Testing and simulating the working conditions of an organic material shredders

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Abstract. The paper presents the results of works carried out by the authors on the design and operation of organic material shredders. It is a widely undertaken research program started many years ago, in recent months devoted to testing the operational wear of a selected shredder and product. Previous research has involved different grinder designs and different ways of disintegrating basic biological materials. In the following years, parameters for different shredded materials were selected for the selected type of knife shredder. After reaching the "most difficult" material for disintegration, the analysis of the design of the shredders and the selection of the system for that particular material was resumed. Tests of structural elements, crucial for the system durability, show the complexity of the grinding process conditions. The selection of key parameters and the simulation of their influence on the course of the process allowed for the development of the process model. Subsequent simulations using the developed model allow you to select the parameters of the shredder in an optimal way.

1. Introduction

The grinding of organic matter has always been a problem in the production process and a significant challenge for machine designers. There is a substantial lack of through descriptions and models for this process, moreover, for most of the products, the parameters for this process must be selected randomly [1-8]. Amongst different grinding processes, processing of grains is significantly more developed than the rest - grinding straw, wet materials, cheese, or yeast. This work addresses the problem of the use of a universal wide-chamber mill, intended for fine and very fine grinding of a wide range of products, especially where other grinding systems fail - when these are greasy, sticky products, sensitive to high temperatures, and also containing large amounts of fats (Figure 1.2).
Fig. 1. View of the shredder from the side of the grinding disc.

Fig. 2. View of the milling machine from the side of the grinding disc with the view of impact pins.
2. The characteristics of the needle milling machine operation

The grinding elements are impact pins (Fig. 2) mounted on two driven discs. Depending on the type of material to be shredded, the discs either counter-rotate or co-rotate. Very high relative speeds of the percussion elements allow for a very fine fragmentation, and the wide chamber prevents the residue of fragmented products from forming inside it [9-10]. The wide door allows easy access to the grinding system components and the chamber interior (Fig. 2).

Examples of products that can be ground using a needle milling machine:
• spices and plants, including those containing fat,
• jelly and thickening products, e.g. gelatines, casein, acacia, pectin’s,
• bakery rejects, including those with high amounts of fats,
• pigments for paints and food dyes, pesticides,
• chemical industry products: magnesium oxide, sodium phosphate, melamine, potassium sulphate and many others.

Additionally, inactive, fodder yeast with a humidity of max. 9% was ground in the investigated milling machine for the purposes of further investigation. The effect of the mill's work, i.e. the quality of the shredded material, is satisfactory and allows it to be transferred to the next stages of the product process. However, the durability of the mill is unsatisfactory, it is characterized by quick wear of the WD disc fingers and the bearings of the WB, rotating discs.

This relationship is strongly related to a certain stage of wear of the shredder fingers and the bearings [11-13]. The limit wear of the shredder fingers mainly means that there is a risk of its fragments getting into the food, but in this case, we are more concerned about it directly causing an excessive
increase in the vibrations of the system (Fig. 3). When the vibration energy limit is exceeded, the bearing rings experience phase changes in the bearing steel. The resulting change in the yield strength of the steel allows for sticking the rolling elements of the bearing with steel from the track (Fig. 4, 5).

Fig. 4. Track surface of the bearing ring.

Fig. 5. Worn rolling elements of the bearing.

Wear of the mill fingers causes unbalance of the rotating mass and changes in the nature of the grinding process, thus causing abrasive damage to the bearings.
3. Research on the dependence of the wear of the mill bearing on the wear of the shredder fingers

In order to determine the wear limit of the fingers, beyond which the bearings will be destroyed, an experiment was carried out to measure the energy of the milling machine. The weight of the new shredder fingers mounted on the disc was measured (Fig. 6). Subsequently, a vibration measurement was carried out, followed by a series of measurements, the last measurement before the process was stopped due to system wear.

After stopping the process, the used fingers were disassembled and weighed (Fig. 7). No unexpected damage was observed in the shredding chamber. The wear of the fingers was typically volumetric with a similar shape as presented in the previous analyses (Fig. 3).
Fig. 7. Weight distribution of the used grinder fingers: Average weight: 10.322 g, dev. std. 0.373 g, dev. std. avg. 0.028442 g, 2 x dev. std. avg. = 0.056884 g = 0.057 g, With 95% confidence level: 

\[(10.322 \pm 0.057) \text{ g}\]

To record the acceleration values, a measurement set was used, consisting of 2 IEPE piezoelectric accelerometers (measurement in the longitudinal and transverse axis), the PA 16000D / 8 conditioning system and the Handyscope HS4 measuring module with dedicated Multichannel software for a personal computer. Samples with a length of 1 second were recorded, with the sampling speed of 100 kS / s (Fig. 8).

Fig. 8. The set-up of the measuring system used for recording vibrations.
An application in the LabVIEW environment has been built for the analysis of measurement data. It makes it possible to determine the effective values of acceleration and velocity, and to determine the fundamental frequency and frequencies of the local maxima.

Fig. 9. Vibration measurement of the damaged grinding system.

The measured acceleration in the longitudinal axis is 20 m / s² (effective value), the acceleration in the transverse axis is 29 m / s² (effective value) (Fig. 9). The value of vibrations made it impossible to work further, moreover, the process was characterized by strong acoustic emission. When analysing the grinder wear model (1), it should be indicated that we are dealing with the relationship between the linear wear process of the fingers and the nonlinear wear process of the bearings. It can be assumed that after the finger wear exceeds 5%, the process conditions are unfavourable for the bearing arrangement and cause permanent damage to the bearings.

4. Conclusion
It is unacceptable for the wear of the grinding element to be only signalled by the destruction of the shaft bearings. Research has shown that 10% wear of the grinding fingers is destructive for the grinder and the grinding process. The results of the measurements indicated that the increase in vibrations occurs rapidly after exceeding the half of the service life, which may indicate wear within 5% of the weight of the fingers. Actions should be taken to make the fingers from a material more resistant to abrasion; and the possibility of changing the bearing arrangement to a more resistant to vibrations should be analysed.

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