# Development of an Automatic Adjustment System for Air-and-Screen Cleaning of a Modernized Combine Harvester

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**Abstract.** The quality of grain separation in a combine harvester has the key role in increasing the efficiency of agricultural machinery use. The separation of grain and legumes should be effective and energy-efficient. One of the options to increase efficiency is to use automated air flow control systems. The use of digital control systems will help control the quality of the resulting grain and beans in real time, reduce damage, and enhance grain purity. To ensure control, we developed software and hardware meant to control the separation process in real time. The experiments show that, for high-quality separation, one has to maintain the air flow speed for soybeans at 8 m/s, for crushed grain – at 5 m/s, and for chaff and straw – at 2 m/s. These limitations were used to develop a software and hardware package that helps increase grain sorting efficiency.

## **1** Introduction

Traditionally, a grain harvester is a complex agricultural unit that performs the functions of grain harvesting, threshing and cleaning. The quality of the operations performed by it has a significant impact on the additional processing of grain to increase the susceptibility of grain and legumes to damage. Several factors have a significant impact on the quality of cleaning, the first one being the operating mode of the ventilation system that may comprise a fan, screen blinds.

The main operating parameters of the ventilation system are the uniform air flow distribution along the cross-section of the air-and-screen system, the air flow speed, and the air flow speed on the screen blinds. Control over these parameters will significantly improve the quality of the resulting grain and legumes [1, 2, 3].

A large number of both grain and leguminous crops are grown in the territory of the Russian Federation, but such a crop as soybean prevails in Amur Region. In comparison with grain, when harvesting soybeans, one finds a large amount of heavy impurities in the grain [5]. To remove them, one has to increase the air flow speed, however, soybean seeds are heavier than grain, which also leads to an increase in the air flow speed to impede high-quality sorting.

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Today, the main focus is on improving screen performance by controlling the operation of the wind-screen cleaning device. The key screen operation parameters are mesh movement in three projections by means of a vibration system. The studies [3, 4] show that a change in the amplitude of movement by 15% leads to a loss of separation efficiency by 5%, and a change in the angle of inclination by 2% reduces it by 55%. Thus, control over these parameters helps increase the cleaning efficiency, however, the screen is hard to control due to the presence of mechanical connections between individual elements, which increases the response time of the system to a control action.

A simpler control method is control over the air flow of the ventilation unit in a combine harvester. An assessment of the ventilation system performance shows that its parameters have a specific impact on individual crops. Thus, when harvesting rice, one has to heat the air flow to  $40^{\circ}$ C due to the high gluten content [4], which reduces moisture adhesion and decreases grain viscosity. The analysis of screen operation during rice harvesting conducted by the authors [4] helps determine that temperature and air flow speed have the maximum impact on the process. When harvesting rapeseed, one has to maintain the air flow speed for separation within 12-14 m/s [6, 7].

It is advisable to control the obtained air flow parameters in real time. Today, such opportunities are ensured by the use of digital technology, similar technologies are used for harvesting both vegetable and grain crops. The proposed solutions are based on the use of algorithms that help calculate a number of parameters and, taking into account the results obtained, adjust process parameters. Thus, garlic harvesting requires the use of an algorithm that helps calculate the length of the plant root and, consequently, adjust the depth of its planting in soil. The most promising soybean harvesting approach is the use of fuzzy logic algorithms, as there is a significant variation in grain parameters in terms of purity, moisture, and the amount of long and short impurities [8]. The proposed models for controlling the parameters of the air-and-screen cleaning device mainly use the hydraulic system of a combine harvester as an actuator. However, it is inertial and does not ensure the prompt adjustment of the required parameters.

A more promising approach is control based on electrical actuators. In this case, the control circuit comprises sensors that record the amount of grain, and a potential actuator is either a fan or a drive for slats [9].

The above-mentioned studies are mainly aimed at using the hydraulic system of a combine harvester as a drive for control objects. However, the use of an electric drive in this case is more preferable, since it solves the problem concerned with the speed of control action transmission. Therefore, we will consider an air-and-screen cleaner with an installed drive for slats as the target of our study. Based on the considered options for controlling the quality of the air-and-screen cleaning in a combine harvester, the goal of our study is to optimize the grain cleaning process by controlling the angle of rotation of the upper and lower screens to improve cleaning quality.

## 2 Materials and Methods

Since all operations on harvesting grain legumes are seasonal, in order to assess the factors influencing the quality of separation, we constructed an experimental installation (Fig. 1) that partially simulates the operation of a combine harvester air-and-screen cleaning system in laboratory conditions. The installation ensures control over the opening angle of the blinds by means of a commutator motor combined with an encoder; the extreme positions of the blinds are fixed with limit switches.



1. control panel; 2. installation frame;

3. electric motor with a drive pulley; 4. V-belt transmission;

5. fan; 6. upper lip screen; 7. air flow speed measurement holes on the upper screen; 8. lip screen blade tilt regulator; 9. lower lip screen; 10. air flow guide

Fig. 1. Laboratory bench simulating the operation of the air-and-screen cleaning system in a combine harvester

The volume of the information flow ensuring the correctness of the data received by the microcontroller in the combine harvester is obtained through the use of sensors installed at the end section of the standard and additional transition grates (Fig. 2, pos. 5).

The software for the ARDUINO modules was created in the C++ language, and for the controllers – in the FBD (Function Block Diagram) language.

**Results and Discussion** 

To implement the software ensuring blind control, we analyzed the grain separation process with due account for the angle of inclination of the blind segments.

Assumptions made:

- the air duct from the fan is flat, its speed is constant in magnitude and direction at any point;

- the grain mixture particles move freely in the flow, like material bodies, without colliding with each other.



1. inclined conveyor; 2, 3, 4. commutator electric motor (electric drive) combined with an encoder (relative displacement sensor) directly attached to the mechanism used to ensure separate control over the screen slats (the front half of the upper screen, the rear half of the upper screen and the lower screen). The extreme positions of the screen control mechanisms are fixed with limit switches located in direct contact with the mechanism used for moving the screen slats, 5. end sensor of the standard and additional transition grates.

Fig. 2. Layout of the sensors and electric drives

Let us consider the case when the initial speed of the grain is zero. In this case, the following forces act on the grain: grain weight, the force of the air flow with due account for the sailing capacity factor, the direction of the absolute speed of the grain coincides with the

direction of the resultant forces  $\overline{m \cdot g} + \overline{R}$  (Fig. 3).



Fig. 3. Diagram of an inclined air flow for fine soybean particles falling from the additional transition grate of the modernized combine harvester

The obtained dependencies are shown in Figure 4.



b)



c)

a) soybean grain at Vcr=11 m/s; b) crushed soybean grain at Vcr=7 m/s; c) chaff, straw at Vcr=3 m/s.

Fig. 4. Dependences of the angle  $\beta$  of the deviation of the absolute speed vector of fine soybean particles from the vertical for different values of the actual air flow speed and its direction determined by the angle  $\alpha_{slats}$  of the air flow direction from the horizontal specified by the position of the upper screen slats

According to the obtained results (Fig. 4), the absolute speed of the air flow at the edge of the additional transition grate, the critical speed on the upper screens of the air-and-screen cleaning system is at least 3-4 m/s.

The analysis of the charts in Figure 4 show that a uniform inclined air flow over the entire height from which the particles fall from the additional transition grate has the greatest deflecting effect for pre-critical speeds: for whole soybean grain – at C=8 m/s, for crushed grain – at C=5 m/s, and for chaff with straw – at C=2 m/s corresponding to  $\alpha_{slats} = 10...30^{\circ}$ . The obtained experimental data on soybean differentiation based on speed will be used for software development.

To further investigate the actual speed of movement of the grain components, the authors conducted a study on the distribution of the air flow speed based on the height from which the particles fall. The obtained results show that chaff and straw impurities at these speeds will definitely fly away in the last quarter of the upper screen.

The further studies show that an optimal screen operation mode is separate regulation of the lip screen. Based on these results, we created the electrical circuit to control screen parameters using commutator motors combined with an encoder shown in Figure 5.



Fig. 5. Control unit of the air-and-screen cleaning system of a combine harvester with a linear displacement sensor

To control the process, we use the OVEN PR200 microcontroller. Control is exercised by means of solid-state relay blocks that supply a control action to the blind drive (Fig. 6.a). The drive rotates the slats at the required angle (Fig. 6.b).





The rotation of the movable segments of the blinds is controlled in accordance with the logical diagram of the program shown in Figure 8.



Fig. 7. Logical control diagram of the PR200 microcontroller

The control is based on recording the opening time of the blinds used to determine the position of the blinds. Due to a slight air gap in the mechanical connections, no precise fixation of the blinds is possible, so we introduce limit switches to control the extreme positions. Thus, when a control signal is given, the blinds rotate and, when the drive reaches the extreme position, the limit switch closes to fix the control limits.

To control the position of the blinds, we developed the software shown in Figure 8.

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Fig. 8. Software block implemented in the C++ environment to control the position of the lip screen slats

## 4 Conclusion

The conducted experimental studies show that the most promising area of studies is control over the air flow in the air-and-screen cleaning system by changing the position of the slats. The authors believe that the most promising approach is to control the position of the blinds due to the absence of a large number of mechanical connections that reduce control efficiency.

The developed control circuit and software help control the opening of the slats on the lower and upper screen shoes using commutator motors.

The proposed set of sensors helps ensure full dynamic control in real time.

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