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EFFICIENT USE OF ASPIRATION SYSTEMS OF GRAIN AND SEED CLEANING MACHINES

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Abstract

Obtaining high-quality grain material in the required quantities in compliance with the scaled dust content of the air in the working area is determined by the efficiency of processes, cleaning methods of the air flow, and the designs of dust collectors for grain and seed cleaning machines. Increase in the productivity of grain and seed cleaning machines, which causes growth of the concentration of fine particles of impurities and dust, is restrained by the lack of efficiency of aspiration systems while cleaning the air flow. Classical improvement of dust collectors with aspiration systems, their separate elements, is confined and limited by design features of mobile grain separators. Based on the analysis of research results, a method was proposed to increase the efficiency of cleaning dusty air flows from light impurities and dust on grain and seed cleaning machines by using the developed rotary cyclone with a multi-disc purifier. Increasing the efficiency of the process of cleaning dusty air flow in the dust collectors requires additional influence on the dispersed particles to ensure their intensive redistribution in the working areas. Dependences of the overall performance on parameters of the offered cyclone are established.

Key words:
cleaning processes, intermediate selection, dusty air flow, cyclone, intensification, cleaning coefficient.

Introduction

Studies of the processes, methods of cleaning the air flow and improving the efficiency of dust collection devices are outlined in the works of (Dadak, 2007; Pavlyuchenko, 2016; Sabirzyanova *et al.* 2017; Vasilieva *et al.* 2007; Kuts, 1986; Maistruk, 2000; Shushlyakov, 2004; Kharchenko, 2007; Aslamova, 1987; Kotov B.I. *et al.* 2019; Tverdokhlib I.V. *et al.* 2016).

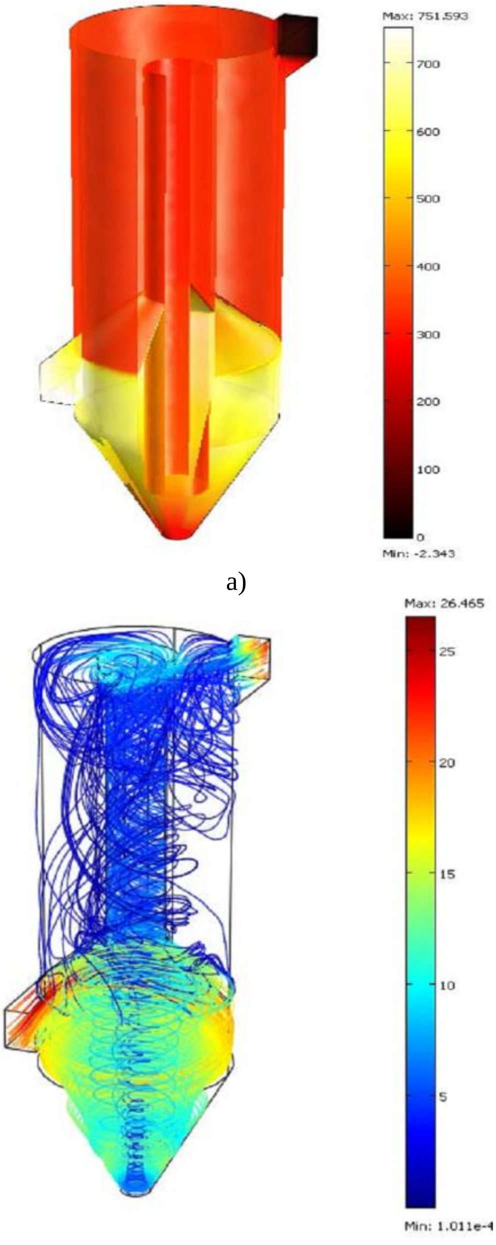
Formulation of problem

Dust collection using rotary dust collectors is one of the promising ways to clean the air flow. Studies of the processes, occurring inside the dust collectors, the trajectory of the air flow in the working areas are given in the works (Vetoshkin, 2005). Typical schemes of movement of dusty flows in rotary dust collectors are shown in (Fig. 1).

Dusty air flow is fed through the lower hole, where it acquires a vortex motion, which is a classic one for the cyclone. Further movement of the air flow is complicated by the rotation of the impeller, which creates additional centrifugal forces that create conditions for effective cleaning of the dust-gas mixture. The next stage is a complex change in the direction of rotation due to the rotation of the impeller. The efficiency of this cyclone is $\eta = 95\ \%$ with the calculated excess pressure (about 750 Pa) on the inlet connection.

Rotating disk systems (Fig. 2) are widely found in gas and steam turbines, heat power engineering, power industry, chemical engineering devices, industrial mass transfer devices, etc. (Shevchuk *et al.* 2012). Dusty air flow is fed into the disk cleaner due to the pressure generated between the disks, the dispersed particles are thrown away from the axis of the disk system. These devices provide the advantage of separating fine particles from the air flow. The disadvantage is that the system has no holes or channels for the removal of purified air flow, which forms an enhanced hydraulic resistance.

Designs of direct-flow dust collectors (Fig. 3) of the cyclone type for dry mechanical cleaning of gases are also well-known. The efficiency of dust capture in the presented cyclones is 70% for particles with a diameter of 10 microns and more with the hydraulic resistance not exceeding 1400 Pa (Dubynin *et al.* 2004).



a)

b)

Figure 1. Scheme of movement of pressure distribution and dusty air flow in the cyclone: a – pressure distribution; b – pressure distribution and gas flow lines at a speed of 20 m/s.

A cyclone with a transverse-flow separation zone (Fig. 3, Fig. 4) is used for increasing the efficiency of air flow cleaning in (Kuznietsov 2004). The dusty air flow enters through the tangential pipe 1 in the swirler 2 of a screw type where it acquires a rotational motion. Under the influence of centrifugal force, the dispersed particles receive a radial motion in the direction from the axis to the wall of the cyclone 3, near which their concentration increases. Concentrated flow of dispersed particles when moving along the wall enters the tangential gap 5 and through it gets into the dust collector 6. The cleaned air flow is pumped out by the fan 8 through the channel 7 and removed from the device.

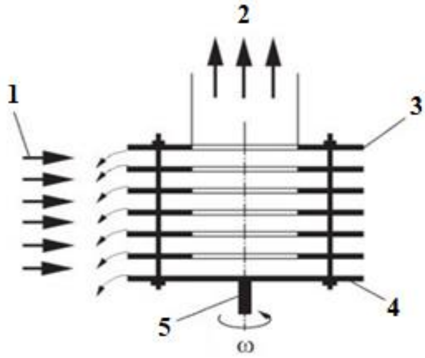


Figure 2. Dust collector with rotating disk cleaners: 1 – dusty air; 2 – purified air; 3 – disc with hole; 4 – solid disk; 5 – shaft; 6 – dust.

The disadvantage of these devices (Fig. 3, Fig. 4) is the use of stationary elements, the action of which is limited by the speed of air flow at the inlet. This creates an insufficient impulse, which is given to fine dust particles and helps to redistribute them to the periphery of the working area. The consequence is lack of efficiency of air flow cleaning. A partial solution to this negative effect is given in the construction (Fig. 4), which provides a fan that absorbs fine dust particles and carries them out through the outlet pipe.

Vortex dust collectors, like cyclones and rotary dust collectors, belong to centrifugal devices. Their distinctive feature is the high efficiency of air flow cleaning from fine fractions less than 5 microns.

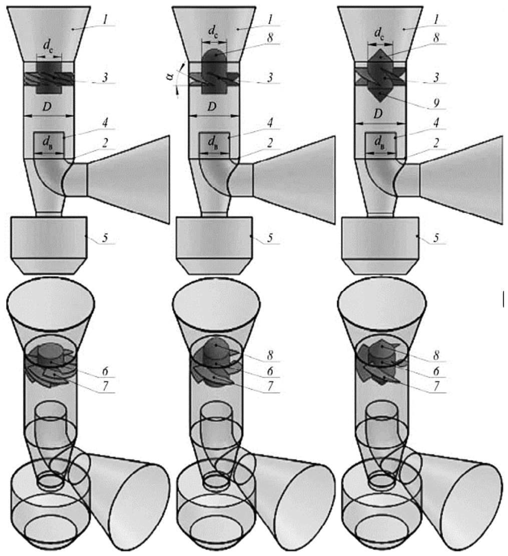


Figure 3. Designs of cyclones with a swirler type "socket" and different types of fairings: 1 – inlet pipe; 2 – case of the device; 3 – swirler; 4 – outlet pipe; 5 – bunker; 6 – cylindrical part of the swirler; 7 – blades of swirler; 8 – upper fairing; 9 – lower fairing; $d_в$, $d_с$ – diameter of the exhaust pipe and the core.

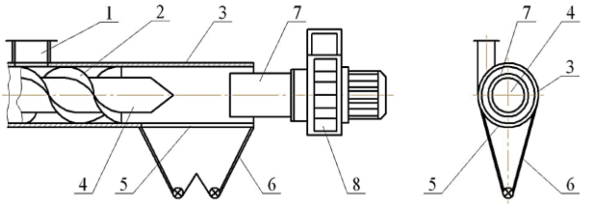
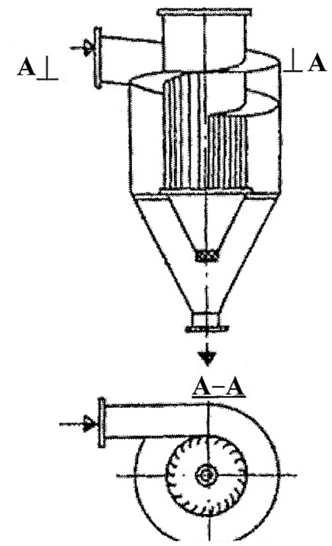


Figure 4. Constructive scheme of cyclone dust collector: 1 – tangential pipe; 2 – screw swirler; 3 – cylindrical case; 4 – insert; 5 – tangential gap; 6 – dust collection chamber; 7 – exhaust air duct; 8 – exhaust fan.



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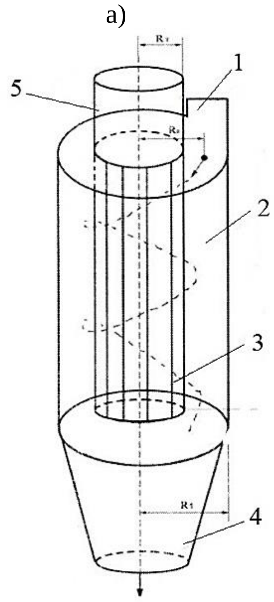

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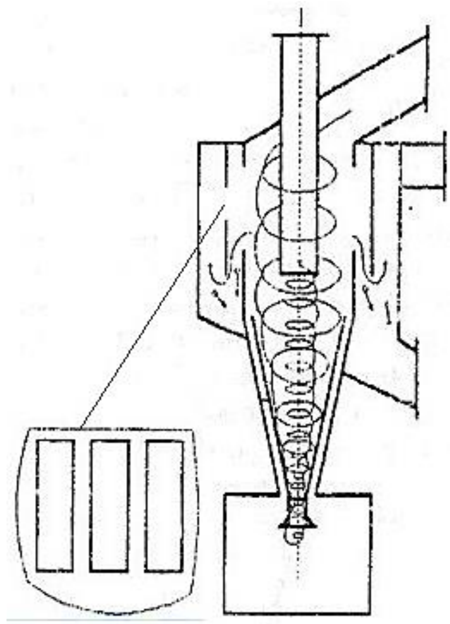
Figure 5. Designs of cyclones with louver elements for removal of clean air: a – centrifugal inertial dust collector designed by V.P. Kuz; b – dust collector with louver separator designed Yu.R. Dadak 1 – inlet pipe; 2 – cyclone case; 3 – louver separator; 4 – conical part of the cyclone; 5 – purified air outlet pipe.

Thus, the use of incoming flow vortices in cyclones contributes to the redistribution of dispersed particles and increase the efficiency of air flow cleaning.

Cyclones with the division of a working area into sections, with removal of the cleared air flow or dispersed particles proved its ability in practice (Fig. 5, Fig. 6).



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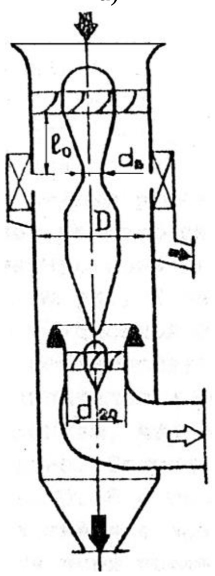


b)

Figure 6. Cyclones with intermediate selection of dispersed particles: a – construction done by V.V. Maistryk; b – construction done by V.S. Aslamova.

Thus, to delimit the working area in (Kotov *et al.* 2019), the authors proposed to use louvers in cyclones (Fig. 5). Installed louver separators remove clean air from the cyclone working area, while increasing the concentration of the dispersed phase and efficiency of air flow cleaning.

The dust collector designed by V.V. Maistryk (Maistruk, 2000) is presented in fig. 6, a. It includes the design of the cyclone and elements of the additional removal of dispersed particles, located on the outer wall of the cyclone, by transverse slits. Due to them, there is an intermediate removal of dispersed particles, which are concentrated near the outer wall of the cyclone and are deposited in the appropriate zone. According to research, this design increases the efficiency of air flow cleaning by 12% compared to a standard cyclone ZN-15. V.S. Aslamova (Aslamova, 1987) developed the design of a direct-flow cyclone using a swirler and intermediate removal of trapped dispersed particles (Fig. 6, b). This construction allowed to act comprehensively on the dispersed particles and get a significant efficiency of air flow cleaning 97…98 %, with the hydraulic resistance of 1.43 kPa.

The analysis (Fig. 5, Fig. 6) shows that the intermediate removal of dispersed particles or clean air from the working area of the devices by slits or louvers improves the efficiency of air flow cleaning.

The analysis of dust collector designs (Didur *et al*. 2013) allowed to determine the following classification: mechanical devices; devices with chemical reaction; devices with the use of filters; combined devices; devices with electrical action.

When choosing a dust collector, it is important to take into account design features. Thus, dry mechanical devices are characterized by a limited scope of use by the criterion of fractional dust, have large size, but they are easy to maintain and eliminate intermittent operation, which is typical for wet devices.

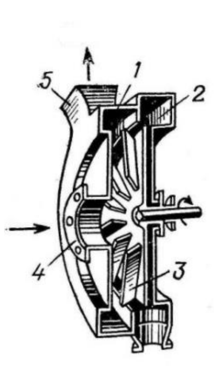
Cyclones are inertial dust collectors, in which the purification of gaseous medium occurs in a rotating flow under the action of centrifugal forces. According to the National Standards of Ukraine DSTU 12.2.043-80 cyclones belong to the 4th and 5th classes of dust collectors by the criterion of efficiency, and catch particles in the size from 8 microns.

Each device has a corresponding area of application and use. The operation mode of the devices is based on one or more processes of degusting, deposition, separation, coagulation, etc.

Main mechanisms can be identified at the core of the work of dust collectors:

- gravitational deposition, when the vertical motion of dispersed particles is caused by gravity;
- inertial separation, when the output of dispersed particles from the curved lines of air flow occurs due to the forces of inertia;
- separation under the action of centrifugal forces, when the dispersed particles are affected by centrifugal forces and there is redistribution of particles to the peripheral walls of the device;
- sticking effect, coagulation starts when dust particles combine with each other and their properties change;
- filtration when dispersed particles are trapped;
- magnetic control by the deposition elements, when the change in the trajectory of the charged dispersed particles occurs in the magnetic field of the device.

Therefore, in view of the arguments stated above, it is obvious that the most promising way to increase the efficiency of air flow cleaning is the use of centrifugal dust collectors. They have high cleaning efficiency with low hydraulic resistance, do not require periodic maintenance, additional energy costs, they are easy to manufacture and install.



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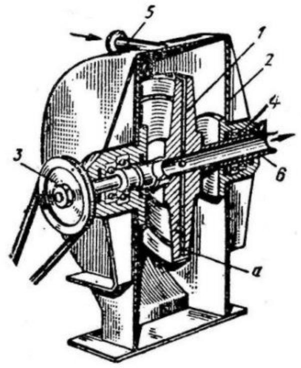

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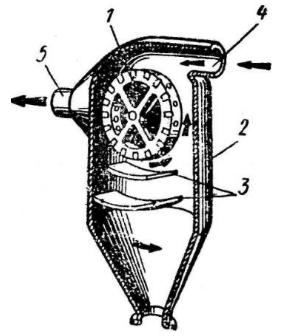

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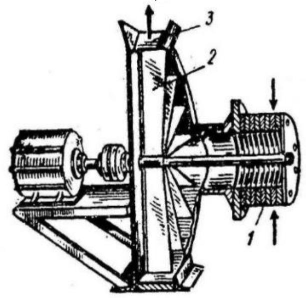

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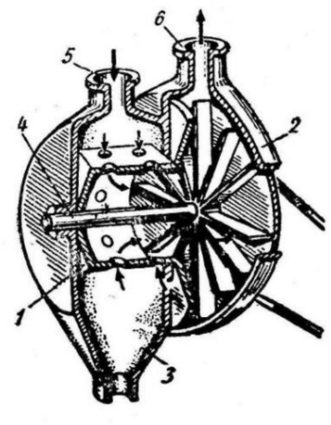


e)

Figure 7. Centrifugal dust collectors: a – centrifugal dust collector (separator); b – centrifugal dust collector CRP; c – centrifugal dust collector designed by Yakimov; d – dust collector designed by Grishchenko; e – centrifugal dust collector designed by Rosenkrantz.

The simplest centrifugal dust collectors of rotational action have the following mechanism: an impeller and a casing (dust receiver) (Fig. 7) (Ivanov *et al.* 2014). To increase the efficiency of the cleaning process, centrifugal dust collectors are equipped with the following elements: discs, blades, etc. for flow direction (Fig. 7, a, b, e), partitions, chambers, etc. for removal of dispersed particles from the working area (Fig. 7, c, d).

The installation of additional elements in cyclones that intensify the redistribution of dispersed particles is shown in (Kuznietsov *et al.* 2009) (Fig. 7). The cyclone has double filtration channels, which provide vortex flow and separation of fine particles up to 1 μm (Tarasenko *et al.* 2017).

Purpose of research

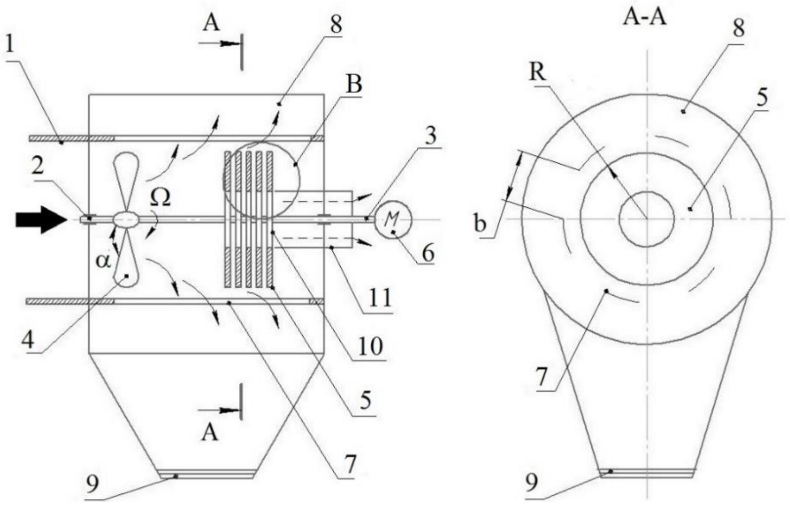
The purpose of the study is to determine a promising way to increase the efficiency of the process of the dusty air flow cleaning by aspiration systems of grain and seed cleaning machines while using the developed cyclone with a purifier with optimal parameters.

Research results and discussion

To increase the efficiency of the process of the dusty air flow cleaning, it is proposed to use a promising method by combining devices with different principles of operation with stage cleaning and intermediate removal of dispersed particles (Fig. 8). (Kharchenko *et al.* 2014).

For this purpose, an active vortex fan 4, an intermediate particle selection through louvers 7 and a multi-disc purifier 5 were used.

The proposed design of the dust collector includes a cylindrical housing 1 with holes 7 (Fig. 8, a), in which a shaft 3 with a swirler 4 and a disk purifier 5 are mounted on the holding blocks 2. The shaft rotates by an electric motor 6. The holes 7 of the housing 1 are installed at an angle to the axis of rotation of the shaft 3 and divide the main working area from the deposition chamber 8, which is installed around the housing 1. A sluice valve 9 is installed in the lower part of the deposition chamber 8.



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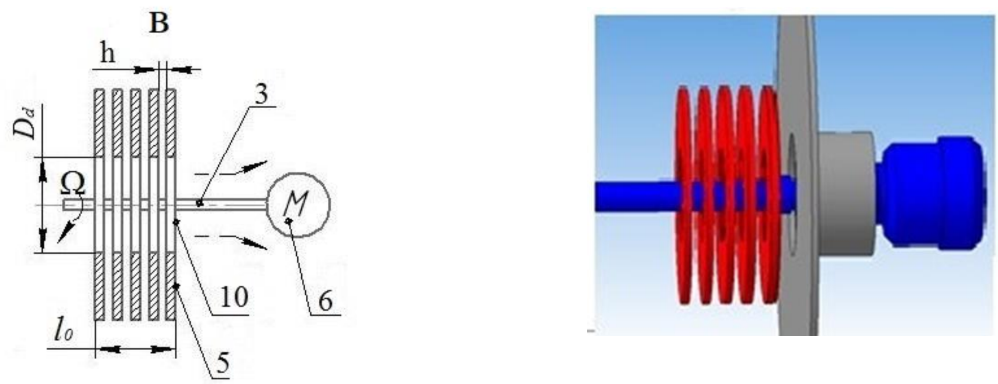

b)

Figure 8. Constructive scheme of the developed rotary cyclone with a multi-disc purifier: a – general scheme; b – multi-disc purifier 1 – housing; 2 – holding blocks; 3 – axle; 4 – swirler; 5 – disk purifier; 6 – electric motor; 7 – louvers; 8 – deposition chamber; 9 – sluice valve; 10 – holes of disks of purifier; 11 – outlet pipe.

A multi-disc purifier 5 (Fig. 8, b) consists of a set of disks of the same diameter, in the central part of which there are holes 10. The air flow is removed from the cyclone through the outlet pipe 11. At a certain gap a layer is formed, from which due to the centrifugal force the particles are separated and sent to the dust chamber 8. This helps to remove effectively fine particles from the air flow between the rotating disks.

For this purpose, an active vortex fan 4, an intermediate particle selection through louvers 7 and a multi-disc purifier 5 were used.

The proposed design of the dust collector includes a cylindrical housing 1 with holes 7 (Fig. 8, a), in which a shaft 3 with a swirler 4 and a disk purifier 5 are mounted on the holding blocks 2. The shaft rotates by an electric motor 6. The holes 7 of the housing 1 are installed at an angle to the axis of rotation of the shaft 3 and divide the main working area from the deposition chamber 8, which is installed around the housing 1. A sluice valve 9 is installed in the lower part of the deposition chamber 8.

Studies of the efficiency of the developed rotary cyclone involved determining the coefficient of purification of dusty air flow with varying values of the following important factors: air flow velocity U_0, the distance between the disks h, angle of inclination of the swirler blades α, the width of the louver opening b, motor rotor speed Ω; the number of discs of purifier n.

The research proved the dependences of the cleaning coefficients of the developed rotary cyclone on its design and technological parameters (Figs. 9 – 11).

Table 1. Research of the coefficients of purification of the developed rotary cyclone from the air flow velocity.

Air flow velocity U_0, m/s	Cleaning coefficient η, %		
	Ω=1000 rpm	Ω=2000 rpm	Cyclone design parameters (Fig. 8)
6	93.1	91.1	n=6 pcs.; h=1 mm; α=20°; b=20 mm
7	93.2	91.2	
8	93.3	91.4	
9	93.4	91.5	
10	93.5	91.8	
11	93.6	92.1	
12	93.7	92.5	
13	93.8	92.8	

Analysis of research (Table 1) shows that the maximum efficiency of the air flow cleaning process is η=93,1…93,8 %, at air flow velocity U_0 = 6…13 m/s and at shaft speed Ω =1000 rpm.

Table 2. Research of the coefficients of purification of the developed rotary cyclone from the air flow velocity

Air flow velocity U_0, m/s	Cleaning coefficient η, %			
	α=10°	α=20°	α=30°	Cyclone design parameters (Fig. 8)
6	93.1	91.1	89.0	n=6 pcs; b=20 mm; h=1 mm; Ω =1000 rpm
7	93.2	91.2	89.1	
8	93.3	91.4	89.2	
9	93.4	91.5	89.4	
10	93.5	91.8	89.5	
11	93.6	92.1	89.9	
12	93.7	92.5	90.1	
13	93.8	92.8	90.5	

Thus, within the range of the studied air flow rate (Table 2) U_0 =6...13 m/s, maximum cleaning coefficient is 91.1…92.8 %, which is 2.3…2.5 % more than at α = 30°.

Table 3. Research of the coefficients of purification of the developed rotary cyclone from the distance between the disks of the purifier

The distance between the disks h, mm	Cleaning coefficient η, %			
	U_0 = 6 m/s	U_0 = 10 m/s	U_0 = 13 m/s	Cyclone design parameters (Fig. 8)
0.5	90.0	89.2	89.0	n=6 pcs.; α =20°; b =15 mm; Ω=1000 rpm;
0.75	91.9	91.2	90.8	
1.0	92.4	91.5	91.1	
1.25	91.1	90.2	90.1	
1.5	88.3	87.7	87.9	

Analysis of the dependences (Table 3) shows that the distance between the disks of the purifier, which provides maximum efficiency of the developed rotary cyclone η = 90.1…92.4 %, is h = 0.75…1.25 mm.

Analysis of experimental studies proved that increasing the velocity of air flow in the ranges under study increases the cleaning coefficient of the developed rotary cyclone from 4…4.8% to 89…93.8 %. The obtained parameters of the rotary cyclone are: the angle of the blades α = 20 °, the rotor speed Ω = 1000 rpm, the distance between the disks of the purifier h = 1 mm.

The hydraulic resistance of the developed rotary cyclone was experimentally determined according to the method and pressure drop before and after using the device with variation of significant parameters of the developed rotary cyclone (Table 4).

Table 4. Research of the hydraulic resistance of the developed rotary cyclone from the air flow velocity

Air flow velocity U_0, m/s	Hydraulic resistance, ΔP			
	n=3 pcs	n=6 pcs	n=9 pcs	Cyclone design parameters
5.0	185	60	40	α=30°; h=1 mm; b =15 mm; Ω =1000 rpm.
7.5	270	85	65	
10.0	310	100	70	
12.5	375	110	65	
15.0	380	118	62	

Analysis of research (Table 4) proved that increasing the speed of air flow U_0 = 5...15 m/s and values of the parameters of the developed rotary cyclone, in the ranges under study, increases the hydraulic resistance in the range of 40…380 PA.

To receive a complete picture of the degree of purification efficiency of the dust flow, the fractional purification coefficient was determined (Table 5) for the fractions of dispersed particles under study.

Table 5. Research of the coefficient of purification of the developed rotary cyclone from the size of dispersed particles

The size of the dispersed particles d_s, μm	Cleaning coefficient η, %		
	U_0 =10 m/s	U_0 =13 m/s	Cyclone design parameters
1	5	7	*n*=6 pcs; *b*=15 m; *h*=1 mm; Ω=1000 rpm.
20	60	37	
40	85	75	
60	92	88	
80	97	96	
100	98	98	

Analysis of research (Table 5) proved that at the speed of air flow in the developed rotary cyclone U_0 =10…15 m/s the cleaning coefficient is η = 5…98 % for dispersed particles in the size up to 90 μm. It must be noted that the developed rotary cyclone captures dispersed particles d_s = 1…40 μm with efficiency η = 5…87 %, which significantly affects the intensification of the process of air flow cleaning in mobile grain separators.

Conclusions

The dependences of the cleaning coefficient on the air flow velocity were experimentally proved. Increasing the velocity of the air flow in the range under study increases the cleaning coefficient of the developed rotary cyclone by 4…4.8 % to η = 91…93.8 %. The ranges of variation of the obtained parameters of the rotary cyclone were: the angle of inclination of the blades $\alpha = 20°$, rotor speed Ω = 1000 rpm, the distances between the disks of purifier h = 1 mm.

Identification of the hydraulic resistance of the developed rotary cyclone with the establishment of the influence of design and technological parameters was experimentally proved. Provided maximum efficiency and minimum hydraulic resistance, the range of disc numbers was determined as n = 6 pcs. The range of variation of the hydraulic resistance of the developed rotary cyclone with the purifier, taking into account its defined rational parameters, was 130…180 PA.

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