of endosperm from the grains is not more than 63...68%, although the endosperm in it is up to 85%. At present, the processes of additional obtaining of endosperm are perfected only by increasing the number of machines or creating multi-roll machines, which only increases energy consumption.

The most energy-consuming parts of the grinding process are the first and second torn systems, where engines up to 17.5 kW are installed, and on subsequent grinding and grinding systems it reaches 7.5 kW. In large mills the machine stock is up to 15 machines and more, which indicates the complexity and energy intensity of this process.

### 3. Principle of operation

An alternative to rolling machines is a pendulum deformer, developed by the professor at the Altay state technical university V.L. Zlochevsky [2]. The principle of operation of this installation is as follows. To destroy the grain, two cylindrical surfaces are used, one of which is the outer surface of the cylinder and the other is the inner surface.

After grabbing the grains (Figure 1), the process of elastic deformation is performed. When the ultimate strength of the shell is reached, the grain breaks down to maximize the opening of the endosperm. Such destruction occurs at the weakened place of the grain - groove. Comparing such a process with grain cutting, which occurs when using corrugated roll systems, we find that using a pendulum deformer, most of the grain will be used to produce flour.

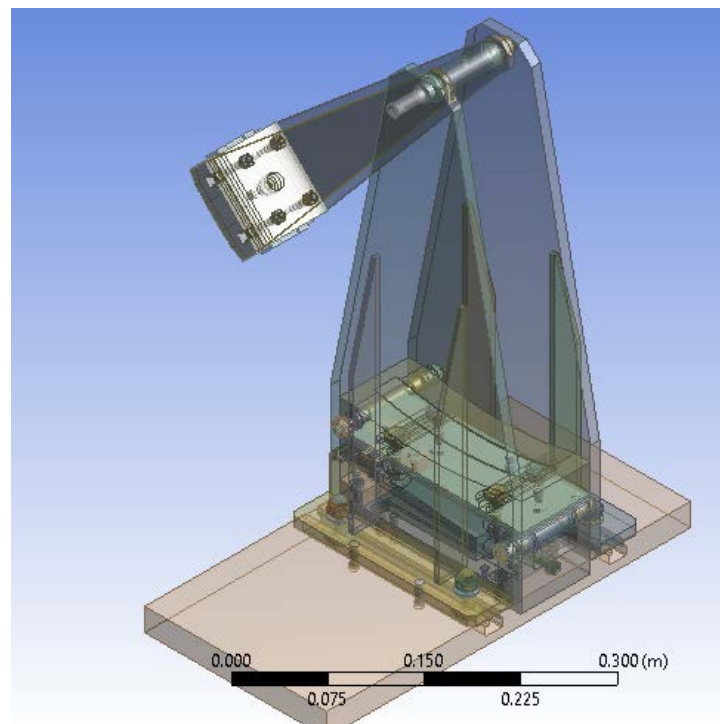


**Figure 1.** Interaction of grain with surfaces: 1 – pendulum surface; 2 – bearing surface; 3 – grain.

The pendulum surface has amplitude and frequency of oscillations, which allows controlling the speed, acceleration of the pendulum and energy costs for grinding. In order to make it possible to change the methods of grain deformation, change the size of the gaps, etc., the supporting (lower) surface of the pendulum is regulated. Using such control it becomes possible to change the geometry of the working area, as well as the working surfaces [2].

The general view of the pendulum deformer is shown in Figure 2.

The pendulum deformer consists of a base on which a rack, guides and a lead screw are installed. A pendulum is mounted on the stand with a shaft. A stepper motor is connected to it. The curved deck is fixed on the pendulum. Based on the substrate, located under the pendulum. The substrate has a concave structure. To the substrate, as well as to the pendulum, a stepper motor is connected. Its necessity consists in that it can be used to adjust the height of the substrate, thereby changing the angle of the meeting of the grain with the surface of the pendulum and the degree of grain refinement [3].



**Figure 2.** Model of the pendulum deformer.

A distinctive feature of the pendulum deformer from roller is that it does not require constant rotation of the working cylinder. Also, in this installation, the problem with overheating of the grains and working surfaces was solved, since the whole grinding process proceeds very quickly, and the working surfaces of the pendulum do not touch each other.

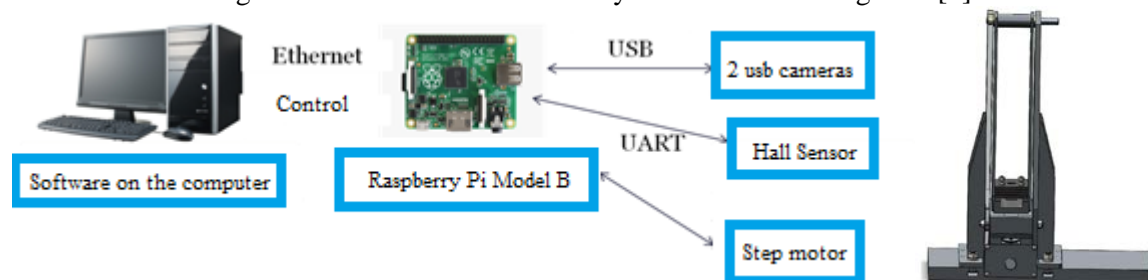
The pendulum deformer can be used in appropriate dimensions, such as a pre-system in front of roller machines, and in laboratory grinds to adjust the operation of rolling machines, as well as in determining the properties of the grain. To control the grinding process and to study the properties of grain, a software and hardware complex was developed.

#### 4. Software and hardware

The automated system consists of the following elements:

- Pendulum deformer, with an angle sensor connected to it, USB-cameras and stepper motors.
- Software on a personal computer.
- Microcomputer Raspberry Pi B +.

The connection diagram of all the elements of the system is shown in Figure 3 [4].



**Figure 3.** The device of the milling products formation system.

Determination of the energy of grain destruction is based on the identification of unambiguous values of the stored potential energy that can be obtained at the extreme points of the pendulum

surface with a damped oscillatory process. It is also necessary to take into account the energy losses due to friction. Thus, the sequence of actions of the method:

- retraction of the pendulum surface by a certain angle  $\alpha_1$  by means of a stepper motor controlled from a personal computer;
- placing the test grain on the support surface;
- release of the pendulum surface;
- fixing the angle  $\alpha_2$  on the opposite side;
- calculation of energy costs of the pendulum deformer, glassiness and strength of grain.

It should be noted that the definition of losses is possible in two ways:

- making an analytical calculation using known theoretical information;
- calculating the losses for the standard oscillation of the pendulum, which is taken to a given angle.

In this paper, the first method is used, although it is possible that in the future the second method will be used.

It is known that for a pendulum:

$$E = m \cdot g \cdot l_m \cdot (1 - \cos \alpha),$$

where  $m$  – mass of the pendulum,  $E$  – pendulum-stored potential energy,  $\alpha$  – angle of deviation of the pendulum,  $l_m$  – reduced length of the pendulum. Proceeding from the fact that the damping decrement of the pendulum is equal to:

$$d = \ln \left( \frac{\alpha_1}{\alpha_2} \right) = \beta T,$$

where  $T$  – period of fluctuation,

it is possible to calculate the energy dissipated in one period:

$$E_p = m \cdot g \cdot l_m \cdot (\cos \alpha_2 - \cos(e^{-\beta T} \alpha_1)).$$

Therefore, in order to determine the energy value for the destruction of the grain, it is necessary to calculate the damping decrement and the period of natural oscillations of the pendulum for a given angle of initial deviation, and also fixing the extreme positions of the surface of the pendulum.

To determine the angular position of the pendulum surface, an industrial encoder was first used to convert the value of the angle into a sequence of pulses. However, due to the low resolving power ( $0.25^\circ$ ), as well as the high cost of the copies with a higher resolution, it was decided to abandon this method of angle measurement. An alternative to the encoder was the non-contact magnetic proximity sensor KMA200 from NXP, which indicated a resolving power of at least  $0.04^\circ$  in digital mode. As it turned out, in the analog mode it is possible to obtain higher values, which was the reason for choosing the analog mode of the sensor operation. The analog interface of the sensor is a differential analog output, varying within 5...95% of the supply voltage, depending on the angular position of the magnet. By the experimental method it was possible to obtain the resolution of the sensor at the analog output  $0.01^\circ$  [5].

To control the grinding process using a pendulum deformer and control its characteristics, the sensors use a Raspberry Pi model B + microcomputer with the control of the developed program. The Raspberry Pi model B + microcomputer controls the lifting of the pendulum surface and the adjustment of the reference surface by means of synchronous stepper motors and the transfer of all collected information from a contactless angle sensor to a computer. The software installed on the computer allows you to view the incoming information in an accessible format, and also allows you to control the pendulum deformer using the command system for the microcontroller and, accordingly, control the stepping motors. Also, the speed and acceleration of the pendulum surface are calculated based on the data obtained from the angular position sensor KMA200.

USB-cameras are used to determine the perfect work of the pendulum deformer. For this we use the formula proposed by P.A. Rebinder:

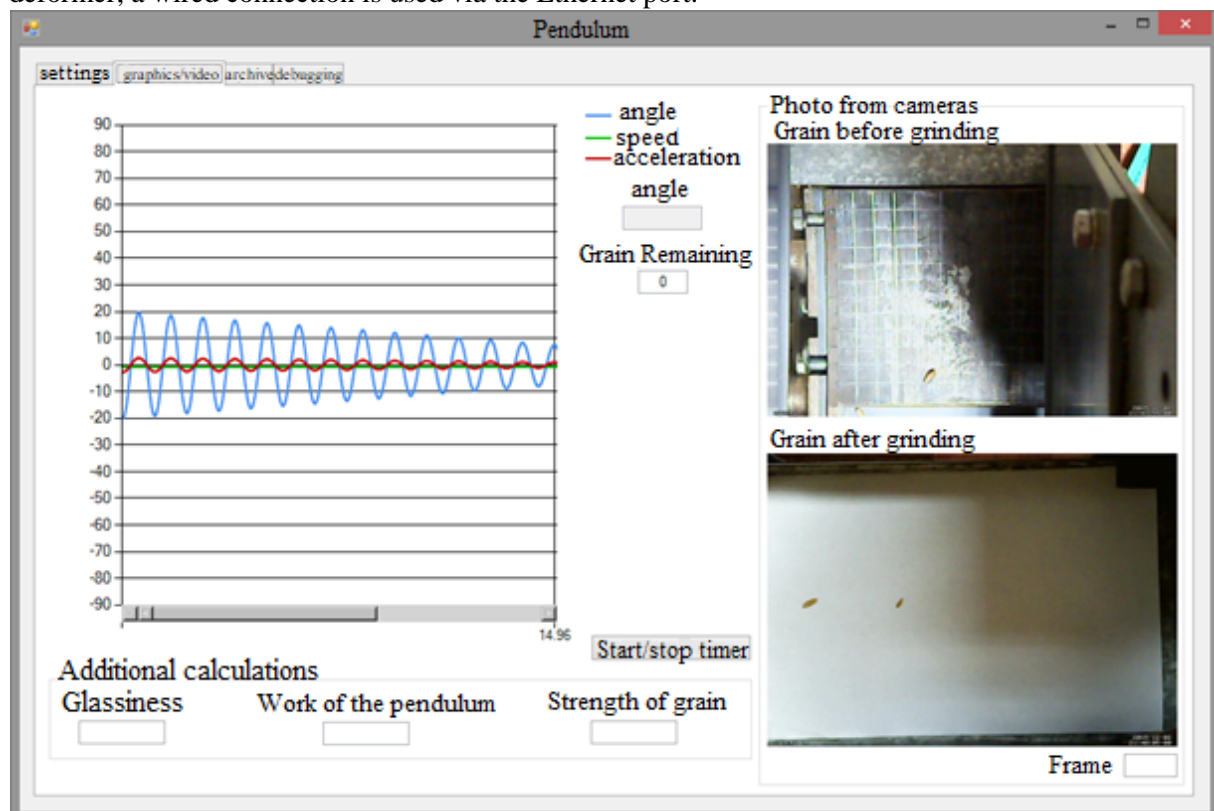
$$A_p = k_v \cdot k_n \cdot V_m + \alpha_{\text{ноб}} \cdot \Delta S$$

where  $A_p$  – energy consumption for destruction;  $k_v$  – coefficient considering what part of the volume of the particle deforms;  $k_n$  – coefficient characterizing the physical and mechanical properties of the body

being destroyed;  $V_m$  – volume of the body being destroyed;  $\alpha_{nos.}$  – specific surface energy of the body being destroyed;  $\Delta S$  – formed when a new surface is destroyed.

Using the openCV library, the grain area is calculated before grinding and after grinding, which allows the software to perform calculations using the Rebinder formula. Images are obtained with USB cameras, by constantly comparing the photos until they become the same, that is, the grinding process stops. On the basis of these photographs, namely the photograph of the grain after grinding, information is taken on the area of the crushed grain, which in turn is used in calculating the work of the pendulum deformer.

The software (Figure 4) for controlling the hardware of the complex is written in the C # programming language. To connect the microcomputer with the software and with the pendulum deformer, a wired connection is used via the Ethernet port.

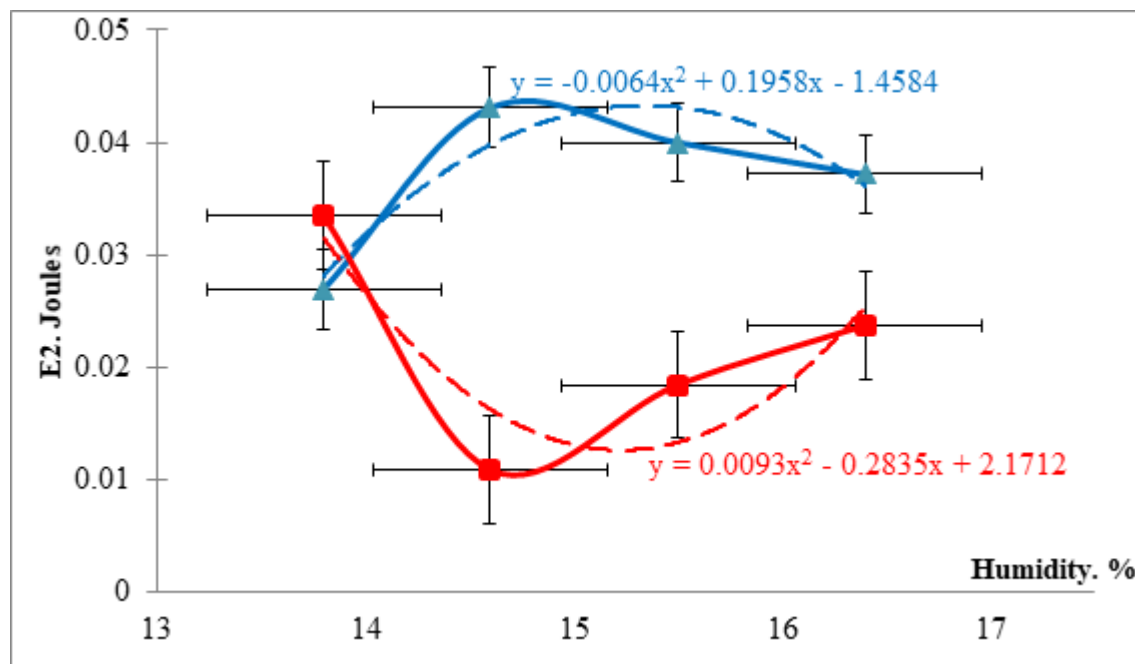


**Figure 4.** Main program screen, graphics / video tab.

A series of experiments revealed the regime of maximum efficiency of the pendulum deformer, shown in Figure 5.

At the current time, there are the following grain characteristics and tuning of the pendulum deformer, which were experimentally verified and confirmed:

- 1) Position of the grains on the deck (in the beginning, in the middle, in the end).
- 2) Angle of deviation of the pendulum (deviates by  $30^\circ$ ,  $40^\circ$ ,  $45^\circ$ );
- 3) The angle of rotation of the grain in the square of the deck (can lie - vertically, horizontally, diagonally).



—■— The vertical arrangement of the grain, the deviation of the surface from the vertical by 45 degrees, the location of the grain on the supporting surface, shifted from the plumb zone by 40 mm down.

—▲— The horizontal arrangement of the grain, the deviation of the surface from the vertical by 30 degrees, the location of the grain on the supporting surface, shifted from the plumb zone by 40 mm down.

**Figure 5.** Range of rational use of the pendulum deformer.

Analysis of the experimental data shows:

1. Depending on the selected regime for one grain, energy costs for the destruction of grain materials are from 0.01 to 0.05 Joules. When grinding on a roller machine, the energy costs are of the order of 0.114–3.24 Joules per grains.

2. Since in grains 1, 6, 8 the grain lies at the beginning of the deck, the kinetic energy reserve is minimal and there is no grain breakage. Therefore, these regimes are not rational.

3. Mode No. 9 has the greatest deviation of the pendulum surface and the grain is located at the beginning of the support surface, then the greatest energy consumption (on average 0.042 Joules) and the maximum speed of the pendulum movement from all modes are observed.

4. Since the grain is located in the middle of the support surface, where the largest values of speed and kinetic energy, due to the location of this zone at the point of the plumb and the angle of the deviation of the pendulum surface  $40^\circ$ , the most rational is mode No. 5, having throughout the experiments average values of energy consumption 0.026–0.028 Joules) (Figure 6).

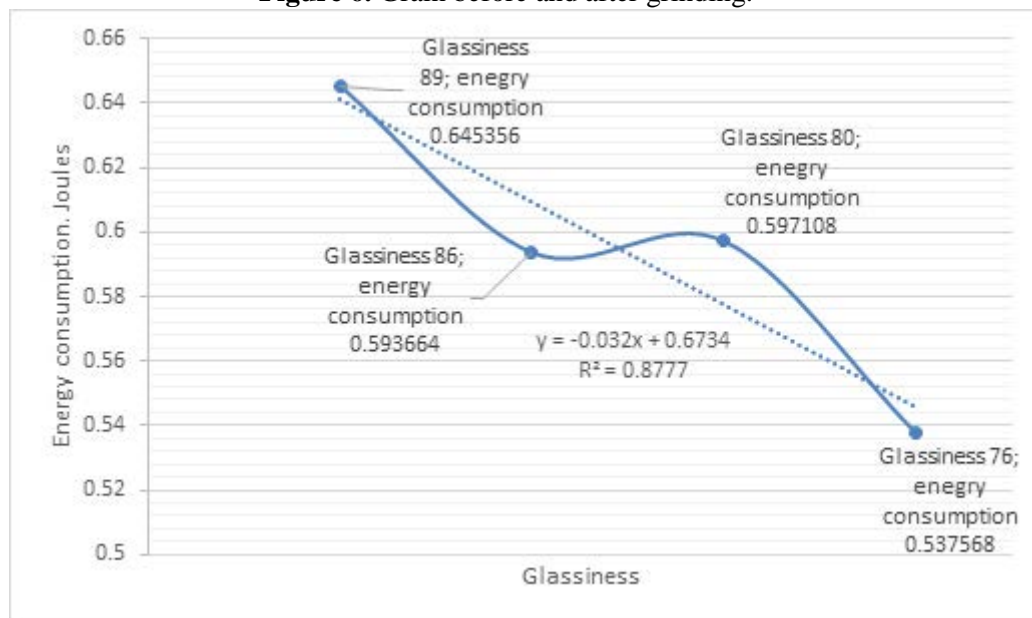
Thus, the characteristics of the rational operating mode of the pendulum deformer are the deviation of the pendulum deformer by an angle of  $40^\circ$ , the horizontal arrangement of the grain material, and its location along the center of the support surface.

The software in the beginning is being taught on different batches of grain with known parameters to study the glassiness. It can be concluded that when the glassiness decreases, the energy consumption for grain refinement decreases, proceeding from the studies on grain refinement (Figure 7) [6].





**Figure 6.** Grain before and after grinding.



**Figure 7.** Dependence of energy consumption on grinding grain from glassiness.

## 5. Conclusion

The result of the work was the development of a controller for the non-contact determination of the angle of the pendulum surface position in order to control the stepper motors and determine the energy consumption for grinding grain. The conducted laboratory tests using the software and hardware complex have shown that the energy consumption when grinding grain on a pendulum deformer is less than when grinding on a roller machine. Also the use of USB-cameras allows to measure the work of the pendulum deformer, and thanks to the "learning" of the program – to measure the glassiness of the grain without violating GOST.

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