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Evaluation of the operation of the fan of the combine harvester air-and-screen cleaning system when using an asynchronous electric motor as a drive

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Abstract. The article presents the results of a study of a combine harvester fan after making design changes aimed at facilitating air flow control in air-and-screen cleaning. To this effect, the mechanical drive of the combine harvester fan was replaced with an electric one having an automated control system based on variable-frequency drive (VFD).

1 Introduction

Currently, production costs optimization using learning system elements is recognized as one of the key potentials of the world economic growth. It is believed that a complete transition to automated workstations can be achieved for at least 5% of jobs [1]. In this case, the use of learning systems in agriculture where the manual labor share reaches 60% can be considered as one of the most promising areas. Automation of production processes will allow to increase produced goods volume, as well as to introduce programmable quality technologies.

The learning systems potential can be used most efficiently in the entire grain crop production process, where the unmanned vehicles based on learning software systems will solve the issue of labor resources, and will also allow a differentiated approach to target production indicators (quality, differentiation by category, etc.). Optimizing the combine harvester process control is directly related to the elimination of unpredictable actions, which include those of an operator. During harvesting, the crop shall be harvested in a short time, and the operator, to speed up the process, adjusts the combine harvester only at the process beginning, which leads to losses due to changing conditions and a decrease in the quality of the grain obtained.

The most pressing issue of controlled quality is related to the seed grain production. Available technologies based on step-by-step processing, first in the processing path of the combine harvester, and then at grain cleaning and drying stations, currently do not provide the required quality established by GOST R 52325-2005. In addition, the used sequential grain conditioning to seed quality increases mechanical damage to the seeds, which reduces their germination.

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One of the problem solving options is to obtain seed grain directly from a combine harvester during harvesting. This will reduce damage to seed grain and the cost of obtaining it during post-harvest processing. Such transfer of the process step can be made possible with the use of automated control of the parameters of the combine harvester air-and-screen cleaning using learning systems, as well as machine vision. Numerous studies show that the cleaning quality, first of all, depends on the fan rpm control and the material supply speed and thus on the air flow velocity in the combine harvester air-and-screen cleaning system [2, 3, 4]. The conducted research suggests that the fan rpm control combined with machine vision and smart electric drive technologies will effectively improve the grain cleaning quality. However, such design changes require experimental studies and models to evaluate the airflow distribution in the processing path [4].

Currently, grain is processed as follows: the grain heap entering the combine harvester thresher is separated onto shaking board (1) (Fig. 1), which makes oscillatory movements, during which partial segregation of grain takes place: the heap is separated – the grain fraction (more dense one) falls to the shaking board surface, and the straw fraction rises to the upper part of the layer. On finger rake (3), the grain fraction is released to arrive at the beginning of the upper lipped screen (5), and the rest of the grain heap flows off the finger rake.

The upper lipped screen (5) also makes oscillatory movements, due to which and due to the air flow supplied by centrifugal fan (4), the straw fraction flows off the extension (6) of the upper lipped screen and is removed from the thresher, and the grain with spikes, which contain unthreshed grain, enters lower screen (7), on which the grain is finally separated. The grain along the grain chute of sieve boot (8) enters grain screw (9), and the spikes coming from lower screen (7) and extension (6) of the upper lipped screen (5) (passage) enter tailings screw (10) and are then fed into the finish threshing device (of autonomous type or combined with a threshing and separating device). The loss of grain cleaning downstream comprises the free grain that flows from extension (6) of the upper lipped screen (5).

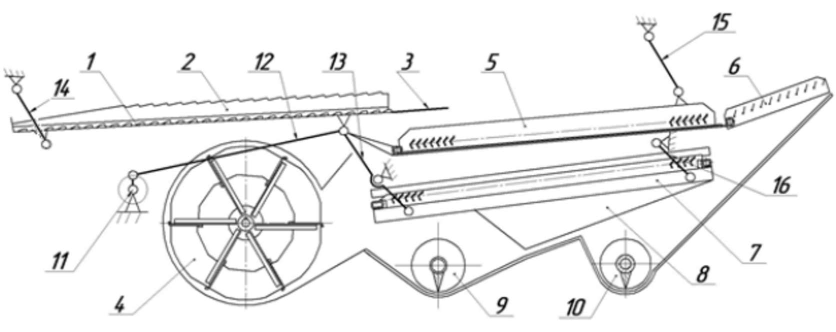

Fig. 1. Standard layout of the combine harvester processing path.

Based on the production process, separation takes place under the impact of both gravitational forces and air pressure from the fan. In this case the key factors of separation quality are the fan air flow parameters. However, the use of combine harvester mechanical drive significantly complicates the control process and renders it ineffective due to the large inertia of the system [5].

To optimize the control process, we propose to use variable-frequency drive instead of a mechanical one. Electric drive will improve the efficiency of controlling the air flow velocity in the processing path and allow to take advantage of microcontroller control [6, 7, 8, 9, 10].

The fan in this case is controlled as follows (Fig. 2): the optical system performs a preliminary analysis of the incoming cut mass to the grain header and optimizes the fan rpm.

The cut mass enters the floating conveyor of the grain header, where a weight (volume) sensor is installed. The received information is sent to the controller and compared with the optical system data, as well as with the DataSet information, and based on the analysis, the processing path operation is optimized.

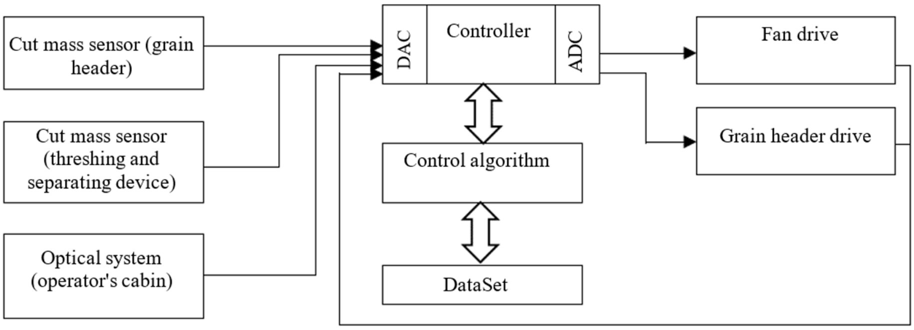

Fig. 2. Block diagram for controlling the fan of the combine harvester processing path.

A cut mass (volume) sensor installed at the input of the threshing and separating device re-optimizes the system. In this way, in-process control is ensured and the incoming heap is divided into three fractions: seed grain, commercial grain and impurities [12].

We have adopted the particle soaring speed as the main parameter for separation. It differs significantly for impurities and grains. So for soybean grain it ranges between 17.3 and 20.2 m/s, for wheat grain – 8.9 and 11.5 m/s, for straw – 2.9 and 9.0 m/s, for chaff – 2.7 and 5.3 m/s [6, 11, 13, 14, 15, 16].

To find the optimal solution, we analyzed the air flow distribution across the cross-section at the outlet of the fan unit diffuser, taking into account the variable-frequency drive control [14].

The study purpose is to determine the quantitative and qualitative characteristics of the combine harvester fan air flow: the average velocity and distribution of air flow velocity across the diffuser cross section when using the fan VFD control to optimize the grain separation.

2 Materials and methods

As the study subject, we use the fan of the Yenisei-1200 combine harvester. To drive the fan, a V-belt drive and an AIR100S4 asynchronous motor, equipped with a frequency converter and instrumentation, were used (Fig. 3). Frequency was controlled in the range between 10 and 100 Hz, speed – between 0 and 1420 rpm.

The factors studied and their levels of variation are presented in Table 1.

Table 1. Factors and levels of their variation.

Level of variation	Factors				
	Opening of shutters of the first half of the upper screen, X_1, mm (b)	Opening of shutters of the second half of the upper screen, X_2, mm (c)	Opening of the lower screen shutters, X_3, mm (d)	Air flow director tilt angle, X_4 deg. (a)	Average air velocity in the fan diffuser, X_5, m/s (v)
- 1	6	6	6	-15	8
0	12	12	10	0	10,25
+1	8	8	14	15	12.5

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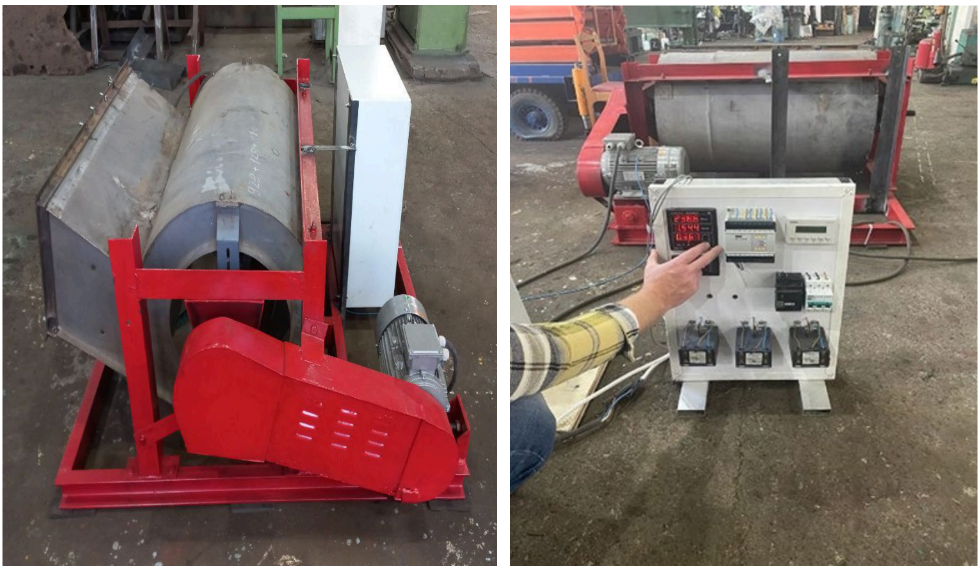
Variation interval	6	6	4	15	2.25
-1.596	2	2	2	-24	6.66
+1.596	23	23	16	24	13.84

Measurements to assess the velocity distribution quality were carried out over the open cross-sectional area of the fan diffuser, divided into 49 equal cells (seven channels each along the height and width of the diffuser).



a *b*

Fig. 3. Combine harvester fan unit: *a* – fan; *b* – control and measuring unit.

3 Results and discussion

To solve this problem, it is necessary to estimate the distribution of air flow velocity across the cross section of the combine harvester fan diffuser. Measurements were taken from September 18 to September 22, 2023. During the experiment, there was determined average air flow velocity across the diffuser cross section vs fan rpm when using an asynchronous motor as a drive.

Measurements carried out at 49 cross-sectional points of the fan diffuser showed (Figures 4 and 5) that the horizontal distribution of air flow velocity at the diffuser outlet is uneven: in lower channels Nos 5, 6, 7 the maximum velocity is closer to the side walls of the diffuser, and the minimum velocity is observed in the center of the diffuser (vertical channel No. 4) – of concave type across the diffuser width, and in upper channels Nos 1, 2, 3 the distribution is opposite – the maximum air flow velocity is in the center across the width of the diffuser and the air flow velocity curve is convexed. Moreover, this distribution of air flow velocity across the diffuser cross section at the fan outlet is recorded in the entire rpm range from 407 to 1164 rpm at 30 and 90 Hz of frequency converter. In the latter case, the air flow velocity at various points in the diffuser cross-section varies from 9 to 19.5 m/s, that is, more than twice. This nature of the change in the width distribution of the air flow in the lower and upper horizontal channels at the fan diffuser outlet shows that there is insufficient axial air inflow through the intakes to its center. A decrease in the air flow velocity in the center of

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lower horizontal channels No. 6 and No. 7 of the diffuser by 54% and a simultaneous increase in the speed in the central part of the diffuser in its upper horizontal channel No. 1 by 58% signifies the obvious uneven distribution of the air flow across the fan diffuser cross section.

Analysis of the vertical profile of the volume velocity curve (Fig. 5) shows that the maximum air flow velocity is achieved in the lower part of the fan diffuser closer to its sidewalls and is approximately 19.5 m/s, and the upper part of the fan diffuser is in the center and is equal to 19 m/s. The most stable speed indicators, close to its mean value over the diffuser area, are observed between channels 2 and 4, both in height and across the width of the diffuser.

Thus, both vertically and horizontally, uneven distribution of air flow is observed, and the velocity varies within fairly large limits.

Graphs of absolute values of air flow velocity are presented in Figure 4. Similar results on the unevenness of air flow velocity were obtained for intermediate frequencies of fan rpm control.

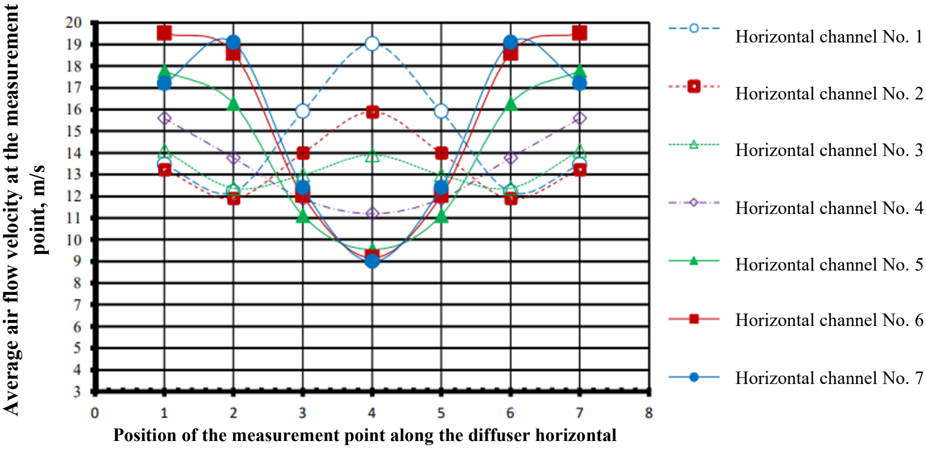

Fig. 4. Distribution of air flow velocity in horizontal channels of fan with 1164 rpm (18-22.09.2023)

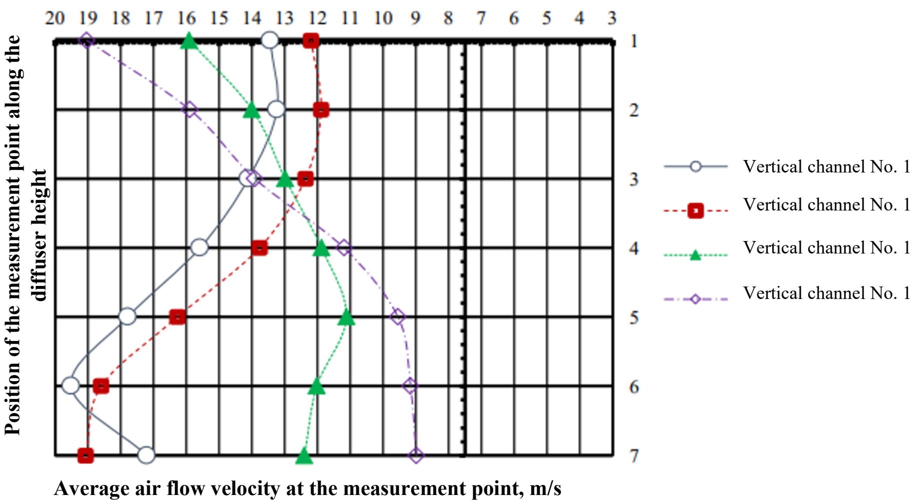

Fig. 5. Distribution of air flow velocity in the fan horizontal channels with 1164 rpm

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As follows from Figure 6, with an increase in the fan impeller rpm by a factor of 2.86, a significant linear increase in the absolute values of the average air flow velocity throughout the diffuser from 5.1 to 14.25 m/s was noted, that is, by a factor of 2.8, and the average unevenness of air flow velocity in horizontal channels changes slightly – 16.45 to 17.9%, that is, by a factor of 1.09. At the same time, large values of unevenness, characterized by the variation coefficient, are typical for the lower horizontal channels, while smaller values are typical for the upper channels with almost identical linear growth pattern across the entire range of the fan rpm variation.

Thus, the nature of distribution of air flow velocities in the fan diffuser depending on the impeller rpm remains fundamentally unchanged. In the center of the diffuser, there is a decrease in the flow rate, which, in our opinion, does not allow fully to separate the components of the grain heap on the second part of the upper screen and across the width of the upper and lower screen. Moreover, the actual rated fan rpm on the base combine harvester equals 754, which, according to the graph in Figure 6, corresponds to an average air flow velocity of 9.4 m/s at the diffuser outlet.

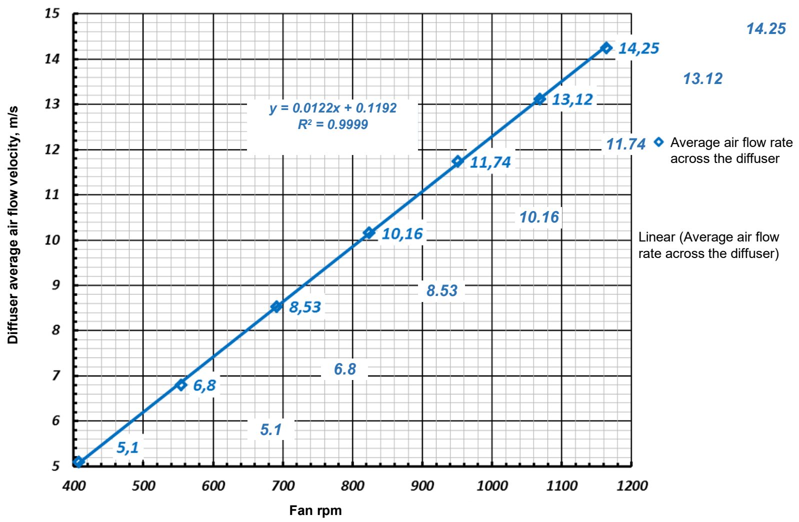

Fig. 6. Change in the average air flow velocity at the diffuser outlet depending on the fan rpm.

The recorded variation of the average air flow velocity over the entire cross-sectional area of the diffuser at the fan outlet with its rpm (Fig. 6) follows a linear law and takes into account potential variations due to the influence of the flow expansion and the air resistance of the grain-straw heap on the surface of the lipped screens. The obtained characteristic allows us to say that, taking into account the soybean grain soaring speed, the asynchronous motor rpm should be maintained above 1000 rpm.

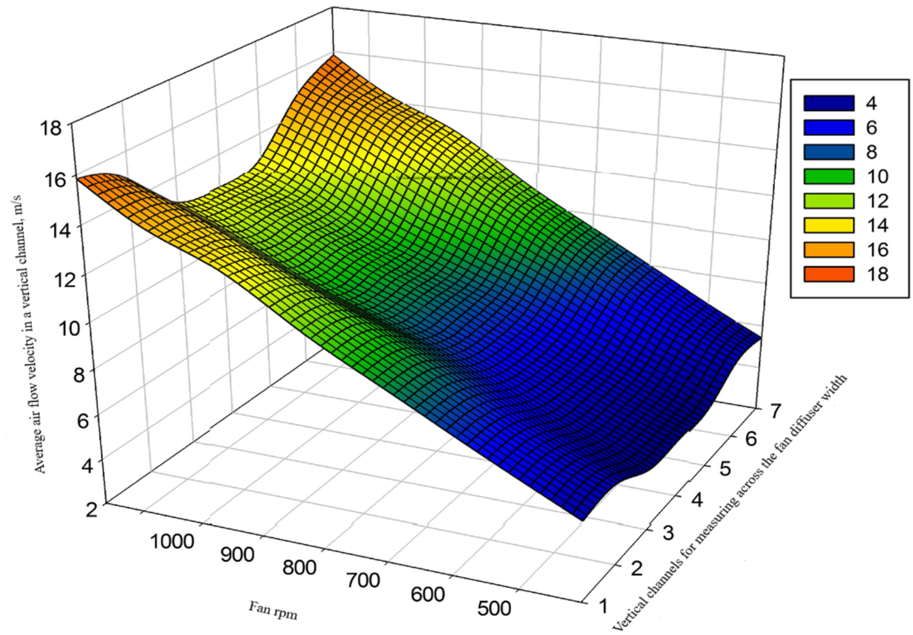

Fig. 7. Distribution of air flow velocity averaged in a vertical channel across the diffuser width depending on the fan rpm.

Even the distribution of the average air flow velocity in the vertical channel, obtained from research and presented in Figure 7, is characterized by a certain amount of unevenness. Thus, the air flow velocity along the edges of the fan diffuser decreases more intensely than along the central axis, causing almost constant unevenness across the diffuser width across the entire range of the fan rpm variation, which is due to its design specifics. The resulting model shows that the average velocity of air flow generated by the fan unit should be increased with its unevenness across the diffuser cross-section reduced. Currently, the fan structural members used for this purpose prove unequal to the set task and require improvement.

Dividing the upper screen into two parts with different adjustments of the angle of the shutters and their automatic adjustment depending on the level of yield and the condition of the soybean crops will allow for better cleaning of soybean grain. Our experiments show that the installation of deflectors-air flow dividers in the fan diffuser allows to direct the increased air flow from below to the corresponding shutters for better blowing of the grain heap layer.

4 Conclusions

During the experiment, design changes in the combine harvester processing path were developed and successfully tested. The design changes allowed to use an asynchronous motor as air-and-screen cleaning fan drive complete with an automated control system that includes a frequency converter and a number of additional elements that increase the system controllability.

The results obtained allow us to say that the air flow velocity in the combine harvester air-and-screen cleaning system varies significantly depending on the system volume. If at the beginning the velocity reaches about 18 m/s, then with increasing distance to the upper lipped screen it drops to 4 m/s, which is clearly not enough to obtain high-quality seeds. There is also unevenness of air flows horizontally; if at the edges of the fan diffuser it approaches 18 m/s, then in the middle part the velocity drop is 55%.

During the research, it was found that the change in the average air flow velocity in the air-and-screen cleaning of combine harvester when using an asynchronous motor as a drive follows a linear law. The resulting mathematical model will improve the process of controlling the combine harvester fan system.

Based on the results obtained during the experiments, it is planned to develop software that will automatically control the grain cleaning quality in real time without the intervention of an operator.

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