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Theoretical Background for Combination of Sieves of Combine Harvester Cleaning System

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Abstract. The study was carried out in order to substantiate the development of a combination of sieves for the cleaning system of a combine harvester. The research is based on the general-logical method and mathematical analysis. It is shown that in the process of separation of a grain heap in the cleaning system of a combine harvester, the effect of an air flow on a given material flow is formed. In the course of the study, analytical dependences are obtained that characterize the change in the displacement of the grain heap layer on the cleaning sieve of the combine harvester in both horizontal and vertical directions relative to the sieve from the speed of the air flow. The relationship between the height of the grain heap layer on the sieve and the air flow rate, as well as between the delivery of the grain heap to the sieve and the air flow rate of the combine harvester cleaning system is disclosed. The systems of equations are shown up that characterize the change in the height of the grain heap layer on the sieve depending on the sieve type and the air flow rate of the combine harvester cleaning system. Graphical interpretation of the obtained regularities which reveal the nature of the change in the height of the grain heap layer on the sieve depending on its type and air flow rate, is presented.

INTRODUCTION

The grain heap entering the sieves of the cleaning system of the combine harvester is a mixture of components (Figure 1) [1–6] with different wind resistance ratios.

FIGURE 1. Grain heap entering the sieves of the combine harvester cleaning system.

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For better separation of caryopses (seeds of agricultural crops) from this mixture, it is exposed to technological influence from the air [3, 7, 8-11]. Process air provides loosening of the grain heap plant material, that is, a spatial lattice is formed through which the caryopses (hereinafter referred to as grain) move as a component of the mixture to the surface of the sieve for subsequent passage through the holes. The presence of the sieve surface, process air and grain heap in the cleaning system of the combine harvester leads to the formation of grain separation process, which is characterized by the complexity of its course and requires further research.

The research is carried out **in order to** identify new patterns that characterize grain separation process in the combine harvester cleaning system. The study is based on the general-logical method and mathematical analysis.

RESULTS AND THEIR DISCUSSION

With the interaction of three components (sieve, process air and grain heap) of the separation process of the combine harvester cleaning system, in particular [12, 13], $R = m \cdot k_p \cdot \Delta U^2$ – the air flow force is formed, where m – product mass; k_p – reduced wind resistance ratio of the grain heap as a kind of a mixture; ΔU^2 – rate of air blowing of the grain heap in the longitudinal direction relative to the sieve. Thus, in [13], it is noted that ΔU can be determined by the following expression:

$$\Delta U = U_v + \omega \cdot r \cdot cos(\upsilon) \cdot sin(\omega \cdot t) \cdot cos(j - \beta) - \dot{x} \cdot cos\,(j - \delta_1)\ , \quad (1)$$

where ΔU – air flow rate, m/sec.;

ω – cyclic vibration frequency;

r – sieve vibration amplitude, m;

ν – roll of the combine harvester cleaning system sieve;

t – time, sec.;

β – vibration direction angle, deg.;

δ_1 – angle of inclination of the comb surface relative to the horizon, deg.

Expression (1) contains the parameter U_V – air flow rate, which should exceed the critical speed (terminal velocity) U_{KR} of those components of the grain heap that are removed outside the combine harvester, and the grain should be left on the sieve surface. Therefore,

$$U_v = \alpha \cdot U_{kr}\ , \quad (2)$$

where α – coefficient characterizing the geometric parameters of the heap components.

Based on expression (2) for a grain heap as a mixture, it is possible to state that

$$U_v = \sum_{i=1}^{n} \alpha_i \cdot \frac{U_{kri}}{n_i}, \quad (3)$$

where n_i – number i – of components of a grain heap, pieces.

As evidenced in practice, the average air rate in the area of the sieves makes 60-70% [11-13] of the critical speed (terminal velocity) of the wheat grain.

Influenced by the air in the combine harvester cleaning system, the grain heap moves both in the horizontal and vertical planes [13], that is, in the longitudinal and transverse directions relative to the sieve, which is described by the following analytical dependencies:

$$\upsilon_{sl}^{g} = 0.02 \cdot U_v^2 - 0.04 \cdot U_v + 0.219; \quad (4)$$
$$\upsilon_{sl}^{v} = 0.007 \cdot U_v^2 - 0.012 \cdot U_v + 0.203,$$

where υ_{sl}^{g} and υ_{sl}^{v} – rate of movement of the grain heap layer respectively in the horizontal and vertical directions relative to the sieve, m/sec.;

U_V – air flow rate, $U_V \in (0.5–6.0)$ m/sec.

The rate of movement of the grain heap layer υ_{sl} along the sieve and its height h_{sl} are interrelated as it is shown:

$$h_{sl} = \frac{q_z}{B_{ro} \cdot \upsilon_{sl} \cdot j_{sl}}, \quad (5)$$

where q_z – delivery of the grain heap to the sieve in the combine harvester cleaning system, kg/sec.;
B_{ro} – sieve width, m;
υ_{sl} – rate of movement of the grain heap layer along the sieve, m/sec.;
j_{sl} – grain heap density, kg/m^3.

Based on the dependences of equations (4) and (5), it is possible to state that $\upsilon_{sl} = \upsilon_{sl}$, then the expression (5) takes the following form:

$$h_{sl} = \frac{q_z}{B_{ro} \cdot j_{sl}(0.02 \cdot U_v^2 - 0.04 \cdot U_v + 0.219)} \,. \quad (6)$$

From the expression (6), it is possible to state:

$$q_z = B_{ro} \cdot h_{sl} \cdot j_{sl}(0.02 \cdot U_v^2 - 0.04 \cdot U_v + 0.219). \quad (7)$$

Expression (7) indicates that with an increase in the air flow rate of the combine cleaning system, it is possible to increase the rate of grain heap delivery to the sieve.

Further, the value h_{sl} from the expression (5) is represented as

$$h_{sl} = \frac{\upsilon_{sl}^v}{t_{sl}}, \quad (8)$$

where υ_{sl}^v – rate of movement of the grain heap in the vertical plane, that is, above the sieve, m/sec.;
t_{sl} – time of movement of the grain heap in the vertical plane, that is, above the sieve, sec.

The value υ_{sl}^v can be expressed as $\upsilon_{sl}^v = 0.007 \cdot U_v^2 - 0.012 \cdot U_v + 0.203$. Then, the expression (5) can be stated as:

$$\frac{0.007 \cdot U_v^2 - 0.012 \cdot U_v + 0.203}{t_{sl}} = \frac{q_z}{B_{ro} \cdot \upsilon_{sl} \cdot j_{sl}}. \quad (9)$$

From the equality (9), it is possible to determine the relationship $\upsilon_{sl} = f(U_V)$. With this aim, it is necessary to perform the following transformation

$$B_{ro} \cdot \upsilon_{sl} \cdot j_{sl} = \frac{q_z \cdot t_{sl}}{0.007 \cdot U_v^2 - 0.012 \cdot U_v + 0.203},$$

which allows us to get

$$\upsilon_{sl} = \frac{q_z \cdot t_{sl}}{B_{ro} \cdot j_{sl}(0.007 \cdot U_v^2 - 0.012 \cdot U_v + 0.203)} \,. \quad (10)$$

The expression (10) shows that the rate of movement of the grain heap on the surface of the combine harvester sieve is inversely proportional to the air flow rate.

As evidenced in practice and confirmed by scientific results [1-6], the value of the air flow rate U_V in the combine harvester cleaning system depends on the type and length of the sieve, which is reflected by the following analytical dependences

$$\begin{aligned} U_v &= -2.0 \cdot L_{ro} + 7.0 \text{ – sample sieve} \\ U_v &= -14.0 \cdot L_{ro} + 24.0 \text{ – lipped sieve} \\ U_v &= -10.0 \cdot L_{ro} + 25.0 \text{ – universal high-performance sieve,} \end{aligned} \quad (11)$$

where L_{ro} – combine harvester cleaning sieve length, $L_{ro} \in (0.5–1.5)$ m.

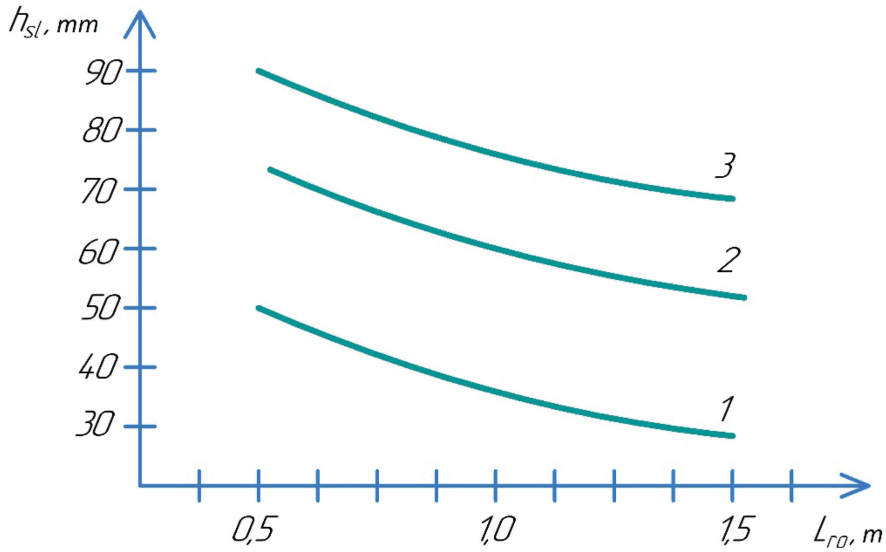
Based on the expressions (6) and (11), the changes $h_{sl} = f(L_{ro})$ can be considered, which is reflected in the following systems of equations

$$\begin{cases} U_v = -2.0 \cdot L_{ro} + 7.0 \\ h_{sl} = \dfrac{q_z}{B_{ro} \cdot j_{sl} \cdot (0.02 \cdot U_v^2 - 0.04 \cdot U_v + 0.219)} \end{cases}$$

$$\begin{cases} U_v = -14.0 \cdot L_{ro} + 24.0 \\ h_{sl} = \frac{q_z}{B_{ro} \cdot j_{sl}(0.02 \cdot U_v^2 - 0.04 \cdot U_v + 0.219)} \end{cases} \quad (12)$$

$$\begin{cases} U_v = -10.0 \cdot L_{ro} + 25.0 \\ h_{sl} = \frac{q_z}{B_{ro} \cdot j_{sl}(0.02 \cdot U_v^2 - 0.04 \cdot U_v + 0.219)} \end{cases}.$$

The graphic interpretation of the systems of equations of the expression (12) is shown in Figure 2.



1 – lipped sieve; 2 – sample sieve; 3 – universal high-performance sieve

FIGURE 2. Change in the height of the grain heap h_{sl} from the length of the sieve and the air flow rate of the combine harvester cleaning system

As the graphical dependences in Figure 2 show, the height of the grain heap layer in the initial part (0.5 m) of the sieve is quite large, since the air flow rate is increased. In the final part of the sieve (1.5 m), regardless of its type, significant decrease in the height of the grain heap layer is observed due to the decrease in the air flow rate, especially concerning lipped sieves. This affects the process of grain separation in the cleaning system and its removal outside the combine harvester.

The grain heap layer on the combine harvester cleaning sieve is a mixture of components. Thus, according to the expressions (3) and (4), the movement of the mixture on the sieve can be considered as the systems of equations in both horizontal and vertical directions relative to the sieve:

- horizontal direction

$$\begin{cases} U_v = \sum_{i=1}^{n} \alpha_i \cdot U_{kri}/n_i \\ \upsilon_{sl}^{g} = 0.02U_v^2 - 0.04 \cdot U_v + 0.219 \end{cases} \quad (13)$$

- vertical direction

$$\begin{cases} U_v = \sum_{i=1}^{n} \alpha_i \cdot U_{kri}/n_i \\ \upsilon_{sl}^{v} = 0.007 \cdot U_v^2 - 0.012 \cdot U_v + 0.203 \end{cases} \quad (14)$$

The graphical interpretation of the systems of equations (13) and (14) is shown in Figure 3.

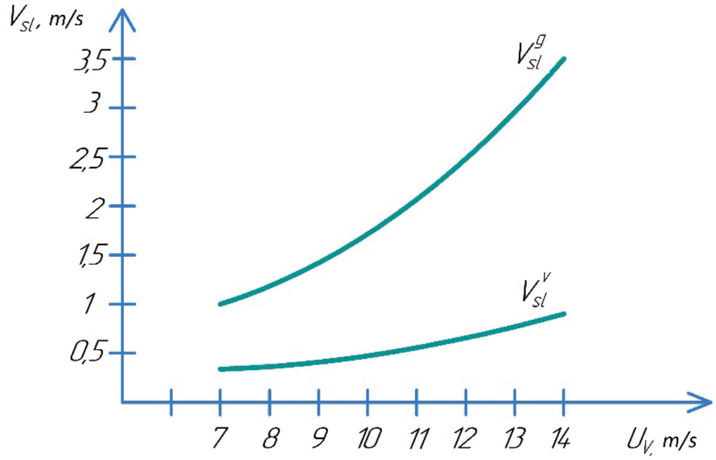


FIGURE 3. Change in the rates of the grain heap υ_{sl}^{g} and υ_{sl}^{v} respectively in horizontal and vertical directions relative to the cleaning sieve depending on the components critical speed and air flow

As the graphical dependences in Figure 3 show, with the increase in the critical speeds of the components of the grain heap, the increase in the rate of movement of the layer is observed both in horizontal and vertical directions, which, in turn, is reflected in the removal of high-grade grain, and much more of crushed grain, outside the combine harvester.

CONCLUSION

Thus, regularities and dependencies that show changes in the technological parameters of a grain heap as a system "grain heap-air-sieve," are obtained. In the course of the study, the influence of the technological effect of air on the parameters of the grain heap on the sieve of the combine cleaning system is established. Regularities and dependencies that characterize changes in the height of the grain heap on the sieves depending on its type and air flow rate, are revealed. This fact makes it possible to develop a combination of sieves in the combine harvester cleaning system in the future.

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