INFLUENCE OF ROTARY GRAIN CRUSHER PARAMETERS ON QUALITY OF FINISHED PRODUCT

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Abstract. At present, modern hammer crushers are widely used for grinding grain, the technological process of which involves suction of the starting material, crushing and pumping the finished product into an intermediate container to separate feed streams. One of the basic working tools is a separating sieve, by means of which the material to be crushed obtains the required dimensions. The aim of the work was experimental finding of a relationship between the parameters of the separating sieve of the crusher and the quality parameters of the crushed grain. During the operation the sieve parameters are changing due to wear and deformation: the shape and size of the holes change, the thickness of the sieve decreases. Experimental studies have shown a significant impact of the changing parameters of the sieve upon the quality of the crushed grain. The obtained approximating formula shows the linear nature of the increase in the length of the holes of the separating sieve of the crusher depending on the processed grain mass with the value of the approximation reliability $R^2 = 0.96$. In order to maintain the quality of the finished product, it is necessary to take into account the change in the sieve parameters of the crusher and to replace the sieves in due time. In order to partly meet the requirements for the allowed values of the quality parameters of the grain crushed by the crusher of the discussed design, it is necessary to limit the maximum processed grain mass of the installed sieves to 149000-160000 kg, with the hole size being 10.96 ± 0.04 mm.

Keywords: crusher, grinding module, sieve, efficiency.

Introduction

One of the priority areas for increasing the productivity of animals is the use of technological equipment for feed preparation, ensuring perfect compliance with the zootechnical requirements [1]. The feed produced from the forage grain is an important source of nutrients for pigs and cattle. Before feeding the grain must be crushed or appropriately treated [2-5]. For grinding grain the agricultural producers widely use at present modern hammer crushers. The technological process of operation of the grain crushers includes suction of the raw material, its crushing, and pumping the finished product into an intermediate tank in order to separate the feed streams and the air-dust medium. In such crushers a separating sieve is installed in the crushing chamber. But in the open-type crushers the separating sieve is installed outside the crushing chamber, for example, in the mixer hopper [6]. The previous studies [7-9] showed a number of advantages and disadvantages of such grain crushers. The main advantages are: simplicity of the device and its operation, small mass-dimensional parameters, a possibility to change the disintegration degree. An essential disadvantage is that the design of the crusher and organisation of the working process does not allow the use of the most effective types of impact destruction. Therefore, when grinding grain in the crushers discussed, less efficient types of impact crushing of grain are used: the impact upon the sieve and the particle collision. The presence of an annular sieve in the grinding chamber leads to intensive wear of the working tools, as a result of which the quality parameters of the finished product deteriorate.

As the earlier studies and observation of the work of the considered crushers showed, the greatest impact upon the quality of the finished product is exerted by the annular separating sieve, which is subject to intensive wear. Besides, this increases the diameter of the holes, decreases the thickness of the sieve, and there appear cracks in the sieve, which can lead to its destruction. Timely replacement of the sieves can eliminate a decrease in the quality of the crushed grain and avoid emergency operation of the crusher. The aim of the work is experimental finding of a relationship between the parameters of the separating sieve of the crusher and the quality parameters of the crushed grain.

Materials and methods

To evaluate the efficiency of the closed-type and the open-type crushers, an analysis of the selected samples of the crushed grain was made under production conditions (Table 1). The following crushers were used: the closed-type crushers DKR-5D; the open-type crushers DB-5, and an experimental crusher [9]. The indicators used for the analysis that characterise the efficiency of the grain crushers were established according to the requirements of the Standard 9268-90 [10] and zootechnical requirements [6]:

P_3 – residue on a classifier sieve with a hole diameter of $3 \cdot 10^{-3}$ m, %;
P_p, – ratio of particles, smaller than 0.2 mm, in the finished product, %;
P_{wg} – ratio of whole grains, %;
d_{av} – grinding module or weight-averaged particle size of the final product, $m \cdot 10^{-3}$.

The grinding module or the weight-averaged particle size of the crushed grain was determined according to the formula [5]:

$$d_{av} = (0.5P_o + 1.5P_1 + 2.5P_2 + 3.5P_3)/100, \quad (1)$$

where P_0 – residue of particles on the tray of the classifier, %;
P_1, P_2, P_3 – residue of particles on the classifier sieves with the hole diameters of 1, 2, 3 m $\cdot$ 10^{-3}, respectively.

When conducting production studies, the DKR-5D rotor crusher was used, the schematic diagram of which is shown in Fig. 1.

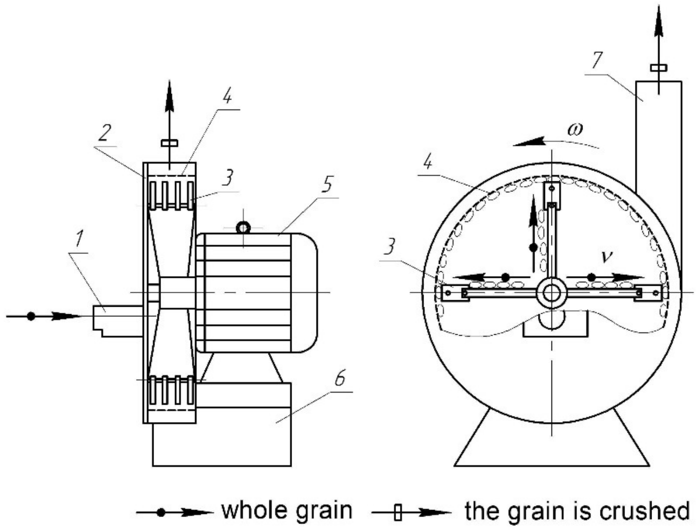

Fig. 1. **Schematic diagram of crusher:** 1 – suction pipe with a metal-stone trap; 2 – crushing chamber; 3 – crushing drum with pivotal hammers; 4 – separating sieve; 5 – electric motor; 6 – frame; 7 – discharge nozzle. 4 – separating sieve; 5 – electric motor; 6 – frame; 7 – pressure inlet

The grain crusher works in the following way. The initial material enters through a flexible air line and the suction nozzle 1, in which the solid admixtures settle, into the crushing chamber 2. With the help of the crushing drum 3 with pivotal hammers the grain is crushed and sieved through the separating sieve 4. The particles of grain that have not passed through the holes of the separating sieve are additionally disintegrated by the crushing drum 3. The crushed grain is moved further behind the sieve of the crushing chamber by the flow of air created by the crushing drum and the fan, through the pressure inlet into the intermediate tank.

Before the production studies all the hammers and the separating sieve of the crusher were replaced with new ones. During the research the processed grain mass of the crusher was recorded; samples of the crushed grain were taken; the dimensions of the sieve holes were measured; analysis of the crushed grain was made according to the standard [11]; the results were recorded in the observation log, and processing was performed.

Results and discussion

The results of the comparative analysis of the quality parameters of the samples crushed by the closed-type and the open-type crushers, as well as the allowed values of the indicators, are presented in Table 1. The quality analysis of the grain crushed by the closed-type crushers shows that only one of the four indicators corresponds to the allowed values, whereas the open-type crushers do not correspond only to one indicator. In order to increase the operating efficiency of the widespread closed-type grain crushers, it is necessary to conduct their modernisation or refinement work [8].

The grinding module or the weight-averaged particle size of the crushed grain was determined according to the formula [6]:

$$L = 6.5 \cdot 10^{-3} T_{g+} + 9.92 , \tag{2}$$

where L – length of the hole, m· 10^{-3};
T_g – processed grain mass of the crusher, kg· 10^3.

Table 1

Results of the sieve analysis of the crushed grain samples

Quality indicatorsof the crushed grain	Allowed values of the indicators for young cattle	Values of the indicators for crushers of the type:	
		closed	open
$P_{3,\ \%}$	not more than 10	0-12.40	1.90-4.70
P_p, %	not more than 2	5.35-28.4	4.30 -12.4
P_{wg}, %	not more than 0.3	0-0.99	0.17-0.18
d_{av},, m· 10^{-3}	1.0-1.8	0.89-1.61	1.50-1.60

Dependence of the change in the length of the sieve hole, revealed as a result of the research, upon the processed grain mass is shown in Table 2 and in Fig. 2.

Table 2

Dependence of the change in the length of the sieve hole upon the processed grain mass

Processed grain mass (T_g), kg· 10^3	Length of the hole (L), m· 10^{-3}	Relative extension, %
0	10.00	0
81.295	10.24	2.4
136.694	10.88	8.8
184.854	11.23	12.3
248.594	11.47	14.7

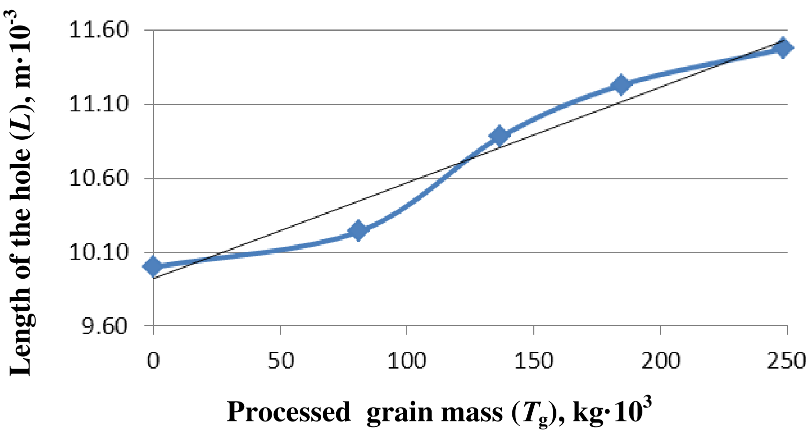

Fig.2. **Dependence of change in length of sieve hole upon processed grain mass**

Dependence of the quality indicators of the finished product upon the processed grain mass – in Table 3 and in Fig. 3.

The obtained approximating formula (2) shows the linear nature of the increase in the length of the holes of the separating sieve of the crusher depending upon the processed grain mass with a reliability value of approximation R^2 = 0.96.

Table 3

Dependence of the quality indicators of the finished product upon the processed grain mass of the crusher

Processed grain mass (T_g), kg·10^3	Ratio of whole grains (P_{wg}), %;	The residue of particles on the classifier sieves with the hole diameters of m·10^{-3}(P_3), %	Ratio of particles, smaller than 0.2 mm, in the finished product (P_p), %;	The grinding module or weight-averaged particle size of the final product (d_{av}), m·10^{-3}
0	1.40	6.36	22.18	1.38
81.295	1.56	6.79	17.26	1.41
136.694	2.75	9.77	13.41	1.56
184.854	2.92	13.16	5.05	1.91

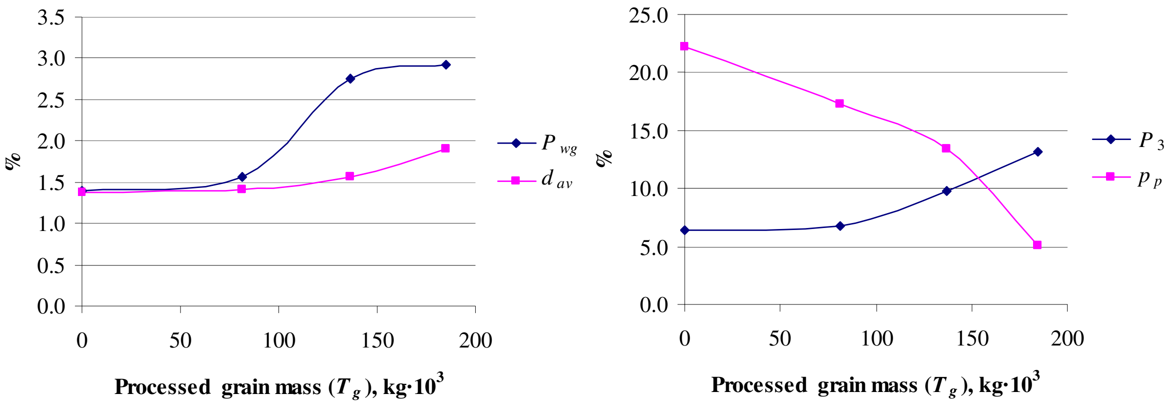

Fig. 3. **Dependence of quality indicators of crushed grain upon processed grain mass of crusher**

When comparing the values of the quality parameters of the crushed grain with the allowed parameters (Table 1), it is evident that the crusher does not meet the requirements, even with non-worn working tools, in the ratio of the whole grains and the particles smaller than 0.2 mm. Increasing the processed grain mass , the dimensions of the separating sieve holes increase, which reduces the quality characteristics of the crusher, in addition to the ratio of the particles with a size of less than 0.2 mm. It stands out that the ratio of the particles less than 0.2 mm diminishes with the processed grain mass increasing, although the other indicators are only going up. It should be noted that with the increase in the length of the hole, an increase in the clear opening of the sieve occurs; therefore, a great number of the big particles of grouts, as well as whole, not crushed grains, are removed from the hammer zone without falling under their crushing effect. Hence it follows that the crusher to be considered needs updating of the design and technological parameters.

If we replace the presented graphs with the approximating equations, found by means of MS Excel (trend line), we obtain the following dependencies (3-6):

the ratio of the whole grains upon the processed grain mass of the crusher

$$P_{\mathrm{wg}} = -2 \cdot 10^{-15} \cdot T_{\mathrm{g}}^{3} + 5 \cdot 10^{-10} \cdot T_{\mathrm{g}}^{3} - 3 \cdot 10^{-5} \cdot T_{g} + 1.395\,, \tag{3}$$

the grinding module upon the processed grain mass of the crusher

$$d_{\mathrm{av}} = 3 \cdot 10^{-11} \cdot T_{\mathrm{g}}^{2} - 2 \cdot 10^{-6} \cdot T_{\mathrm{g}} + 1.3816\,, \tag{4}$$

the ratio of the pulverised fraction upon the processed grain mass of the crusher

$$P_{\mathrm{p}} = -4 \cdot 10^{-10} \cdot T_{\mathrm{g}}^{2} - 2 \cdot 10^{-5} \cdot T_{\mathrm{g}} + 21.997\,, \tag{5}$$

the residue on the sieve with the hole diameter of 3 mm upon the processed grain mass of the crusher

$$P_3 = 3 \cdot 10^{-10} \cdot T_g^2 - 2 \cdot 10^{-5} \cdot T_g + 6.3221 . \quad (6)$$

Based on the results obtained, one can graphically or analytically solve the inverse problem and find extreme values of the processed grain mass and the length of the sieve hole, using the allowed values of the quality parameters of the final product. To obtain the average grinding module of 1.0-1.8 mm (Fig. 3), the maximum processed grain mass is 156000 ± 6500 kg, with the hole size being 10.96 ± 0.04 mm. Increasing the processed grain mass , the residue of P_3 also exceeds 10 %, when grinding 149000 ± 4900 kg of grain. The use of such a solution will allow the sieve to be replaced in a timely manner on the crusher in question.

Conclusions

1. The closed-type crushers generally do not meet the zootechnical requirements and need to improve the quality of the final product.
2. The obtained approximating formula shows the linear nature of the increase in the length of the holes of the separating sieve of the crusher depending on the processed grain mass with the value of the approximation reliability $R^2 = 0.96$.
3. On the basis of the obtained results, it is possible to graphically or analytically find the extreme values of the processed grain mass and the length of the sieve hole, using the allowed values of the quality parameters of the final product.
4. In order to partly meet the requirements for the allowed values of the quality parameters of the grain crushed by the crusher of the discussed design, it is necessary to limit the maximum processed grain mass of the installed sieves to 149000-160000 kg, with the hole size being 10.96 ± 0.04 mm.

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