Analysis of the size of shredded particles in a multi-disc grinder

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Abstract. The result of a shredding process should be a product of specific dimensions obtained with the consumption of the minimum amount of energy per unit of weight. There are several parameters that affect the efficiency and quality of the shredding process (including temperature and rotational speed). The article presents the station of a multi-disc grinder whose design is based on a computer with a control and measurement application developed in the LabVIEW environment, a CMOS camera, and a multi-functional DAQ device. The station makes it possible to look for optimum settings of the control system in order to obtain an appropriate particle size. The size of the shredded particles is justified by the requirements of the downstream process: extrusion in the case of plastics and digestibility in the case of biological materials.

1. The problem of materials shredding
Shredding of materials, even though it appears to be a simple process, is complex and requires knowledge of multiple fields of science, including design and operation of machinery, solid-state physics, chemistry, and mechanics [1–4]. At a time when high energy efficiency is mandatory, optimization of the energy consumption during the shredding process is of key importance. On the other hand, some characteristics of the product, such as moisture content and size of the shredded particles, as well as the temperature of the product during the shredding process, are also important [5, 6]. High temperature may have a negative impact on the quality characteristics of the product (e.g. content of nutrients in biological materials) and may even prevent achieving the appropriate final form of the product (plastics) [2, 6, 7].

In the research conducted so far by the authors, the sizes of the particles were determined after the experiment by placing the material in a vibrating sieve. As a result of operation of the sieve, particles whose size was smaller than the limit size of the analytical sieve were placed in a container and their total weight was determined; this made it possible to determine the percentage of particles of appropriate size. This method resulted in a significantly longer time required for the tests and, most of all, did not make it possible to trace the results of the tests in an ongoing manner. The station described herein is free from this negative characteristic.

2. Design of the multi-disc grinder station
There are many types of grinder designs, including crusher, knife, disk, and roller types, which are used depending on, among other things, the type of the input material [2].
A multi-disk grinder has several disks mounted coaxially, whereby some of the disks may be set on the main shaft and some on the rotating body. The disks have cylindrical openings and may differ by the number of the openings and their positions on the disk (figure 1).

![Figure 1. Example of grinder disks [1].](image)

The grinder in question has five disks, each with individually adjustable angular speed and direction of rotations. The grinder can be controlled from the level of the computer equipped with an application designed in the LabVIEW environment provided by National Instruments [8]. The control and measurement unit is the U6 device made by LabJack. The rotational speed is adjusted by frequency converters that communicate with the computer through a serial bus.

The block diagram of the shredding system is shown in figure 2 and the photograph of the entire station is in figure 3.

![Figure 2. Schematic diagram of the grinder' measurement and control system.](image)

As has been mentioned, the basic advantage of the station discussed herein is the possibility to measure the size of the particles in the course of the experiment.

The material in the hopper is fed into the main chamber and then the shredded particles of the material are forwarded to the vibrating feeder from which they fall into the illuminated measurement chamber (figure 2, figure 4). The image of the falling particles is recorded with the UI-1240SE-C-HQ color camera with resolution equal to 1.31 Mpix (1280 × 1024) and a Pentax lens and a set of lens distance rings. The software layer uses the Vision machine vision module of the LabVIEW environment, which enables cooperation with USB cameras [8, 9].
3. Measurement capability

For the camera field of vision equal to $25\, \text{mm} \times 20\, \text{mm}$, the measurement system provides resolution equal to $r = 0.02\, \text{mm/pixel}$.

The minimum diameter of the detected particle depends, among other things, on the parameters set during the experiments, which are available in the vision functions of the LabVIEW environment and which make it possible to eliminate the smallest objects and objects whose shape is significantly different from a round shape. Most input parameters of the program must be selected experimentally for the specific sample of the material.

The uncertainty of the particle measurement is due mostly to the resolution of the measurement system and to the calibration error. The calibration was performed after the measurement system has been assembled using a calibration grid with circular marks with the diameter of $l = 4\, \text{mm}$ located $1\, \text{cm}$ apart from each other. The accuracy with which the grid was made is equal to $\Delta l = 0.2\, \text{mm}$.

The component dependent on the calibration was calculated, assuming a rectangular distribution of probability, using the following formula [10]:

$$u_{\text{cal}}(D) = \Delta l / 2\sqrt{3}. \quad (1)$$
At the resolution of \( r = 0.02 \text{ mm/px} \), the standard uncertainty contributed by it is equal to:

\[
    u_{\text{res}}(D) = \frac{r}{2\sqrt{3}}
\]

also assuming a rectangular distribution.

The total measurement uncertainty is the geometric sum of uncertainties \( u_{\text{cal}} \) and \( u_{\text{res}} \):

\[
    u(D) = (u_{\text{cal}}^2(D) + u_{\text{res}}^2(D))^{1/2}
\]

and is equal to 0.06 mm. The expanded uncertainty, with the expansion coefficient \( k = 2 \), is equal to \( U(D) = 0.12 \text{ mm} \) [10].

An example of an image with recorded particle, described by a surface field in pixels, is shown in figure 5. If a shredded biomass product is intended to be used for energy-related purposes, it can be assumed that the diameter of 97% of the product should be smaller than 0.2 mm; in the case of products shredded for food-related purposes, the diameters of 0.8 mm to 1 mm are the most beneficial. The application of the grinder makes it possible to determine the percentage of particles in 15 intervals (classes) of diameters of up to 3 mm. There are professional particle size analyzers available in the market whose parameters are much better (e.g. a Fritsch analyzer with the measurement range of 0.08 \( \mu \text{m} \) to 2 mm); however, as in the sieve method, they can be used only after the shredding is completed. The station discussed herein makes it possible to trace the results of the experiment in a continuous manner and, if necessary, to immediately change the parameters of the process. What is important in the case of the station presented herein is that the cost of a separate analyzer is significantly higher than the expenses related to the construction of the measurement part of the grinder.

![Figure 5. Processed image from the camera.](image)

The test grinder station presented herein makes it possible to select optimum settings of rotational speed and rotation direction of individual disks so as to achieve the required characteristics of the product, taking into account the total power consumed by the motors. Any failures in the operation of any subsystem are indicated on the front panel of the application and the entire process is stopped. The result of operation of the computer application is an Excel file with the power consumption, torque, and rotational speed values recorded for the individual motors driving the disks and the number of the recognized objects for over ten diameter ranges. The results obtained in the process of shredding using the laboratory station will enable further analysis of the shredding process for different materials.

One of the outcomes of the research is the construction of a new station with an RPW precise grinder for biological materials in which the particle measurement method described herein is also used [6].
Figure 6. View of the control and measurement panel for analysis of the image of shredded particles.

Also, a control and measurement panel was built (figure 6) that includes visualization of particle measurement and the status of important process parameters, and a new system was designed for collection of shredded particles that includes pneumatic transport of biological material, which takes place when shredding is performed with a sub-precise grinder.

4. References

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