Study of the operation of a combine harvester cleaning system with a sieve screw separator in the conditions of operation on slopes

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Abstract. The article presents the results of studies of a cleaning system with a sieve screw separator in operation conditions of a combine harvester on slopes. The grain heap in the proposed cleaning system is moved by screws, which ensures uniform feeding of the grain heap to the upper sieve with longitudinal tilts of the combine. Autonomous operation of the screws reduces the uneven distribution of grain heaps across the width at the beginning of the upper sieve of the cleaning system. Preliminary separation of grain reduces the grain flow to the upper sieve by more than 60%. Laboratory studies have shown a decrease in grain loss with a transverse tilt of the combine of 8 degrees from 1.17% in the compared treatment system to 0.75% in the treatment system with a sieve screw separator. An additional reduction in grain losses was achieved by installing longitudinal partitions with a height of 0.13 m on the upper sieve, preventing the grain heap from shifting sideways on the upper sieve. The theoretical coefficient of variation in the grain heap layer thickness at the end of the upper sieve is 0.18. Grain losses in the proposed cleaning system, calculated by the mathematical model of separation, amounted to 0.14%, which is 8 times lower than the compared cleaning system.

1. Introduction.
The grain heap in the combine cleaning system is in a fluidized state due to sieve vibrations and exposure to airflow. When the combine moves up or down the slope, the speed of the grain heap increases or decreases, respectively. With a lateral tilt of the combine, the grain heap is shifted to the sidewall. This leads to deterioration of the cleaning system quality and the lateral tilt of the combine leads to increasing grain losses [1, 2]. Stabilization of the upper sieve position in two planes relative to the horizon [3, 4] provides a reduction in grain losses, while the uneven feeding of grain heaps to the upper sieve reduces the efficiency of the cleaning system. Therefore, the cleaning system of the hillside combine harvester should provide not only stabilization of the distribution of the grain heap on the upper sieve but also a uniform feed of the grain heap. One of the structural and technological solutions for the combine harvester cleaning system in the hillside operating conditions is the combination of preliminary separation, uniform feeding and distribution of grain heaps on the upper sieve of the cleaning system. The article aims to study the operation of a cleaning system with a sieve screw separator in the conditions of operating a combine harvester on slopes.

2. Object of study.
The object of research is the separation of grain heaps in the cleaning system, including a sieve screw separator [4] and an air-sieve cleaning system.

The sieve screw separator (figure 1) is intended for preliminary separation of a grain heap. The sieve screw separator is installed instead of the shaking board and contains augers 1 with blades, a wavelike sieve 2 and a shortened shaking board 3. The centrifugal fan 4 contains an additional nozzle. The separation of the grain heap in the considered cleaning system occurs due to the influence of the airflow and the blades when moving the grain heap on the sieve.

![Figure 1. The cleaning system with a sieve screw separator.](image)

3. Research methods.

The study of grain separation in the proposed cleaning system was performed using comparative laboratory tests and mathematical modeling.

In theoretical studies, the grain loss after the cleaning system \( P(\%) \) was determined by the separation model [5], which for the studied cleaning system has the following form:

\[
P = 100 \left[ \frac{k}{i=0} \exp \left( -\mu_p \cdot \Delta x \cdot \exp(\Delta V_k \cdot i - V_{hn}) \right) \right].
\]

Where

\( i \) is the number of the current section of the grain heap along the length of the upper sieve;

\( k \) is the number of \( \Delta x \)-long sections along the length of the upper sieve;

\( \mu_p \) is the separation coefficient of the grain heap;

\( V_{hn} \) is coefficient of variation of grain heap layer thickness at the beginning of the sieve;

\( \Delta V_k \) is the step of changing of layer thickness variation coefficient along the sieve length.

The separation coefficient \( \Delta V_k \) was determined by the formula:

\[
\Delta V_k = \frac{V_{hn} - V_{hk}}{k},
\]

\( V_{hk} \) is the coefficient of variation of the layer thickness at the end of the sieve.

The separation coefficient \( \mu_p \) depends on the separation coefficient in the basic cleaning system and on the thickness of the grain heap layer in the cleaning under examination. In the adopted separation model, the parameter \( \mu_p \) is set equal to the shift of the grain heap on the upper sieve in one oscillation [5]. For one oscillation of the sieve, the grain heap moves over a distance \( \Delta x \), and the coefficient of variation changes by value.

The coefficient of variation at the beginning of the upper sieve depends on the operation of devices installed in front of the upper sieve of the cleaning system. In the studied cleaning system it depends on the operation of the sieve screw separator. The heap variation coefficients were determined experimentally using grain heap samplers and theoretically according to the developed method [5].

The experiments were carried out in a laboratory setup (figure 2). When examining the operation of experimental cleaning, a sieve screw separator was installed instead of the shaking board, containing four augers with right hand and left hand screws, installed alternately.
Figure 2. Scheme of the laboratory setup: side view (a); cross section of a sieve screw separator (b); conveyor feeders (1); sieve screw separator (2); shaking board (3); oscillatory drive mechanism (4); fan (5); upper sieve with longitudinal partitions (6); lower sieve (7); containers for collecting separated materials (8); auger (9); sieve (10).

The comparison was carried out with a basic cleaning system containing a shaking board, an upper sieve, a lower sieve and a centrifugal fan. The experiments were carried out on wheat heap with a moisture content of 10 to 12% and a content of straw impurities of 30%. Design and technological parameters of a laboratory setup with a sieve screw separator: pitch of sieve screw separator blades - 100 mm; blade width - 60 mm; screw rotation speed - 330 rpm, sieve holes diameter - 12 mm; fan impeller rotation speed - 690 rpm; the gaps between the fins of the upper and lower sieves are 13.5 mm and 9 mm, respectively. Qualitative indicators of the operation of the cleaning system were determined — grain loss \( P \) and the content of impurities in grain \( Z \).

4. Results and Discussion.

The displacement of the grain heap on the upper sieve with the lateral tilt of the combine leads to a change in the distribution of the grain heap on the upper sieve. Basic cleaning parameters: two longitudinal partitions 0.05 m high were installed on the shaking board; three partitions 0.05 m high are installed on the upper sieve; coefficient of variation at the beginning of the upper sieve \( V_{hn} = 0.46 \); at the end of the upper sieve \( V_{hk} = 0.52 \). The sideways shift of the grain heap on the upper sieve leads to an increase in grain losses (figure 3).

It was found that with a transverse roll of 8° \( (\alpha) \), grain losses of 0.5% were observed when feeding grain heaps of 1.6 kg / s \( (q) \), and when feeding 2.9 kg / s, grain losses amounted to 1.17%. The theoretical value of grain losses calculated by the formula (1) equals \( P = 1.25\% \).

In a cleaning system with a sieve screw separator, screw conveyors operate autonomously, transporting and separating grain heaps. This leads, firstly, to a decrease in the load on the upper sieve (up to 40% of the total grain weight comes onto the sieve), and secondly, the distribution of the grain heap is improved - the coefficient of variation at the beginning of the upper sieve is \( V_{hn} = 0.24 \). However, in the cleaning system of the scheme under consideration, the grain heap is shifted sideways on the upper sieve towards the slope, which causes an increase in the coefficient of variation by the end of the sieve to 0.52, which explains the high level of grain loss. When feeding a grain heap of 2.9 kg / s, the grain loss was 0.75% (figure 4).
The shift of the grain heap sideways towards the slope can be prevented by installing longitudinal partitions on the upper sieve. Since the sieve screw separator consists of four screws, it is advisable to install three longitudinal partitions on the upper sieve, dividing the upper sieve into four parts. Figure 5 shows the results of calculating the grain heap distribution at the end of the upper sieve, provided that at the beginning of the upper sieve the grain heap is fed uniformly across width. The data were obtained according to the developed method [6]. To avoid the redistribution of grain heaps on the upper sieve, the height of the partitions should be at least 0.13 m.

Therefore, one of the technical solutions of a combine harvester with a sieve screw separator is the use of four longitudinal partitions 0.13 m high on the upper sieve. To feed the grain heap to the upper sieve at a rate of 2.9 kg/s and with a lateral tilt angle of 8°, the coefficient of variation at the beginning of the sieve is 0.24, and at the end of the sieve 0.18.

The grain loss of the proposed cleaning system was determined by the formula (1). The calculation was carried out with a length of the upper sieve of 1.3 m, a grain separation coefficient of 5.1 m \(^{-1}\). The estimated value of grain losses is 0.14%, which is 5 times lower than the cleaning system with a sieve screw separator and 8 times lower than the basic cleaning system.

5. Conclusion
The cleaning system with a sieve screw separator containing four screws and three longitudinal partitions 0.13 m high mounted on the upper sieve is proposed. Loss of grain in the proposed cleaning system is reduced eightfold in comparison with the basic cleaning system.

References

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