

Innovative study on pneumatic separation of grain heap and economic feasibility of design versions

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Abstract. The paper is dedicated to the innovative analytical research in the field of pneumatic separation concerning the issues of grain heap feed for harvester-thresher cleaning, composition of tailings and the amount of grain. The problem of improving the separation of air-sieve cleaning of modern combines is of great current interest. The cleaning design with the use of pneumatic and inertia separator of small grain heaps for high-producing harvester-thresher is developed. The engineering study is conducted for the installation of the 8-bladed rotor above the chaffer sieve for experimental cleaning taking into account dimensional limitations and minimal alteration of the current air-sieve cleaning. The results of the study show the opportunity of better operation of the design of small grain heap cleaning with the application of pneumatic and inertia separator. The developed solutions make it possible to reduce grain losses and increase the harvester-thresher productivity level, as a result of which it is expected to achieve the economic effect assessed in the study.

1 Introduction

At present time the urgency of the problems concerning enhancement and productivity increase of harvester-threshers, search and use of reserves for grain harvesting efficiency increase, optimization of agricultural equipment parameters, is most notably increasing, since the production of grain crops in Russia is considered as one of the criteria for the country food safety state assessing. In the furtherance of the goal of performance improvement of harvester-threshers the versions of application of various designs for small grain heap cleaning are discussed in the paper from the perspective of its efficiency increase. To achieve high cleaning rates of small grain heaps it is suggested to use the innovative technical solution, more specifically, the pneumatic and inertia separator of small grain heaps.

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2 Materials and methods

The research methodology consists in the univariate experimental procedure on the mockup of harvester cleaning including the adjustment of functional design type with the subsequent analysis of process parameters. Three functional designs of small grain heap cleaning are tested in the series of experiments.

The test material is the original wheat heap “Bezostaya-1”, grain moisture is 12.8-14%, the composition of tailings is 30%, including cracked straw 0.03-0.15 m long - 6%, spikelets unthreshed - 1%, chaff and light waste - 23%. The feed ranged from 2.33 kgf-m to 5.23 kgf-m.

Calculation of economic efficiency achieved as a result of implementation of suggested technical solution is conducted using methodologies described in the sources [2-3]. Let us calculate the cost of additional grain production received due to the reduced grain losses and increased cleaning productivity comparing the basic design with the two projected ones. To define these indicators and economic effect let us use the following formulas.

The volume of season grain losses for combines P_{zer} is defined as:

$$P_{zer} = K_p \times F_z \times U_{sr}, \quad (1)$$

where K_p is harvester's grain loss coefficient;

F_z is the area of grain crops of one farm unit, ha (averagely, it is possible to set as 4200 ha in the Rostov region);

U_{sr} is the average yield of grain crops, ton / ha (in accordance with the data of the Federal State Statistics Service, it is equal to 3.5 ton / ha in August 2020).

The volume of additional production for the season D_p is calculated using the formula:

$$D_p = P_{zer}^{baz} - P_{zer}^{pr} \quad (2)$$

where P_{zer}^{baz} is the volume of grain losses in the basic period;

P_{zer}^{pr} is the volume of grain losses in the projected period.

The cost of additional production S_{dop1} can be defined according to a formula:

$$S_{dop1} = D_p \times C_{zak}, \quad (3)$$

where C_{zak} is the average farm-gate price of grain, rubles / ton (in accordance with the data of the Federal State Statistics Service it is equal to 13756 rubles in 2020).

The cost of additional products obtained by increasing the harvester-thresher productivity S_{dop2} can be determined using a formula:

$$S_{dop2} = \frac{U_{sr} P_p C_{zak}}{100} \left[\frac{1+n_2}{2} \times n_2 \times (W_{dn_2} - W_{dn_1}) + F_{sez} - W_{dn_1} \right] \times \frac{(n_2+1)+n_1}{2} \times (n_1 - n_2), \quad (4)$$

where P_p is the percent of average grain loss, %;

W_{dn_1} and W_{dn_2} mean the daily output of harvester-thresher in basic and project cases, ha;

n_1 and n_2 mean the number of full work days per season, days;

F_{sez} is the seasonal harvesting area, ha.

The indicators W_{dn_1} and W_{dn_2} are calculated as follows:

$$W_{dn} = 7 \times W_{ch} \times K_{sm}, \quad (5)$$

where K_{sm} is the shift factor (set to 1.5);

W_{ch} is the output of harvester-thresher per hour of shift time, ha.

The indicators n_1 and n_2 are defined using a formula:

$$n = \frac{F_{sez}}{W_{dn}} \tag{6}$$

The results of the calculation are shown in Table 1.

Table 1. Calculation of the cost of additional grain production obtained by reducing grain losses and increasing cleaning productivity

Indicators	Basic case	Projected case 1	Projected case 2
Volume of season grain losses, ton	220.5	195.51	183.7
Volume of additional production for the season, ton	-	24.99	36.8
Cost of additional production obtained by reducing grain losses, rubles	-	343762.44	506220.8
Cost of additional production obtained by increasing cleaning productivity, rubles	-	175106.5	303359.5
Total cost of additional grain production, rubles	-	518868.9	809580.33

The indicators given are calculated for one farm unit (7 harvester-threshers). To determine the economic effect, it is necessary to calculate the amount of investments in the project, as well as annual operating expenses. The investments K_{pr} include the cost of equipping harvester-threshers with the pneumatic and inertia separator which makes it possible to improve the efficiency of cleaning small grain heaps.

The operating expenses I_e are determined as follows:

$$I_e = S_{ust} \times (k_{ss} + N_A), \tag{7}$$

where S_{ust} is the cost of equipping combines with the pneumatic and inertia separator, rubles;

k_{ss} is the multiplier that takes into account lifetime of the equipment (can be set to 0.25);

N_A is the depreciation rate per year (15%).

The calculation of economic efficiency is performed for five years with the application of the discounting methodology. When specifying the discount rate, the inflation rate is taken into account (5% in 2020), as well as the uncertainty level of forecasted crop (6%) and other possible negative factors (3%). The discount rate E is therefore set at a rate of 14%. The discount coefficient K_d is defined by the formula:

$$K_d = \frac{1}{(1+E)^t}, \tag{8}$$

where t is the number of years before the reduction.

The present value of additional production DS_{dop} is defined using a formula:

$$DS_{dop} = S_{dop} \times K_d \tag{9}$$

The annual economic effect E_g is calculated as follows:

$$E_g = DS_{dop} - K_{pr} - I_e \tag{10}$$

The mid-year economic effect E_{sg} is determined using the formula:

$$E_{sg} = \frac{\sum_{i=1}^n E_g}{n}, \quad (11)$$

where n is the number of years of project implementation.

The discounted payback period $T_{d.ok}$ can be defined as:

$$T_{d.ok} = \frac{K_{pr}}{E_{sg}} \quad (12)$$

3 Results

As a result of conducted studies, the cleaning design with the use of pneumatic and inertia separator of small grain heaps for high-producing harvester-thresher is developed [1, 3-16]. The engineering study is conducted for the installation of the 8-bladed rotor above the chaffer sieve for experimental cleaning taking into account dimensional limitations and minimal alteration of the current air-sieve cleaning. The outer diameter of the rotor is 0.184 m, the height of the blades is 0.05 m, the blades are installed radially (Figure 1). The specifics of the operation consists in the fact that the grain heap accelerated by the bladed rotor is supplied only to the surface of the chaffer sieve made of separating elements and effectively blown by the air-blast.

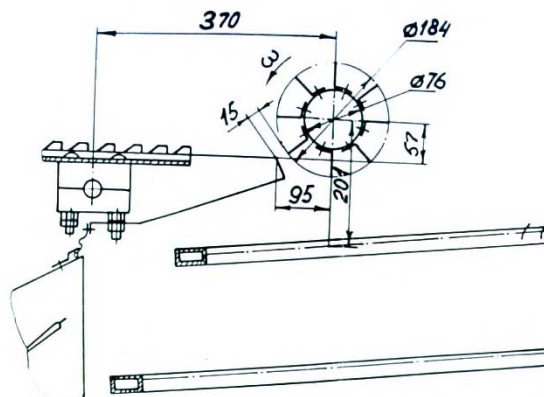


Fig. 1. The installation configuration of the bladed heap separator in the harvester-thresher cleaning system

The coordinates of the bladed rotor relative to the chaffer sieve and the shaking board are defined, the location and configuration of the deflector shield installed at the end of the shaking board, the fan neck, and the location of the deflectors in the fan neck are determined (Figure 2).

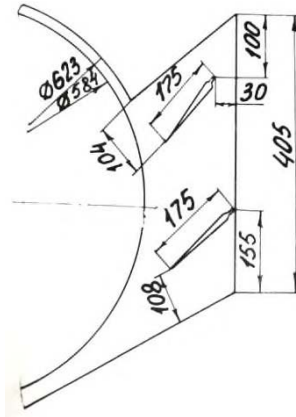


Fig. 2. The installation configuration of deflectors in the fan neck

The following changes in the design of series-produced air-sieve cleaning are suggested: it is decided to raise the end of the shaking board by 0.012 m to make a rational gap between the bladed rotor and the chaffer sieve, which is necessary for blowing and partially cleaning grain heap from small grain impurities. This is implemented by installing a gasket 0.006 m thick between the surface of the shaking board and the rear suspension case of the shaking board. A moving (relative to the rotor) deflector shield is installed at the end of the shaking board instead of the current finger rake (Figure 3).

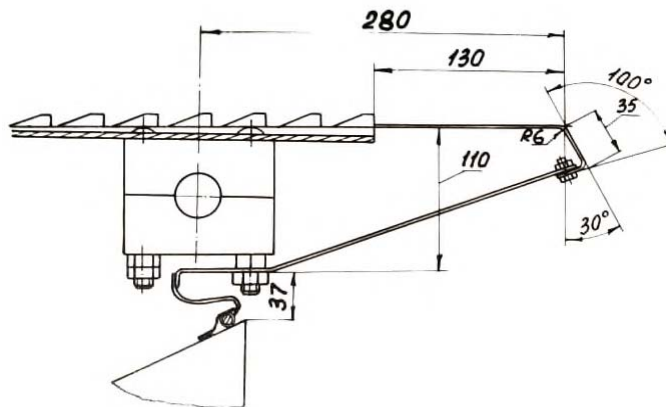


Fig. 3. The installation configuration of the moving deflector shield on the shaking board

The series-produced cleaning system of harvester-thresher was modeled in the first series of tests (Figure 4) in order to compare the technological parameters of the grain heap cleaning processes, as well as to comply with the airflow indicators applied in the series-produced cleaning.

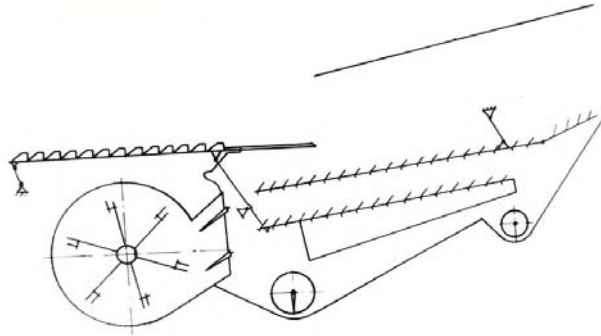


Fig. 4. The design of series-produced air-sieve cleaning

The settings of the cleaning model used in the first functional design correspond to the similar settings of the harvester-thresher parameters: the angle of chaffer sieve inclination is 5° ; the angle of chaffer rake inclination is 18° ; the chaffer fin opening value is 0.014 - 0.016 m; the shoe sieve fin opening value is 0.01 - 0.012 m; the opening value of the front part of the chaffer fin is 0.025 - 0.026 m; the opening value of the rear part fin of the chaffer rake is 0.014 - 0.016 m, the fan rotation frequency is 620 rpm. The main performance indicators of the test bench for series-produced cleaning are shown in Table 2.

Table 2. The main performance indicators of series-produced cleaning

Test number		1	2	3	4	5	6	7	8	9	10
Cleaning load	kgf-m	2.39	2.42	3.21	3.62	3.69	3.78	4.33	4.75	5.09	5.13
Purity of refined grain	%	99.87	99.85	99.44	99.17	99.28	98.99	98.07	98.54	98.76	97.98
Specific grain loss in chaff	%	0.199	0.221	0.309	0.419	0.486	0.531	0.617	0.686	0.723	0.787

A functional design of small grain heap cleaning with pneumatic and inertia separator with a diameter of 0.184 m was used in the second series of tests (Figure 5). The separator is installed at the end of the shaking board by a moving deflector shield; the chaffer sieve is series-produced, the shoe sieve is series-produced. Installation of two deflectors in the fan air duct makes it possible to produce a high-speed air flow in the blown gap between the bladed rotor and the chaffer sieve surface.

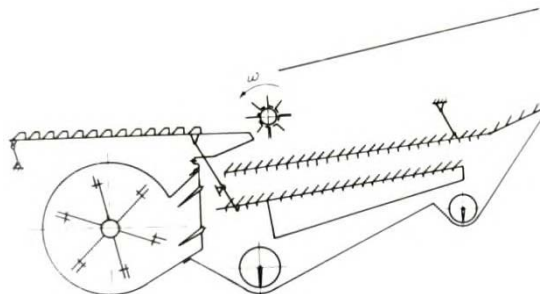


Fig. 5. Air-sieve cleaning design with bladed rotor and series-produced chaffer sieve

The cleaning model settings used in the second functional design correspond to the similar settings of the harvester-thresher parameters. The rotational frequency of the bladed rotor is 260 rpm. The main indicators of the grain heap cleaning process, obtained as a result of the tests, are provided in Table 3.

Table 3. The main performance indicators of cleaning with the bladed rotor and series-produced chaffer sieve

Test number		1	2	3	4	5	6	7	8	9	10
Cleaning load	kgf-m	2.33	2.43	3.17	3.55	3.87	3.90	4.10	4.67	5.11	5.23
Purity of refined grain	%	99.6 6	99.4 5	99.3 5	99.1 5	99.0 5	98.8 3	98.9 1	98.7 9	98.6 6	98.4 6
Specific grain loss in chaff	%	0.17 5	0.26 6	0.31 3	0.38 6	0.42 5	0.46 1	0.49 4	0.56 2	0.62 4	0.65 9

A functional design of small grain heap cleaning with pneumatic and inertia separator with a diameter of 0.184 m was used in the third series of tests (Figure 6). The separator is installed at the end of the shaking board by a moving (relative to the rotor) deflector shield. The chaffer sieve is made of two sections, when the front part is made of wire components and has an increased relative “effective screening area” against the fin surface of the series-produced sieve; the shoe sieve is series-produced. Two deflectors are installed in the fan air duct that makes it possible to produce a high-speed air flow in the blown gap between the bladed rotor and the chaffer sieve surface.

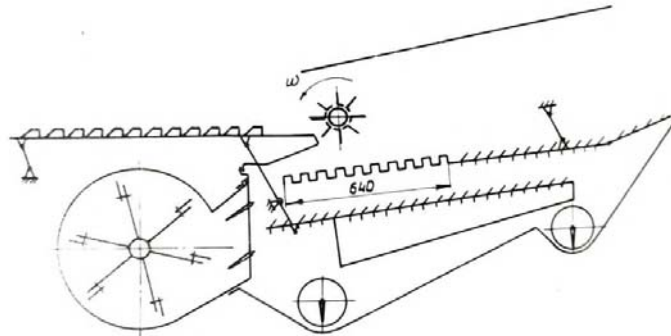


Fig. 6. Air-sieve cleaning design with bladed rotor and two-section chaffer sieve

The cleaning model settings used in the third functional design correspond to the similar settings of the harvester-thresher parameters. The rotation angle of wire components of the improved front part of chaffer sieve is 0° . The rotational frequency of the bladed rotor is 260 rpm. The main indicators of the grain heap cleaning process, obtained as a result of the tests, are presented in Table 4.

Table 4. The main performance indicators of cleaning with the bladed rotor and two-section chaffer sieve

Test number		1	2	3	4	5	6	7	8	9	10
Cleaning load	kgf-m	2.43	2.45	3.25	3.27	3.61	3.89	4.31	4.83	5.20	5.18
Purity of refined grain	%	99.4 3	99.2 6	99.3 2	99.2 5	99.1 9	99.0 8	98.9 4	98.9 1	98.8 6	98.7 9
Specific grain loss in chaff	%	0.07 8	0.16 3	0.21 8	0.29 6	0.35 4	0.37 6	0.38 1	0.46 2	0.53 1	0.56 5

The calculated indicators of economic efficiency of considered technical solutions are provided in Table 5 for projected case 1 and in Table 6 for projected case 2.

Table 5. Calculation of annual economic effect and discounted payback period for projected case 1

Indicators	Years				
	1 year	2 year	3 year	4 year	5 year
Investments, rubles	300000	-	-	-	-
Operating expenses, rubles	120000	120000	120000	120000	120000
Cost of additional grain production, rubles	518868.9	518868.9	518868.9	518868.9	518868.9
Discount coefficient	0.8772	0.7695	0.675	0.5921	0.5194
Discounted cost of additional grain production, rubles	455148.15	399252.77	350221.73	307212.04	269484.25
Annual economic effect, rubles	35148.15	279252.77	230221.73	187212.04	149484.25
Mid-year economic effect, rubles	176263.79				
Discounted payback period, years	1.7				

Based on the calculation results given in Table 5 one may conclude that application of pneumatic and inertia separator for the air-sieve cleaning suggested in the study can be considered cost effective, since, according to the estimations, the mid-year economic effect from the project implementation for one farm unit will be equal to 176263.79 rubles and discounted payback period amounts to 1 year 9 months.

Table 6. Calculation of annual economic effect and discounted payback period for projected case 2

Indicators	Years				
	1 year	2 year	3 year	4 year	5 year
Investments, rubles	350000	-	-	-	-
Operating expenses, rubles	140000	140000	140000	140000	140000
Cost of additional grain production, rubles	809580.33	809580.33	809580.33	809580.33	809580.33
Discount coefficient	0.8772	0.7695	0.6750	0.5921	0.5194
Discounted cost of additional grain production, rubles	710158.18	622945.77	546443.66	479336.55	420470.65
Annual economic effect, rubles	220158.18	482945.77	406443.66	339336.55	280470.65
Mid-year economic effect, rubles	345870.96				
Discounted payback period, years	1				

According to the obtained values of indicators, it can be concluded that the projected case 2, which involves equipping the harvester-threshers with the pneumatic and inertia separator, as well as improvement of the chaffer sieve design, is more cost-effective in comparison with both the basic case and the projected case 1. The mid-year economic effect obtained due to the project implementation is 345870.96 rubles, which is 169607.17 rubles more than in the projected case 1. The discounted payback period amounts to 1 year in this case.

4 Conclusions

On the basis of obtained results of the tests conducted, the conclusions are as follows.

1. The quality functioning of the design of small grain heap cleaning with the pneumatic and inertia separator and series-produced chaffer sieve (Figure 5) is possible. A reduced level of grain loss in the harvester-stacker is observed in comparison with the reference.
2. It is advisable to use a combination of separating surfaces as the chaffer sieve for the design of small grain heap cleaning with the pneumatic and inertia separator, where the separating surface located under the bladed rotor should have an increased “effective screening area” for unimpeded separation of grain from accelerated and enriched airflow of the grain heap. The unscreened part of the grain along with long and coarse impurities, moving further along the chaffer sieve, get on its second section made of series-produced fin, where its further separation takes place.
3. Generally, the suggested solutions for improving the system of small grain heap cleaning will provide the reduction of grain losses with increase in harvester-thresher’s productivity, as a result of which it is expected to achieve the economic effect calculated in the paper.

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