Differentiated threshing of seed corn with minimal grain crushing

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Abstract. To increase the efficiency of the process of seed corn threshing in stationary conditions, an axial-rotor thresher with a pneumoadaptive deck is proposed and constructed, which allows differentiating the threshing forces in the threshing chamber. The index of unthreshed seeds loss on cobs and free grain loss, defined in previous studies, allowed one to establish a rational interval of the rotor speed of the proposed thresher, which is 150 ... 170 min⁻¹. The rationality of this interval was checked by the grain-crushing index, which is an indicator of the effective use of the threshing force of the impact. Experimental studies of this indicator were carried out in the range of rational rotor rotation frequencies (150 ... 170 min⁻¹), as well as to study the regularity of grain crushing changes, additional studies were carried out at a frequency of 190 min⁻¹. It was found that at rotor speed 170 min⁻¹ grain crushing is 1.4%, and at 190 min⁻¹ it significantly exceeds the permissible value. A mathematical expression is proposed that shows the dependence of the force of the working bodies of the pneumoadaptive deck hitting the grain on the rotor speed, confirming the correctness of choosing a rational interval of the rotor speed. Research results indicate that when the rotor speed does not exceed 170 min⁻¹, the stresses in the grain body under the impact of the working bodies do not reach the maximum permissible value. At the same time, the grain retains its integrity, and the crushing index remains minimal.

1. Introduction
Increasing the production of high-quality grain is one of the most important tasks that the FAO solves to improve agricultural productivity and sustainability. Among grain crops, a steady increase in production is typical of corn, since the yield potential of this crop has not been exhausted yet. Increasing corn grain production requires improving of mechanized harvesting technologies. In this regard, the research is aimed at developing an experimental database on the mechanized technology of differentiated threshing of seed corn cobs, which allows one, by minimizing grain damage, to preserve its yield. Implementation of differentiated threshing technology requires the creation of highly efficient threshing machines for primary corn seed production [1, 2].

2. Materials and methods
The experiments were carried out with dent corn varieties CADR 267 MV. The grain humidity in the threshed cobs was within 12...15 % We used generally accepted methods of ranking and selecting the active factors of the experiment, as well as existing methods of planning and carrying out one-factor experiments in the laboratory. The results were statistically processed using the program
3. The study of the process of threshing corn

From the point of view of the quality of threshing, the efficiency of the thresher of seed corn cobs is characterized by the following indicators: unthreshed seeds loss on cobs and free grain loss index, macro- and micro damages, as well as grain crushing index. Among the variety of types of grain damage, crushing is distinguished into a separate group. Technical conditions for the production of threshing equipment established that this index should not exceed 2%. Crushing is an indicator of the differentiation of the threshing force of the impact in the threshing chamber. If the impact of the working body causes stress in the grain body above the maximum permissible value, then the grain is broken into parts, this phenomenon is called grain crushing during threshing.

To test the hypothesis of increasing the efficiency of the seed corn threshing process by differentiating the threshing forces with a pneumatic adaptive deck, an experimental model of a thresher was constructed (Figures 1 and 2). A detailed description of the proposed threshing machine is provided in the source [4].

![Figure 1. General view of the axial-rotary thresher with the pneumatic adaptive deck (RU 171115; RU 196681; UA 18265; UA 30366; UA 86546).](image)

The work [5] shows the results of an experimental study of the unthreshed seeds loss on cobs and free grain loss index in the proposed design of the threshing machine. The research data showed that the rational interval of the rotor speed is within 150...170 min⁻¹, and feed rate – 0.8...1.1 kg·s⁻¹, which allows one to provide unthreshed seeds loss on cobs index up to 1.5%, and free grain loss index is no more than 1% [5]. The next stage of the study is to check the efficiency of the threshing machine on an index of crushing.

It is obvious that this index is related to the value of the rotor speed, so experimental studies were carried out not only in the rational range of rotor rotation frequencies, 150...170 min⁻¹, but also at an extreme frequency of 190 min⁻¹. This made it possible to see the patterns of change in the crushing index more fully.

Experimental studies were based on the methods described in [5-7] and included the following stages:

- preparing the pneumatic adaptive deck of the thresher for the experiment;
- installation and control the desired rotor speed;
- the formation of the necessary masses of unthreshed cobs;
- the submission of the masses of the cobs into the threshing machine;
• sampling from the threshed grain silo;
• separation of the selected samples into whole and crushed grains and formation of the corresponding masses;
• weighing the obtained masses and comparing them;
• carrying out statistical processing of research results;
• graphical interpretation and analysis of research results.

Figure 2. Design and technological scheme of the axial-rotary thresher with pneumatic adaptive deck, devices for loading and oriented feed of cobs in the thresher (RU 171115; RU 196681; UA 18265; UA 30366; UA 86546).

Diagrams of the results of the study of the grain-crushing index in the threshing machine of the proposed design are presented in Figure 3.

The diagrams show that at the lower limit of the rational interval of the rotor speed (150 min\(^{-1}\)), the grain crushing index is 1%, and at the upper limit of the rational range of the rotor speed (170 min\(^{-1}\)) - does not exceed the acceptable values and is 1.4%, which fully meets the requirements for selective threshing equipment.

At a rotor speed of 190 min\(^{-1}\), the thresher worked non-stop, but the crushing index increased almost twice. This is due to the fact that the impact force of the working body on the grain in the cob begins to exceed the maximum allowable value. As a result, the system of natural protection of the grain in the cob from mechanical influences is overcome, and in the zone of contact with the working parts, a part of the endosperm is separated from the grain. The diagrams show that at a rotor frequency rotation of 190 min\(^{-1}\), the grain crushing index is 3%, which corresponds to the requirements for feed corn threshers. This indicates the possibility of using a thresher for threshing corn for all purposes: seed, food and feed grain [8].

Based on the Hertz theory [9], a formula was developed for calculating the impact force on the grain by the working bodies of the pneumoadaptive deck in the thresher of the proposed design:

\[
P = \Delta \cdot \left(1 - 1.6 \cdot \frac{E_2^{2/3} \cdot R_2^{1/3}}{E_i^{2/3} \cdot R_i^{1/3}}\right) \cdot \left(\frac{4 \cdot \sqrt{R_i^3}}{3 \cdot \pi \cdot (k_1 + k_2)}\right)^{2/5} \cdot \left(\frac{5 \cdot V^2}{4 \cdot \frac{m_i + m_2}{m_1 \cdot m_2}}\right)^{3/5}
\]

(1)

where \(P\) - force of impact on the grain by the working parts of the pneumatic adaptive deck, N;
\(\Delta\) - degree of differentiation of the force of a direct central impact, by means of a pneumoadaptive deck;
$E_1$ and $E_2$ - elastic moduli of contacting bodies, Pa;
$R_1$ and $R_2$ - radii of curvature of contacting bodies in the contact area, m;
$k_1$ and $k_2$ - respectively, the coefficients that depend on the Young's modulus and the Poisson's ratio of the contacting bodies;
$V$ - speed of the rotor blade at the moment of impact, m·s$^{-1}$;
$m_1$ and $m_2$ - the mass of the contacting bodies, kg.

Figure 3. Diagrams of the results of the study of the grain crushing index at a fixed rotor speed and a feed of 1 kg·s$^{-1}$: a – n=150 min$^{-1}$; b – n=170 min$^{-1}$; c – n=190 min$^{-1}$.
The calculation performed using this formula allowed one to create a graphical dependence of the impact force on the grain by the working parts of the pneumoadaptive deck on the rotor speed in Figure 4.

According to the results of studies described in [1, 2, 10], the maximum impact value on corn grain is 680.2 N.

The calculated graphical dependence shows that at 170 min⁻¹ the maximum value of the impact on the grain is 620 N, which corresponds to the norm, and an increase in the rotor speed to 190 min⁻¹ leads to a significant excess of the maximum permissible value of the impact force. This explains the experimentally obtained doubling of the value of the crushing index at an extreme rotor frequency rotation of 190 min⁻¹. Approximation of the calculated data shows the power dependence of the impact force on the grain by the working parts of the pneumatic adaptive deck on the rotor speed.

![Figure 4](image.png)

**Figure 4.** Calculated graphic dependence of the impact force on the grain by the working part of the pneumoadaptive deck on the rotor speed.

Therefore, the crushing index confirms the previously selected rational frequency range of rotation rotor 150 ... 170 min⁻¹. The entire set of research results is the foundation for further exploratory studies of the efficiency of the threshing machine of the proposed design estimated by the index of macro- and micro-damages of the grain.

The results of the calculation confirm this scientifically based assumption.

4. Conclusion

The use of an axial-rotary thresher of seed corn cobs with a pneumoadaptive deck allows differentiating the impact force in the threshing chamber, so this design is promising, and its further research is advisable from a scientific point of view.

Going beyond the rational range of rotor speed experimentally showed the efficiency of the threshing machine at a frequency of 190 min⁻¹. At the same time, the grain crushing rate exceeded the permissible value set for seed corn, but is within the acceptable limits for threshing feed corn. This indicates the possibility of using a thresher for threshing corn for all purposes: seed, food and feed grains.

The experimentally obtained results of the crushing index of 1 ... 1.4% correspond to the generally accepted regulatory requirements established by the technical conditions for the production of threshing equipment.

The calculation of the impact force on the grain by the working parts of the pneumoadaptive deck confirms the experimentally obtained boundaries of the rational interval of the rotor speed.

The results of the research allow to plan and implement an experiment to study the influence of structural and technological parameters of the proposed threshing machine on the index of macro-and
micro damages of grain. The entire set of experimental data opens up the prospect of creating a highly effective technology of differentiated threshing and technical means for its implementation in practice.

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