Theoretical determination of the probability of a particle passing through an oblong opening of a sieve of grain cleaning machines for cleaning agricultural crops

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Abstract. The work of produced domestic grain cleaning machines is based on the reciprocating motion of the sieve mills. The increase in the productivity of such machines by traditional methods has exhausted itself. Therefore, agricultural enterprises of the country of various forms of ownership need high-performance innovative grain cleaning machines for post-harvest grain processing. The article studies the various methods and solutions that affect the intensity of the grain separation process and increase the qualitative and quantitative indicators of the operation of grain cleaning machines. According to the performed theoretical studies, the completeness of separation on the surface of the sieve depends on the probability of the passage of the grain through the oblong hole of the flat sieve, located at an angle, when interacting with the long edge, performing reciprocating oscillations. It is theoretically determined that in the range \( \alpha \) from 0 to 20° the probability of the passage of a particle increases from 0.315 to 0.548 or by 1.7 times. At the same time, as shown by the production check of the operation of the sieves of the proposed design, the productivity of the grain cleaning machine increased by 23 %, and the quality of cleaning the grain mixture meets the agrotechnical requirements.

1. Introduction

The grain heap coming from the combines consists of the grain of the harvested crop and various impurities. Their separation is carried out on grain cleaning machines based on the difference in the physical and mechanical properties of the grain material. The main task of post-harvest processing is to obtain grain to the required conditions, depending on the purpose (feed, food, or seed), which are regulated by state standards.

The solution to this problem is achieved by cleaning, sorting, and drying. It is known that the work of mass-produced domestic grain cleaning machines is mainly based on the reciprocating movement of sieve mills. The increase in the productivity of such machines by traditional methods, is no longer relevant. It is necessary to continue the search for the development and creation of innovative technologies and technical means for post-harvest grain processing. Agricultural enterprises of the country of various forms of ownership need and need such high-performance grain cleaning machines.

2. Results

There are known various methods and ways to solve this important national problem.
For example, a sieve mill of a grain cleaning machine that makes circular movements. It has been determined that the separation process improves at the angle of inclination of the edge of the sieve holes $\beta = 45^\circ$, the frequency of sieve vibrations $n = 110 \text{ min}^{-1}$, the amplitude of the sieve vibrations $A = 0.09 \text{ m}$, the angle of the transverse inclination of the sieve $\alpha_p = 1.5^\circ…2.5^\circ$. It was found that with such parameters and operating modes, the orientation of the caryopsis concerning the sieve holes changes several times faster than with the reciprocating motion. At the same time, it is noted that the throughput increases and the quality of cleaning the grain mixture meets the agrotechnical requirements [1–4].

Known are the results of a study of the operation of the sieve of the grain cleaning machine, located in such a way that the direction of the long crosspieces of the sieve coincides with the direction of vibrations and is perpendicular to the direction of grain movement. As a result of the experiments, the most significant factors influencing the completeness of grain separation from the parameters of a flat sieve performing transverse vibrations were determined and substantiated: the value of the specific load $(G) = 0.335…0.838 \text{ kg/(m}^2\text{‧s})$; sieve pitch angle $(a) = 10…16^\circ$; sieve vibration amplitude $(R) = (7.25…9.25) \times 10^{-3} \text{ m}$; sieve vibration frequency $(n) = 450…550 \text{ min}^{-1}$ [5].

This article presents the theoretical definition of the probability of the passage of a weevil through an oblong hole of the sieve, located at an angle.

It is known that in most grain cleaning machines, the standard sieve has oblong holes located with the long side in the direction of the longitudinal axis of the sieve, which coincides with the direction of the grain flow.

Entering the sieve, the particles of the grain heap are randomly arranged on it. Moreover, two situations are possible. First, when the weevil enters the area of the hole, then at a certain position of the particle relative to the hole, it can pass through the hole. This situation has been thoroughly considered and studied [6, 7].

The second situation is when the weevil hits the jumper. In this case, considering longitudinal vibrations of the sieve, the relative movement of the weevil will be parallel to the longitudinal edges of the holes and, if the center of gravity of the weevil is located on the area of the bridge, then it cannot get into the zone of the hole. Consequently, the particles located on the bridges do not participate in the separation process. Their entry into the zone of holes is possible as a result of a random process of interaction with other particles or in the case of a special sieve design, for example, with bridges having a cross-section in the form of a triangle or a circle.

Thus, for the particle to be able to pass through the opening of the sieve, it must be in the zone of the opening and be located relative to the edges of the opening in a certain way. Assuming these events to be independent, the probability of a particle passing through the holes of the sieve will be as follows:

$$P = P_r \cdot P_e$$

where $P$ is the probability of a particle passing through the sieve opening;

$P_r$ – the probability of the "through" arrangement of the particle on the edges of the hole;

$P_e$ – the probability of particle interaction with the edges of the hole, due to the trajectory of the particle on the bridge.

To determine the probability that when the particle moves in the direction of the longitudinal axis of the sieve, it will meet the longitudinal edge of the hole located at an angle to the direction of grain movement, the study uses the design scheme (Fig. 1). This figure shows a fragment of a sieve consisting of one hole and one crosspiece.

The position of the weevil is taken as such when the long axis of the weevil is parallel to the edge of the hole (2). The validity of this assumption is confirmed by the results of the analysis of the statistical characteristics of the distribution of grains on the sieve [8, 9], since the mathematical expectation of the random variable $M_\gamma$ is approximately equal to the arithmetic mean of the observed value $\gamma_{av}$ and is: $M_\gamma = 1.269^\circ \approx \gamma_{av} \approx 0$. 

\[2\]
To determine the probability $P_{\alpha'}$ the study uses the ratio of the elementary area of the $ABB'A'$ sieve (Fig. 1) formed by the area of one hole and the area of one bridge and a part of the elementary area on which either the particle is in the area of the hole in the through position, or from which it can be in the through position when moving along the bulkhead in the direction of the hole edge.

If $0 \leq \alpha' \leq \arctg \frac{h_l}{l}$, where $h_l$ is the width of the lintel, $l$ is the length of the hole; then the geometric relationships of the scheme in Figure 1 are as follows:

$$P_{\alpha} = \frac{S_{ABDC} + S_{CDK}}{S_{AB'B'A'}} \quad (2)$$

after transformations:

$$P_{\alpha} = \frac{h_0}{h_0 + h_l} + \frac{l \cdot \tan \{\alpha'\}}{2(h_0 + h_l)} \quad (3)$$

Figure 1. Calculation scheme for determining $P_{\alpha'}$. The arrow indicates the direction of movement of the particle.

If $\arctg \frac{h_l}{l} < \alpha' \leq \frac{\pi}{2}$, then from the geometric relationships in Figure 1 we write:

$$P_{\alpha'} = 1 - \frac{S_{BB'F}}{S_{AB'B'A'}}$$

after transformations:

$$P_{\alpha'} = 1 - \frac{h_l^2 \cdot \cot \alpha'}{2 \cdot l \cdot (h_0 + h_l)} \quad (4)$$

and in the end:
\[ P_{\alpha'} = \begin{cases} \frac{h_o}{h_o + h_l} + \frac{l}{2} \cdot \tan \left( \frac{\alpha'}{2} \right) & \text{at } 0 \leq \alpha' \leq \arctan \frac{h_l}{l} - 1 - \frac{h_l^2 \cdot \cot \left( \frac{\alpha'}{2} \right)}{2 \cdot l \cdot (h_o + h_l)} \text{ at } \arctan \frac{h_l}{l} < \alpha' \leq \frac{\pi}{2} \end{cases} \quad (5) \]

For a quantitative assessment of the dependence of the probability of interaction of a particle with the edges of the oblong hole of the sieve on the angle of inclination of the hole to the longitudinal axis of the sieve according to equation (5), calculations were performed. The calculation results are presented in Table 1.

**Table 1. Probability \( P_{\alpha'} \) depending on the angle of the hole location \( \alpha' \)**

| \( \alpha', \text{ deg.} \) | 0   | 2.5 | 5   | 10  | 20  | 30  | 50  | 70  | 90  |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \( P_{\alpha'} \)          | 0.468 | 0.59 | 0.614 | –- | –- | –- | –- | –- | –- |
|                            | 0.62 | 0.813 | 0.91 | 0.943 | 0.973 | 0.988 | 1.0 |

The probability of \( P_{\alpha'} \) was calculated with the initial values: for a sieve with a hole size of 2.2 × 20 mm and a lintel width of 2.5 mm (\( h_o=2.2 \text{ mm, } h_l=2.5 \text{ mm, } l=20 \text{ mm} \)); for a weevil with dimensions \( a=5.2 \text{ mm, } b=2.1 \text{ mm and surface curvature radii } R_1=2.5 \text{ mm and } R_2=0.7 \text{ mm} \).

According to the results of calculations using equation (2), the dependence \( P=f(\alpha') \), was obtained, which is shown in Figure 2.

**Figure 2.** Dependence of the probability of a particle passing through the sieve opening on the opening angle

As can be seen from the graph, the angle of inclination of the sieve holes to the longitudinal axis increases the probability of particle passage into the sieve hole. The greatest probability increases at small angles of inclination of the holes. In the range \( \alpha' \) from 0 to 20° the probability of the passage of a particle increases from 0.315 to 0.548, that is, 1.7 times.

### 3. Conclusion

A production check of the operation of the sieves of the proposed design showed an increase in productivity by 23 % due to an increase in the probability of particle passage into the hole by 1.7 times at a hole edge angle of 20°. The quality of cleaning the grain mixture meets the agrotechnical requirements [8].

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