STUDIES OF PNEUMATIC COLLECTOR OF GRAIN KNOCKED OUT BY REEL BATS / *РЕЗУЛЬТАТИ ДОСЛІДЖЕНЬ ПНЕВМОВЛОВЛЮВАЧА ЗЕРНА, ЩО ВИБИВАЄТЬСЯ ПЛАНКАМИ МОТОВИЛА*

Ph.D. Eng. Shvedyk M.
Lutsk National Technical University / Ukraine
Tel: +38(0332)74-61-32; Fax: +38(0332)74-61-03; E-mail: lab-amb@ukr.net

Keywords: *reel, grain, impact, pneumatic collector, cyclone, pipeline, pressure*

ABSTRACT

In the article the studies of crop losses causes during harvest are presented. It is established that a significant cause of grain loss is a non-simultaneous ripening in the wheat. Thus, during reel bats impacts on stalks, the largest and most valuable grains that ripen earliest are knocked out of the wheat and fall to the ground. It is established that these losses are significant and irreversible. The current technical condition of combine harvesters cannot eliminate these losses. To eliminate these losses, a new design of pneumatic collector has been proposed in the article. The principle of its work is based on the vacuum created. Due to the vacuum, the grains that were knocked out from the wheat by reel bats are sucked and sent into the cyclone.

РЕЗЮМЕ

В статті наведено результати досліджень причин недобору врожаю під час його збирання. Встановлено, що істотною причиною втрати зерна є неодночасне його дозрівання в колосі. Як наслідок під час ударів планок мотовила по стеблах, найбільш крупні і найцінніші зернівки, які найпершими дозрівають, вибиваються з колоса і падають на землю. Встановлено, що ці втрати є значними і незворотними. Сучасний технічний стане зернозбиральних комбайнів не дозволяє усунути ці втрати. Для усунення цього недоліку в статті запропоновано конструкцію пневмовловлювача. Принцип його роботи ґрунтується на розрідженні, що створюється в конфузорі. Завдяки розрідженню все зерно, що вибивається з колоса планками мотовила, засмоктується і спрямовується в циклон.

INTRODUCTION

In the structure acreage of world agriculture the cereal crops occupy more than half. Its main areas are in Asia, North America, Europe, Australia and Africa. Over the past five years, Ukraine increased its grain production at a rapid pace and proved its total yield more than 60 million tons, which gave it the opportunity to take the second place on the world market among the countries-exporters of grain.

However, in order to stay on the market and among the world leaders it's necessary to continue to increase the volume of its production. But given the fact that in the structure of grain production in Ukraine about of 50% are the cereal crops, almost two-thirds of which prone to lodging, the timing of the harvest increased, and the process of machines operation is much more complicated. As a result, it leads to losses of grain which reaches 10-30%, and sometimes more, as the lodged grain stay below the headers cutting height *(Hrechkosiy V. et al, 1991)*.

To prevent the lodged grain currently used two methods - chemical and biological. The main point of the first method is that plants are treated with special chemicals that inhibit the plants growth and favor to thickening of the stalk, root development and make it resistant to lodging of cereals *(Alferov S. et al, 1981; Hrechkosiy V. et al, 1991)*. However, this method is not always effective. More promising is the use of short stalked, dwarf varieties which are characterized by high resistance to lodging of cereals and high yield. However, these varieties require shallow depth of seed placement - not more than 2 cm *(Shmat I. et al, 2009; Sysolin P. et al, 2001),* because they cannot grow in all areas.

Another cause of significant losses of grain is the ripening heterogeneity of grain in the wheat. Thus, at the time of harvest ripens earliest and lose contact with the wheat the largest and most valuable grains, which are located in its upper part. As a result, during the impacts on the stalk of the reel bats these grains are knocked out of the wheat and fall to the ground. Simple calculations show if of each wheat is knocked out of 2 grain, and in the time of harvest on fields of 1 m^2 on the average there are 500-600 stalks (*Hrechkosiy V. et al, 1991*), then on each hectare of at 6-8 hundredweight of grains are knocked out. Practically, these losses are irreversible, because the current technical condition of combine harvesters does not permit to eliminate it.

The conducted structural and biological analysis of standing crop of cereal crops shows that 70% of full grain is stored in 30-centimeter layer of wheat, and the rest - in the low-growing stalks, called undergrowth, where the grain by its properties is small, feeble and useful only to feed *(Dubrovin V., Shvedik N., 2014)*. It is obvious that these biological characteristics of cereal crops should form the basis for developing a new principle of its harvesting - namely, the volume reduction of biological mass that is feed for the threshing and for the cleaning.

Therefore there is a need to develop new working bodies that could fully ensure the effective harvesting not only of erect and lodged grain but also collect the grain knocked out by reel bats and would create conditions for a sharp increase of the productivity of combine harvesters.

MATERIAL AND METHOD

The effectiveness of the harvest in different countries is solved in different ways *(Ivan Gh., Usenko M., 2014; Ivan Gh., Vladut V.N, 2014; Moiceanu G. et al, 2015; Xiaoning Zhu et al, 2015)*. But we believe the most effective way to defect correction is the use of two-tier cutting of grain with separate threshing of the upper and lower tiers of wheat part and pneumatic lifting of the lodged grain and pneumatic collecting of the grain knocked out by the reel bats, based on creating of a vacuum in the area of reel. Process scheme of pneumatic collector of grain knocked out by combine harvesters reel bats is shown in Fig.1.

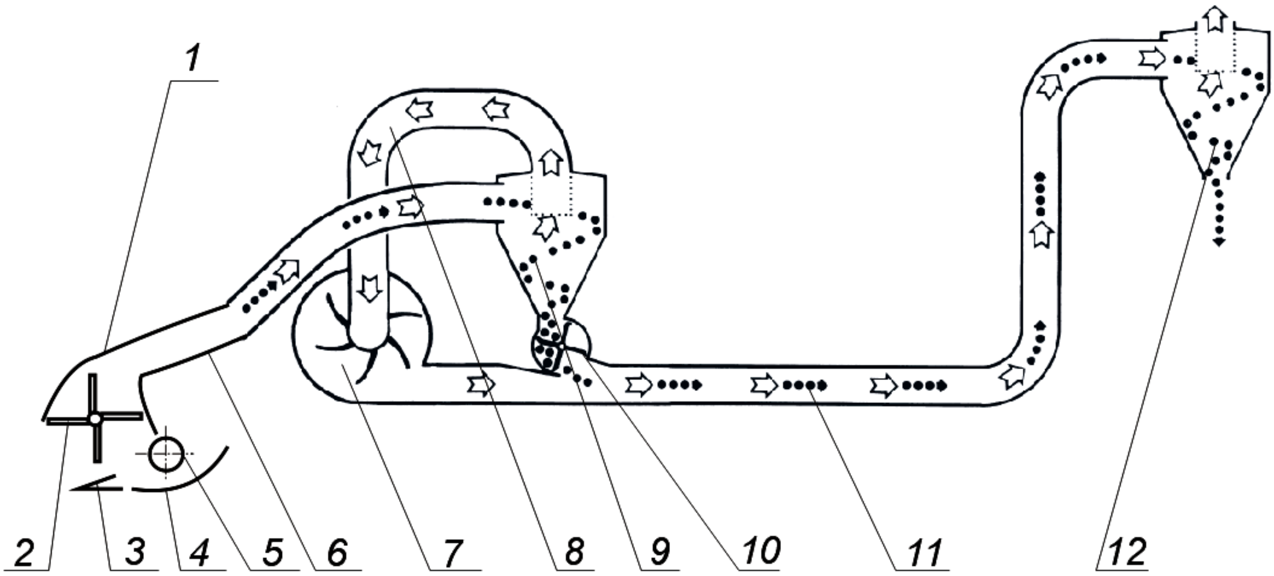

Fig.1 - Process scheme of pneumatic collector of grain knocked out by combine harvesters reel bats
1 – pneumatic collector; 2 – reel; 3 – cutter bar; 4 – header gutter; 5 – header auger; 6 – pneumatic pipeline; 7 – extractor-type fan; 8 – suction pipe; 9 – suction cyclone; 10 – rotor valve; 11 – transport line; 12 – offloading cyclone

The technological process of grain collecting is as it follows. When driving a combine harvester in the field, the extractor-type fan *7* through the pipe *8* sucks the air from the suction cyclone *9* and creates a vacuum in it, which through flexible pneumatic pipeline *6* extends to pneumatic collector *1*. Due to the vacuum, the lodged grain rise and enter the zone of the reel, which leads it to the cutter bar *3*.

After cutting, the wheat part of grain placed on the header gutter *4* upper tier and then by header auger *5* is supplied in inclined camera. This grain that falls out of the wheat during the lifting of stalks and by the reel bats *2* impacts sucked by the flow of air into the cyclone *9* where the grains and air are shared. Extractor-type fan accelerate the air to the speed of $v \approx 25$ m/s while the rotor valve *10* provides a uniform grain supply into the transport line *11* and it is transported to the offloading cyclone *12*. There, the exhaust air with light mixture removed through the top hole of the cyclone in the atmosphere, and the grain is emptied into a special tank for its accumulation.

Expediency of pneumatic collector using will depend primarily on the ratio of the additional cost of diesel oil necessary to drive the fan and the market value of collected grain. Consumption of diesel fuel depends on the pressure losses in the suction path of pneumatic collector. To determine these losses it must first make a pneumatic scheme of pneumatic collector that shown in Fig.2.

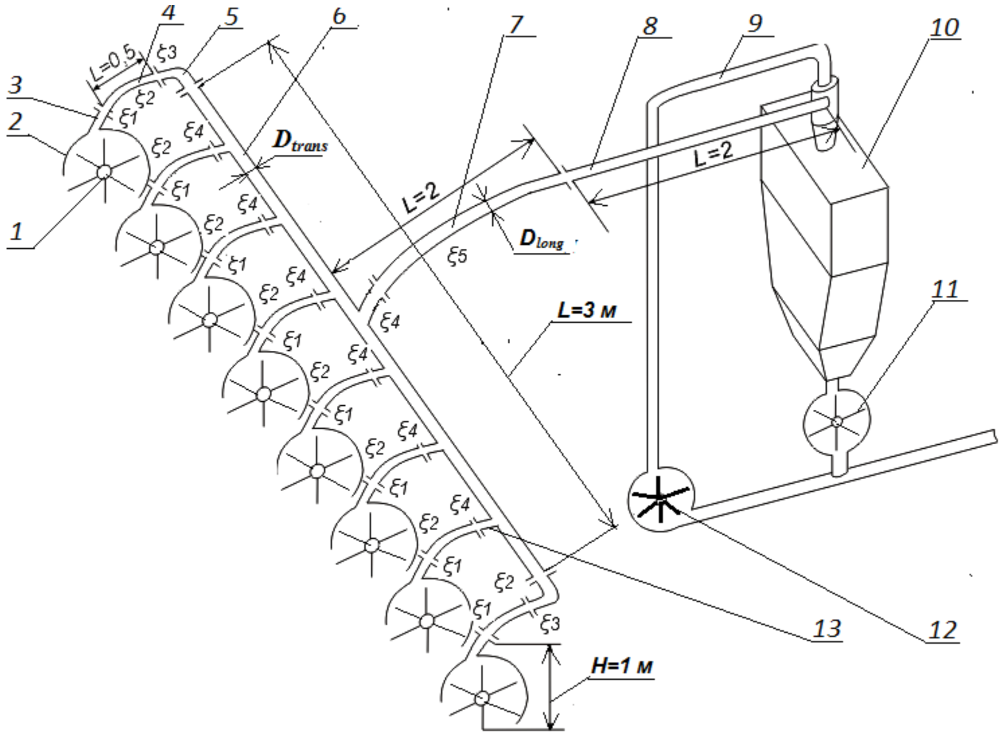

Fig.2 – Pneumatic pipeline layout scheme and placement of design elements, in which the local resistances results

1 – reel; 2 – fan; 3 – fan branch pipe; 4 – connecting branch pipe; 5 – knee; 6 - transverse pipeline; 7 – flexible pipeline; 8 - horizontal pipeline; 9 - suction pipeline; 10 – cyclone; 11 - rotor valve; 12 – fan; 13 – branch tube

Cutter bar does not effect virtually on the process of grain knocking out. Therefore, it is not considered in researches and not included in the scheme. On this scheme all fans and pipelines and branch pipes that connect them are shown. It also noted all the local resistances where pressure losses occurring (knees and narrowing of the pipeline, unloaders, etc.). The above scheme shows that the static pressure is spent to overcome friction in the pipeline, local resistances (knee, deflectors, discharger and flexible pipeline) and to lift the grain. That is, the total pressure losses $\sum h$ in suction path can be defined by the formula:

$$\sum h = h_1 + h_2 + h_3 + h_4 + h_5, \text{ [Pa]} \tag{1}$$

where:

h_1 - pressure loss from friction when clean air moving along the pipeline, [Pa];
h_2 - pressure loss from friction when the mixture of air and grain moving through the pipeline, [Pa];
h_3 - pressure loss in local resistances (knees and narrowing of the pipeline, unloaders, etc.), [Pa];
h_4 - pressure loss in fan to lift the grain, [Pa];
h_5 - pressure loss in the unloaders (cyclone), [Pa].

To check the accepted hypothesis authenticity can be conducted an experimental research. The main material that was studied in this paper was the haulm stand of the wheat and its grain. Research conducted in the field in the three replications according to developed methods using the experimental device.

Experimental device for pneumatic collecting of the grain knocked out by reel bats during its movement over the haulm stand of cereal crops is shown in Fig.3.

The device consists of pneumatic collector *11* and the cyclone *5*, which are installed on the self-propelled chassis *1* and connected to each other by flexible pneumatic pipeline *8*. This pneumatic collector is installed on the side of the self-propelled chassis on the rectangular frame (console) which is attached to adjustable risers which are installed on the frame and the cyclone is installed directly on three pillars. To the cyclones upper flange is attached the branch pipe with a hole that is cut off by the support *7*, and at the end of the branch pipe the fan *6* is installed. To lower cyclones flange is attached the transparent cone which is closed at the bottom by the cover.

Devices movement is carried out by using of winch *3*, which is driven by the electric motor *2*, which is powered by a battery 4.

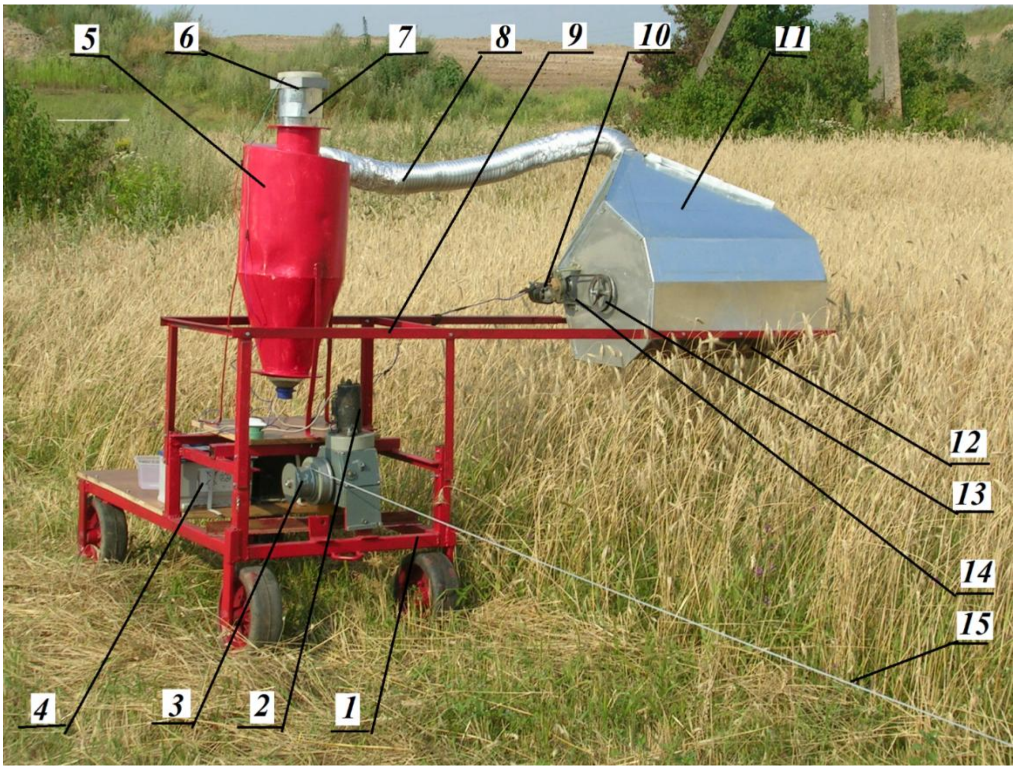

Fig.3 - Experimental device for collectiing of the grain knocked out by reel bats
1 – self-propelled chassis; 2 – electric motor; 3 – winch; 4 – batteries; 5 – cyclone; 6 – fan; 7 – support; 8 – pneumatic pipeline; 9 – console; 10 – electric motor; 11 – pneumatic collector; 12 – reel; 13 – pulley; 14 – belt; 15 – rope

For this, the rope *15* unwound from the winches drum and by free end with the hook is attached to a metal rod that is rammed into the ground.

The drive of the reel *12* is carried out by the V-belt drive *14* from the electric motor *10* through a worm reducer and the cyclones *5* fan *6* is driven by its own electric motor. All DC motors are powered by batteries with a voltage of 12 V.

Given that the reels and fans, the electric motor is powered by one battery and the chassis electric motor - by the other. Start the electric motors by using of individual switches.

The process passes as follows. At first turns on the fan *6* of the cyclone *5* and makes the vacuum in it, the depth of which is regulated by the change of the size of the inlet hole on branch pipe by moving of the support *7*. Then, turns on the electric motor *10* of the reels *12* drive and then the electric motor *2* of the winch *3*. When reeling the rope *15* on the winches drum the wagon *1* moves along the standing crop on the edge of fields or stubble and the pneumatic collector *11* moves over the layer of ears of wheat of the standing crop. Given that the reel bats separate the portion of the stalks from the main standing crop and incline it inside the pneumatic collector reproducing the same work process of the combine harvester header. Because of the vacuum from the cyclone *5* through the pneumatic pipeline *8* extends inside the pneumatic collector *11*, the grain knocked out from the wheat by the reel bats is sucked and transported by air flow in the cyclone. Here the air is separated from the grain and through the top branch pipe by the fan *6* is thrown out into the atmosphere, and the grain falls into the bottom of the cyclone and is collected in a transparent cone.

After passing by self-propelled chassis of a test length equal to 12.5 m the electric drives of winches, reel and fan are turned off and at the bottom of the cyclone where the box is placed, then the cover unscrewed and the grain by gravity emptied from the cone into the box. Then this grain from the box emptied into a plastic bag, putted in it the label prepared beforehand, in which indicated a sort, experiment # and replication #, then closed it tightly and emptied into a separate box for further processing in steady state conditions.

On the pneumatic collector was installed the reel with five bats of the diameter of 0.5 m and the length of 0.75 m. The width *a* and the length *b* of the inlet port at the bottom of pneumatic collector are equal accordingly to 0.8 m and 0.5 m.

Since the test length of the standing crops field in each experiment was similar to 12.5 m, so the area of layer of wheat ear, which is processed by reel bats is also was similar to 10 m^2.

RESULTS

Components of pressure losses in the suction path of pneumatic collector can be defined as follows.

1. Pressure losses *h* of friction when moving clean air along the pipeline can be defined by the Darcy formula *(Kondakov V. et al, 1973)*:

$$h = \lambda \frac{L \rho v^2}{2gD} \quad [\text{Pa}] \tag{2}$$

where:

λ - friction resistance coefficient;
L - length of pipeline, [m];
ρ - air density, [kg/m^3];
v - air speed, [m/s];
g - gravitational acceleration, [m/s^2];
D – diameter of pipeline, [m].

Friction resistance coefficient can be defined by the Brazius formula (*Krasnikov V., 1981*):

$$\lambda = \frac{0.3164}{R_e^{0.25}} \tag{3}$$

here:

R_e - Reynolds number, which is defined as *(Kondakov V. et al, 1973)*:

$$R_e = \frac{v \cdot D}{\upsilon} \tag{4}$$

here:

υ - air kinematic density, [m^2/s].

By the air temperature of $t = 30°$ C, which mainly corresponds to actual conditions of harvesting $\upsilon = 16.6 \cdot 10^6$ m^2/s.

Effective calculated length of the pipeline can be determined taking into account its piping layout, Fig.1. The scheme is shown that the total length of the suction pipeline consists of two parts. To the first part $\sum L_{p1}$ belong the branch pipes that connect the fans with transverse pipeline with diameter D_{trans}, i.e.:

$$\sum L_{p1} = 8 \sum L_{conf} + \sum L_{bp} + \sum L_{kn} \quad [\text{m}] \tag{5}$$

and to the second part $\sum L_{p2}$ belongs the transverse pipeline and two areas of longitudinal pipelines with diameter D_{long}, i.e.:

$$\sum L_{p2} = 8 \sum L_{tc} + \sum L_{fp} + \sum L_{hp} \quad [\text{m}] \tag{6}$$

where:

L_{conf} - fan length (vertical part of pipeline), [m];
L_{bp} - length of the connecting branch pipes, [m];
L_{kn} - knee length, [m];
L_{tc} - length of transverse collector, [m];
L_{fp} - length of flexible pipeline, [m];
L_{hp} - length of horizontal pipeline, [m].

Now by the formulas (3) and (4) can be defined the Reynolds number and friction resistance coefficient for each of the pipelines part.

Using the formula (1) can be defined the pressure loss h_{trans} of air friction during its movement in area of transverse pipeline with diameter D_{trans} having a total length $\sum L_{trans}$ and h_{long} for longitudinal pipeline with diameter D_{long} having a total length $\sum L_{long}$.

Therefore

$$h_1 = h_{trans} + h_{long}. \quad [\text{m}] \tag{7}$$

2. Pressure loss h_2 of friction when moving through pipelines of mixture of air and grain can be defined by the formula (*Krasnikov V., 1981*):

$$h_2 = h_1\left(1 + c\cdot\mu\right)\ \text{[m]} \tag{8}$$

where:

c - coefficient that depends on the concentration of the mixture, speed and physical and mechanical properties of grain. When v_p = 13-26 m/s the value of the coefficient is in the range of c = 0.83-0.31;

μ - coefficient of weight concentration of the mixture.

3. Pressure losses h_3 in local bearings (knees, by narrowing of the pipeline, unloaders, etc.) can be determined by the formula (*Kondakov V. et al, 1973*):

$$h_3 = \sum \xi \frac{\rho v^2}{2g}\ \text{[m]} \tag{9}$$

where:

ρ - air density, [kg/m^3];
v - air speed, [m/s];
g - gravitational acceleration, [m/s^2];
ξ - sum of the coefficients of local resistance.

According to the pneumatic diagram of the grain pneumatic collector:

$$\sum \xi = 8\xi_1 + 8\xi_2 + 2\xi_3 + 3\xi_4 + \xi_5 \tag{10}$$

here:

ξ_1 - coefficient of local resistance of unexpected narrowing that occurs in fan.

The value of this coefficient can be determined by the formula *(Krasnikov V., 1981)*:

$$\xi_1 = 0,5\left(1 - \frac{F_{ap}}{F_{ac}}\right) \tag{11}$$

here:

F_{ap} – area of the pipeline, [m^2]: $F_{ap} = \dfrac{\pi D^2}{4}$;
F_{ac} – area of open hole of fan, [m^2]: $F_{ac} = a\cdot b$;
a and b - width and length of fan hole, [m^2];
$\xi_2 \ldots \xi_5$ - coefficient of local resistance that occurs accordingly in connecting branch pipe, connected knees, branches and flexible pipeline and is determined by the formula (*Potapov G., 1990*):

$$\xi_2 = \sqrt{\frac{\delta}{90^\circ}} \tag{12}$$

here:

δ - angle of branch pipe, knee, branch of flexible pipeline, [deg.]. For pneumatic collector these angles are accordingly 60°, 90°, 90°, 45°;
ξ_3 - coefficient of local resistance that occurs in connection knees with angle of knee 90°. Its value can be determined by the formula (12);
ξ_4 - coefficient of local resistance that occurs in branches. As branches are mounted on the pipe at the angle 90°, its value is also can be determined by the formula (12);
ξ_5 - coefficient of local resistance that occurs in the flexible pipeline with the angle 45°.

4. Loss of pressure h_4 in fan for lifting the grain can be determined by the formula *(Krasnikov V., 1981)*:

$$h_4 = g\cdot\mu\cdot\rho\cdot H\ \text{[Pa]} \tag{13}$$

where:

g – gravitational acceleration, [m/s^2];
μ - concentration factor of air mixture;
ρ - air density, [kg/m^3];
H - height of grain lifting, [m]. It is determined by the size of pneumatic collector (Fig.2) and is 1 m.

5. Pressure loss h_5 in unloader (cyclone) can be determined by the formula *(Kondakov V. et al, 1973)*:

$$h_5 = \xi \frac{\rho v^2}{2g} \text{ [Pa]} \tag{14}$$

where:

ξ = 2.5 - coefficient of local resistance that occurs when the air-grain mixture inlet in the cyclone;

ρ - air density, [kg/m^3];

v - air speed, [m/s];

g - gravity acceleration, [m/s^2].

For example is taken a 4-meter harvester-threshers header and by the present methods can be determined the total pressure losses. Σh in the suction path of pneumatic collector consists of eight fans. Height of grain lifting in each fan is H = 1.0 m and the width and the length of its inlet hole are a = 0.7 m and b = 0.5 m. The total length of pipelines in accordance with the scheme (Fig.2) are ΣL_{trans} = 13.0 m and ΣL_{long} = 7.0 m.

For calculations is taken the transverse pipeline diameter D_{trans} = 0.078 m and longitudinal pipeline diameter D_{long} = 0.150 m *(Dubrovin V., Shvedik N., 2014)*. Can be accepted also v = 25.0 m/s, μ = 3...5, c = 0.31...0.35 *(Krasnikov V., 1981)*. Thus, under these conditions the total pressure losses Σh in the suction path according to calculations from the formula (1) can vary from 0.6 kPa to 1.2 kPa.

6. After determining of the air total losses can be determined the inputs of air power N to drive the fan, which creates a vacuum in fan needed for collecting (suctioning) of grain knocked out by reel bats and its supplying to the cyclone by the formula (*Krasnikov V., 1981*):

$$N = \frac{\sum h \cdot v}{3600 \cdot \eta_{be} \cdot \eta_{te} \cdot \eta_{fe}} \text{, [kW]} \tag{15}$$

where:

v - air velocity, [m/s];

η_{be} - bearing efficiency;

η_{te} - transmission efficiency;

η_{fe} - fan efficiency.

After applying in the formula (15) the data v = 25.0 m/s, η_{be} = 0.97, η_{te} = 0.99 i η_{fe} = 0.8 the power losses required to drive the fan, which creates a vacuum in pneumatic collectors fans (total pressure losses Σh in the suction path defined by the formula (1) and are 0.6 kPa and 1.2 kPa) are accordingly N_1 = 5.42 kW and N_2 = 10.84 kW.

The experimental research results by using of pneumatic collector device (Fig. 3) showed that by reel speed increasing from 50 rpm to 75 rpm when the self-propelled chassis moving with the speed of 1.5 m/s which corresponds to the combine harvesters operating regime the knocked out grain mass increased from 277 g to 330 g, and while moving the self-propelled chassis with the speed of 2.5 m/s the knocked out grain mass increased from 293 g to 365 g. These losses show that in real conditions of work of combine harvesters on each fields hectare it can be knocked out by the reel bats from 460 kg to 600 kg of grain. The nature of grain (1000 pcs. of grains) on discount area was 60 g. Analysis of the studies showed that analytically determined by the formula (1) the total pressure losses Σh in the suction path ranges from 0.6 kPa to 1.2 kPa and coincide with the experimental data. In accordance with the vacuum gauge readings the vacuum in the fan in the first case was 0.75 kPa and in the second - 1.32 kPa. Thus, given in the article the analytical dependencies make it possible to determine with sufficient precision the pressure losses in the suction path of pneumatic collector and the power necessary to drive its fan. The studies will be useful in the development and design of pneumatic collector, which will be installed on production combine harvesters.

CONCLUSIONS

1. By reel speed increasing from 50 rpm to 75 rpm when the self-propelled chassis moving with the speed of 1.5 m/s which corresponds to the combine harvesters operating regime the knocked out grain mass from layer of ears of wheat on each area of 10 m^2 increased from 277 g to 330 g and by the self-propelled chassis moving with the speed of 2.5 m/s – increased from 293 g to 365 g.

2. In real conditions of work of combine harvesters on each field hectare it can knocked out by the reel bats from 460 kg to 600 kg of grain.
3. In order to provide 100% of grain collecting knocked out by reel bats when the combine harvester moves at a speed of 1.5 m/s and 2.5 m/s in fan must be created the vacuum accordingly 0.75 kPa and 1.32 kPa. The power needed to drive the fan can range from 5.42 kW to 10.84 kW.

REFERENCES

[1] Alferov S.A., Kaloshin A.I., Ugarov A.D., (1981), *How a harvester-thresher works (Как работает зерноуборочный комбайн),* p.190, Ed. Mechanical Engineering, Moscow/Russia;

[2] Dubrovin V., Shvedik N., (2014), Analysis of the proses of interaction of the reel bat with layer of ear of wheat (Анализ процесса взаимодействия планки мотовила с колосоносным слоем), *MOTROL. Commission of Motorization and Energetics in Agriculture*, Vol.16, no.3, pp.273-278, Lublin/Poland,;

[3] Hrechkosiy V.D., Alimov D.M., Kyforenko V.I., ed al., (1991), *Overall mechanization of grain production (Комплексна механізація виробництва зерна),* p.216, Ed. Harvest, Kiev/Ukraine,;

[4] Ivan Gh., Usenko M., (2014), Theoretical study on feeding the tangential threshing system of conventional combine harvesters (Studiu teoretic privind alimentarea cu masa vegetala a aparatului de treier tangential all combinelor de recoltat cereale), *INMATEH. Agricultural Engineering Journal,* Vol.42, no.1, pp.33-40, Bucharest/Romania,;

[5] Ivan Gh., Vladut V.N., (2014), Kinematic study of threshing process conducted by tangential threshing system of conventional cereal harvesting combines (Studiul cinematic al procesului de treier realizat de aparatul de treier tangentiual al combinelor conventionale de recoltat cereale), *INMATEH. Agricultural Engineering Journal,* Vol.44, no.3, pp.59-68, Bucharest/Romania,;

[6] Kondakov V.N., Korobov M.M., Gritsyuk I.G., et al., (197 (3), *Pneumatic and hydraulic transport in the food industry (Пневматический и гидравлический транспорт в пищевой промышлености),* p.182, Ed. Food Industry, Moscow/Russia;

[7] Krasnikov V.V., (1981), *Carrying and lifting machines (Подьемно-транспортные машины),* p.263, Ed. Kolos, Moscow/Russia;

[8] Moiceanu G., Voicu Gh., Paraschiv G. et al, (2015), Mechanical properties of energetic plant stems - review (Proprietatile mecanice ale tulpinilor plantelor energetice-review)*, INMATEH. Agricultural Engineering Journal,* Vol.45, no.1, pp.149-156, Bucharest/Romania;

[9] Potapov G.P., (1990), *Load-haul-dump machine for livestock farming. Handbook (Погрузочно-транспортные машины для животноводства. Справочник)*, p.239, Ed. Agropromizdat, Moscow/Russia;

[10] Shmat I.K., Sysolin P.V., Samarin O.E., et al., (2009), *Methods and design principles of agricultural machines and units. Manual (Методи і принципи проектування сільськогосподарських машин і агрегатів. Навчальний посібник),* p.132, Ed. Oldie-plus, Kherson/Ukraine;

[11] Sysolin P.V., Salo V.M., Kropivny V.M., (2001), *Agricultural machines: theoretical foundations, construction, design. Arable farming machines (Сільськогосподарські машини: теоретичні основи, конструкція, проектування. Машини для рільництва),* Vol.1, p.384, Ed.Harvest Kiev/Ukraine;

[12] Xiaoning Zhu, Rui Yan, Hongli Wang, (2015), Harvesting scheduling operations for the machinery owners under multi-farming, multi-type situation with time window – an empirical study arising in agricultural context in China （基于时间窗的多农机点、多农田作业点、 多机型的混合农机资源调度问题研究）, *INMATEH. Agricultural Engineering Journal,* Vol.46, no.2, pp.175-182, Bucharest/Romania.