№ 2 (129) / 2025
Vol. 129, № 2 / 2025
Техніка, енергетика, транспорт АПК
UDC 621.867.133
DOI: 10.37128/2520-6168-2025-2-12

STUDY OF THE FEATURES OF GRAIN TRANSPORTATION OF VARIOUS AGRICULTURAL CROPS BY SCRAPER ELEVATORS OF COMBINE HARVESTERS

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In the vast majority of modern combine harvesters, scraper elevators with centrifugal unloading are used for grain transportation. The main disadvantages of such elevators include: direct and reverse grain pouring; crushing and compression damage to the grain by the working bodies of the scraper elevator; lack of consideration of the physical and biological characteristics of the grain of various crops harvested by combines. Such elevators have one nominal speed of movement of the chain with scrapers, do not consider the degree of loading of the grain-transport line of the threshing machine. For example, when threshing grass seeds with a KZS-9-1 "Slavutych" combine, the productivity of the scraper elevator is on average 0.1...0.3 kg/s, and it is designed for 5...5.5 kg/s., we have increased energy costs for transportation.

Another problem is aimed at reducing the degree of crushing and compression damage to the grain by the working bodies of the scraper elevator of the combine harvester. And the disadvantage of the mechanical drive of the elevator is also the constant ingress of part of the grain into the gap between the hinges of the chain with scrapers and the drive sprocket.

According to the results of experimental studies, it is possible to determine that on modern combine harvesters it is advisable to introduce an electric drive with computer control of the speed of grain transportation both by the scraper elevator and by the grain transport group as a whole. For the KZS- 9- 1 "Slavutych" combine harvester, the speed of grain transportation can be changed in the range of 260…360 min^{-1} with an increase in the centrifugal unloading sector to 160^0. At the same time, the use of an electric drive also solves the technical problem of replacing the axial side feed of grain from the lower grain auger of the combine thresher with a radial top feed. This solution will reduce grain destruction.

Key words: *elevator, grain flow, grain crushing, unloading sector, circular circulation.*

Eq. 4. Fig. 4. Table.1. Ref. 10.

1. Problem formulation

In the vast majority of modern combine harvesters, both domestic and foreign, scraper elevators with a centrifugal type of unloading and flat rectangular scrapers are used to transport grain and small piles in the threshing line [2, 8]. The main disadvantages of such elevators include: direct and reverse grain pouring; crushing and compression damage of grain by the working bodies of the scraper elevator; lack of consideration of the physical and biological characteristics of grain of various crops harvested by combine harvesters when designing the structural, technical and technological parameters of scraper elevators. As a rule, such elevators have one nominal speed of movement of the chain with scrapers, do not take into account the degree of loading of the grain transport line of the threshing and separation device of the combine harvester. At the same time, the main structural parameters of the scraper elevator are nominal for the operation of the combine harvester on threshing high-yielding grain crops. In another case, when the ratio of the mass of threshed grain to the leaf-stem mass prevails in the direction of straw, respectively, the real degree of loading of scraper elevators is significantly less than the nominal indicators. For example, when harvesting high-yielding, weed-free winter wheat by the KZS-9-1 "Slavutych" combine harvester, the scraper grain elevator transports up to 5 kg/s. And when threshing grass seeds (for example, alfalfa) by such a combine, the productivity of the scraper elevator is on average 0.1...0.3 kg/s. And the technical and technological parameters of the elevator remain unchanged. As a result, we have increased energy costs for transporting grain by the grain transport group of the threshing and separating device of the combine.

Another problem that we propose for discussion in this publication is the problem of reducing the degree of crushing and compression damage to grain by the working bodies of the scraper elevator of a combine harvester. In our opinion, the use of a mechanical drive of a chain with elevator scrapers has led in practice to the manufacture of a design of a grain transport line of a threshing machine with axial grain feed in the transition: lower grain auger - scraper grain elevator. And the disadvantage of such a technical solution is the constant ingress of part of the grain into the gap between the hinges of the chain with scrapers and the drive sprocket. In this zone, the grain is constantly destroyed, as a result - increased crushing and compression damage to the grain. For this reason, pneumatic transport systems are used in selective combine harvesters instead of scraper grain elevators.

In addition, our research can be integrated into the overall strategy for the harmonious development of agriculture in Ukraine, aimed at increasing the environmental friendliness of agricultural products [7, 9]

2. Analysis of recent research and publications

Thorough theoretical and experimental studies on the regularities of technological processes, including grain transportation by scraper elevators, have been carried out by such prominent scientists as Pogoriliy L. V., Sakun V. A., Listopad G. E., Bosoy E. S., etc. [1, 3]. But nowadays, with the introduction of precision farming systems into production, namely the elements of such systems – working bodies that have the ability to change technological modes and settings directly during the execution of mechanized operational technologies, research on improving the quality of grain transportation by scraper elevators of combine harvesters does not lose its significance and acquires a harmonious continuation.

In our opinion, the stable operation of the grain transportation systems of the combine harvester as a whole, and accordingly, the stable operation of the grain scraper elevator, calculated under the condition of the maximum permissible load taking into account the variety of seeds of agricultural crops harvested by combine harvesters, is one of the main reasons for the identified shortcomings in the operation of such machines.

3. The purpose of the article

The purpose of this study there is a justification for the feasibility of using automatic variable operating modes of the grain scraper elevator on modern high-performance combines, depending on the harvesting conditions.

Research objectives:

– to conduct research on the experimental setup we developed to identify the dependencies between the speed of grain transportation by a scraper elevator and the degree of grinding of such grain;

– provide practical recommendations on grain transportation modes using a scraper elevator of a combine harvester when threshing grain of various crops.

4. Results and discussion

Experimental studies aimed at identifying the patterns of grain flow during grain transportation by a scraper elevator of a combine harvester were carried out on the installation developed by us in Fig. 1 [2, 4, 5]. The main emphasis is on the degree of grain damage by mechanical destruction depending on the speed of transportation. Regarding the processing of the obtained values, methods and techniques of statistical processing of experimental data, comparison methods were used.

The scheme of the experimental setup we developed is shown in Fig. 1. The object of the study was a scraper elevator 1 of a combine harvester with flat rectangular scrapers. The geometric and technological parameters of such an elevator are identical to the scraper elevators used for transporting grain on the combine harvesters "Slavutych" and "Skif". Such an elevator is installed on a frame with the possibility of changing the angle of inclination. In our case, the angle of inclination was 750, which simulates the grain elevator of the combine harvester "Slavutych".

The main concept of creating such an experimental installation was that a fixed mass of grain moves cyclically in a closed circle. Equipped with a slide, pre-calibrated productivity regulator 6, the hopper performs the function of a “grain accumulator”. The drive of the scraper elevator is electric with the ability to change the speed of grain transportation in a wide range by using a DC electric motor 3. The idle part of the scraper elevator is equipped with an additional special rectangular hole comparable to the overall dimensions of the elevator casing. Such a hole is made in order to determine the mass of the return grain flow. The hole is closed by the lower flap 13.

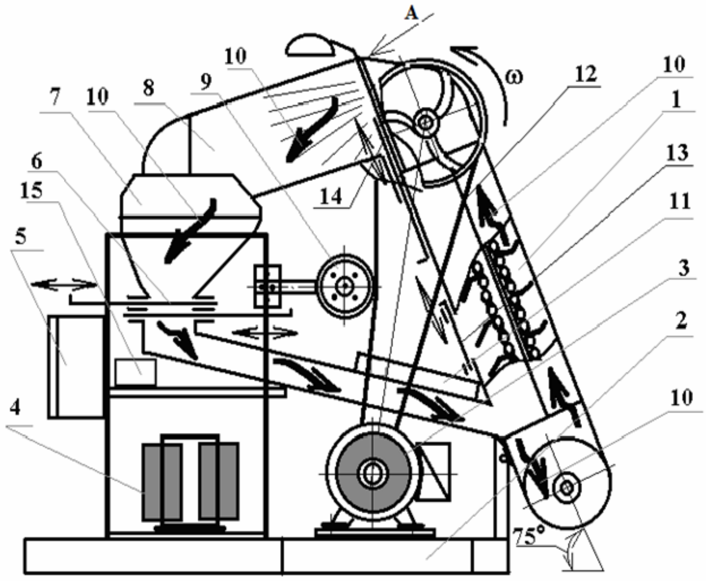


Fig. 1. Scheme of the experimental setup:
1 – grain scraper elevator; 2 – main frame; 3 – DC electric motor; 4 – transformer with diode block; 5 – electrical power cabinet; 6 – gate valve; 7 – storage hopper; 8 – reloading chamber; 9 – tension mechanism; 10 – hopper loading zone; 11 – storage capacity for measuring grain circular circulation; 12 – V-belt transmission; 13 – lower gate valve; 14 – upper regulating gate valve; 15 – computer unit for measuring grain transportation performance.

Grain feeding with a given capacity can be carried out in the lower part of the scraper elevator in both radial and axial directions.

The centrifugal unloading zone is located in the upper part of the grain scraper elevator (zone A), a more detailed technological scheme of such a zone is shown in Fig. 2.

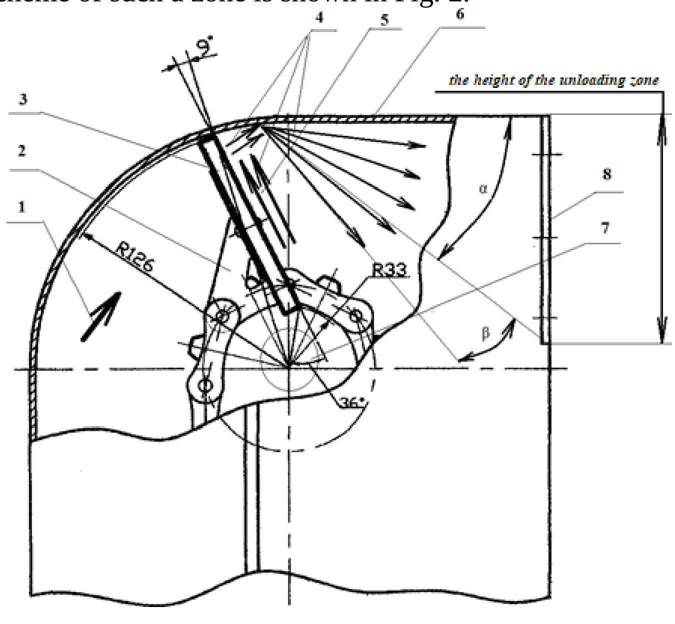


Fig. 2. Diagram of the upper part of the scraper elevator of the combine harvester type "KZS-9-1" "Slavutych":
1 – direction of rotation of the scrapers; 2 – elevator scraper bracket; 3 – scraper; 4, 5 – simulated directions of movement of grain layers during centrifugal unloading; 6 – cover; 7 – shaft with drive sprocket of the elevator chain; α – unloading sector angle; β – grain reverse shedding angle.

Regarding the theoretical aspects of grain movement along the elevator scraper during centrifugal unloading, such movement can be described by a differential equation taking into account the initial conditions (Fig. 3a).

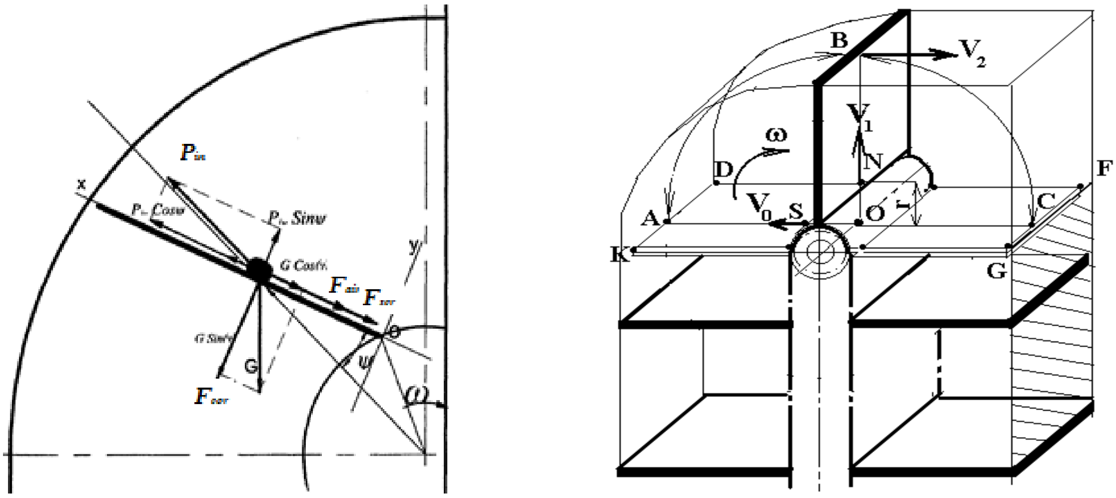
The following forces act on the grain: $G = mg$ – grain weight; N – normal surface reaction; $F = kN$ – friction force of the grain on the scraper surface; $P_{in} = mr^2$ – centrifugal force of inertia; $F_{air} = kmv$ – the force of air resistance that arises when a material point moves relative to the scraper and acts in the direction opposite to such movement; $F_{cor} = 2mv$ – Coriolis force.

The positive direction of motion is the movement of the grain up the scraper under the action of force. The differential equation of motion in vector form has the form [6,8]:

$$m\left(d^2xdt^2\right) = P_{in} + G + F_{cor} + F_{scr} + F_{scr1} + F_{air}\,, \qquad (1)$$

or:

$$m\left(d^2xdt^2\right) = m^2x - km\ dxdt - 2\,fm\ dxdt - \left[mg\ \cos\left(-t\right) + fmg\ \sin\left(-t\right)\right]. \qquad (2)$$



a *b*

Fig. 3. Calculation schemes for substantiating the completeness of centrifugal unloading of grain in a scraper elevator: a – force scheme, b – direction of motion scheme.

The general solution of the differential equation can be written as:

$$X_{gen} = C_1e^{t_1} + C_2e^{t_2} + A_1\cos\left(\xi - t\right) + B_1\sin\left(\xi - t\right). \qquad (3)$$

To invent calculation coefficients C_1 and C_2 we use the initial conditions:

$$C_1 = \frac{((k+2f\omega)/2 + (\sqrt{(k+2f\omega)^2+4\omega^2}/2))(-B_1\sin\xi - A_1\cos\xi + r)}{-\sqrt{(k+2f\omega)^2+4\omega^2}} +$$

$$+\frac{+A_1\omega\sin\xi + B_1\omega\cos\xi}{-\sqrt{(k+2f\omega)^2+4\omega^2}},$$

$$C_2 = \frac{((k+2f\omega)/2 - (\sqrt{(k+2f\omega)^2+4\omega^2}/2))(-B_1\sin\xi - A_1\cos\xi + r)}{-\sqrt{(k+2f\omega)^2+4\omega^2}} -$$

$$-\frac{-A_1\omega\sin\xi + B_1\omega\cos\xi}{-\sqrt{(k+2f\omega)^2+4\omega^2}},$$

where $\xi = \psi + \gamma$, $tg = \frac{\sin}{\cos} = \frac{1}{f}$, that is $= arctg\left(\frac{1}{f}\right)$.

For the elevator of the KZS–9 “Slavutych” grain combine, the solution to the compound differential equation will be written as:

$$X_{gen} = (0,01008\ldots0,01149)e^{(27,53\ldots22,81)t} + (0,0123\ldots0,01336)e^{-(49,866\ldots60,09)t} -$$
$$-(0,001\ldots0,0016)\cos((2,588\ldots2,416)-37,07t)+ \quad (4)$$
$$+(0,0034\ldots0,00318)\sin((2,588\ldots2,416)-37,07t).$$

To fulfill the condition of unloading grain (Fig. 3(b)), which at the moment of time when the scraper reaches the sector of throwing the BOS, is at its base - point O (the worst condition for the start of unloading), it is necessary that the time of passage of the scraper through the BOS sector is not less than the time of grain movement from point O to point B.

The distance OV for the scrapers of the KZS-9 combine is 100 mm [according to the working drawing]. The average time of grain movement along the scraper from point O to point B is 0,08 s, the minimum movement time is 0.06 s, the maximum is 0,130 s.

The time taken by the scraper to pass through the throwing sector (unloading sector) is determined by the angular speed of rotation of the upper sprocket of the elevator. (ω=37,07s^{-1}) and taking into account the design features of the casing: the unloading sector in KZS-9 has 115^0 , The time taken by the scraper to pass through the unloading sector is: 0,050s.

Thus, in the calculated range of values $X_{заг}$ For KZS-9, using equation 4, it is possible to determine the permissible range of changes in the speed of grain transportation by the elevator, provided that complete centrifugal unloading is maintained (Fig. 4).

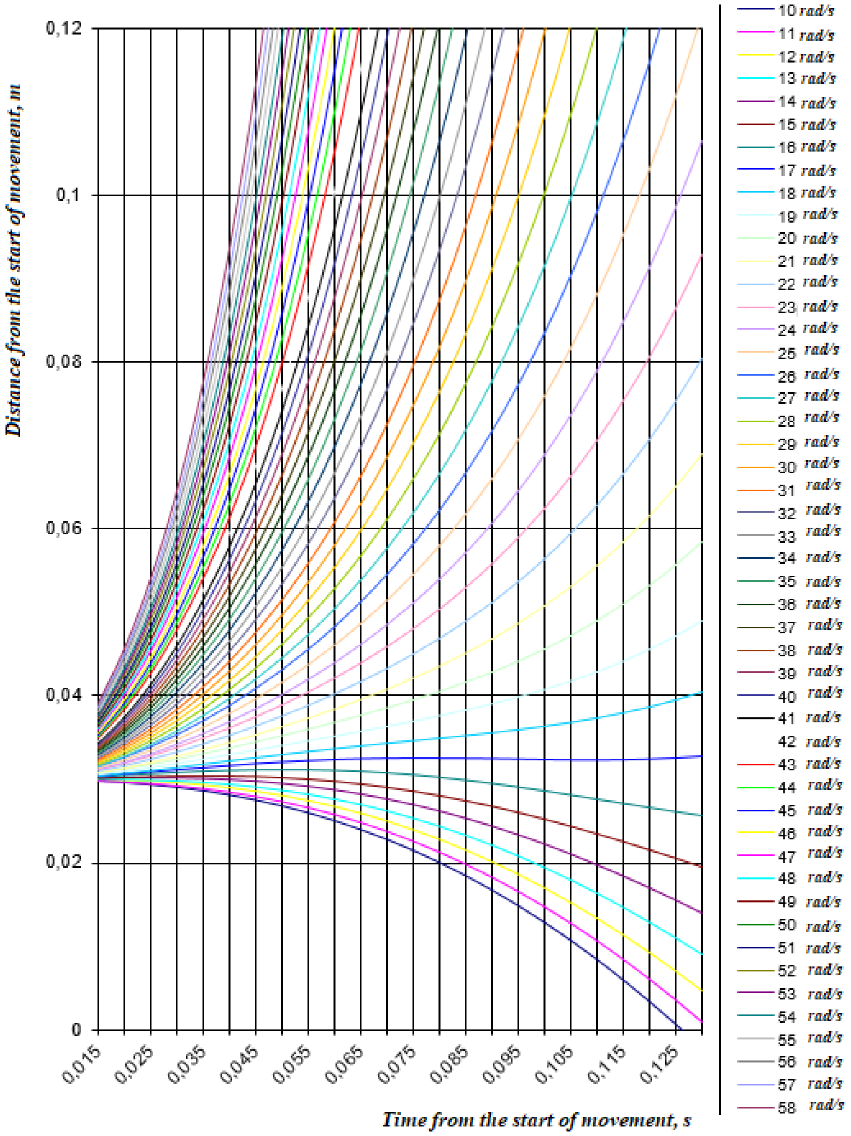


Fig. 4. Diagram of grain movement along the elevator scraper during centrifugal unloading according to equation (4) when the transportation speed changes

This range became the basis for the development of methodological aspects of experimental research, namely: a previously known mass of grain was poured into the bunker of the experimental installation. As previously written, in the first case, it was winter wheat grain, in the second, corn, and in the third, alfalfa. Then the installation was switched on to the nominal mode of transportation of the relative scraper elevator and using computer equipment and a speed sensor, the number of cycles of grain passing through the installation in a circle was measured. After that, the elevator was stopped, the grain was unloaded, and divided into two fractions: visually whole and crushed. The fractions were weighed separately. The transportation speed was measured using a drive shaft speed sensor and computer equipment.

The experiment was repeated at least ten times, then the transportation speed was changed. The obtained numerical values of the experiment are given in Table 1.

Table 1

Average percentage of destroyed grain relative to the total transported mass per one cycle of transportation by a scraper elevator of a combine harvester of the Slavutych type, %

Grain transportation speed, min^{-1}	Average percentage of destroyed grain relative to the total transported mass per one transportation cycle by a scraper elevator of a combine harvester of the Slavutych type, %			
	Winter wheat	Corn	Winter vetch	Stokolos (fire)
260	0,38	0,39	0,38	0,40
280	0,4	0,43	0,42	0,43
300	0,47	0,47	0,55	0,57
320	0,48	0,52	0,6	0,62
340	0,55	0,6	0,83	0,78
360	0,7	0,65	0,9	0,86

According to the results of experimental studies, it is possible to determine that the speed of grain transportation by a scraper elevator of a combine harvester with a centrifugal type of unloading has a significant impact on the quality of transportation, which is measured in relative units in terms of one transportation cycle. That is, we have confirmed that by changing the speed of grain transportation in a scraper elevator, it is possible to reduce the degree of grain damage caused by grinding. But how to do this in practice? We know that the bulk of threshing and separating devices is equipped with grain transport systems with mechanical drives - as a rule, these are chain or belt drives. At the same time, the transportation speed is constant, designed for harvesting high-yielding crops. Changing sprockets or installing additional mechanical gearboxes is economically impractical, in addition, this path leads to the complication of the drive mechanisms of the combine harvester and its increase in price. And this is technically and economically impractical. Therefore, the problem remained unresolved for some time.

But the experience of using agricultural machinery with variable seed and fertilizer consumption rates has proven that a practically justified alternative to a mechanical drive in this case is an electric drive with computer control.

Accordingly, where to get electrical energy? And here is the advantage in the paradigm of building modern agricultural machinery of the NEXAT system tractor [10].

5. Conclusion

When using scraper elevators based on bushing-roller chains in grain transport systems of modern combine harvesters, the main disadvantages in their operation can be considered to be the presence of reverse grain flow, mechanical crushing and compression damage to the grain; increased energy costs for transporting grain, especially low-yielding crops - seed grasses.

According to the obtained results of experimental studies, it is possible to determine that the speed of grain transportation by the scraper elevator of a combine harvester with a centrifugal type of unloading has a significant impact on the quality of transportation, which is measured in relative units per one transportation cycle.

On modern combine harvesters, it is advisable to introduce an electric drive with computer control of the speed of grain transportation both by the scraper elevator and by the grain-transport group as a whole. If we consider the scraper grain elevator of the KZS-9-1 "Slavutych" combine harvester as an example, then the speed of grain transportation without violating the conditions of complete centrifugal unloading can be changed by changing the speed of the drive sprocket in the range of 260…360 min^{-1} when increased to 160^0 increasing the centrifugal unloading sector.

The use of an electric drive also makes it possible to solve the technical problem of replacing the axial side feed of grain from the lower grain auger of the combine thresher with a radial top feed. This solution will reduce grain destruction in the area of the lower drive sprocket and scraper chain of the grain elevator.

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ДОСЛІДЖЕННЯ ОСОБЛИВОСТЕЙ ТРАНСПОРТУВАННЯ ЗЕРНА РІЗНОМАНІТНИХ СІЛЬСЬКОГОСПОДАРСЬКИХ КУЛЬТУР СКРЕБКОВИМИ ЕЛЕВАТОРАМИ ЗЕРНОЗБИРАЛЬНИХ КОМБАЙНІВ

У переважній більшості сучасних зернозбиральних комбайнів для транспортування зерна використовуються скребкові елеватори з відцентровим типом розвантаження. До основних недоліків таких елеваторів можливо віднести: прямий та зворотний сип зерна; подрібнення та компресійне пошкодження зерна робочими органами скребкового елеватора; відсутність врахування фізичних та біологічних особливостей зерна різних сільськогосподарських культур, що збираються комбайнами. Такі елеватори мають одну номінальну швидкість руху ланцюга зі скребками, не враховують ступінь завантаження зерно-транспортної лінії молотарки. Так, наприклад, при обмолоті комбайном КЗС- 9- 1 «Славутич» насінників трав, продуктивність скребкового елеватора в середньому – 0,1…0,3 кг/с, а він розрахований на 5..5,5 кг/с., маємо підвищені енергетичні затрати на транспортування.

Ще одна проблема спрямована на зменшення ступеню подрібнення та компресійного пошкодження зерна робочими органами скребкового елеватора зернозбирального комбайна. А *недоліком механічного приводу елеватору також є постійне потрапляння частини зерна в проміжок між шарнірами ланцюга зі скребками та привідної зірочки.*

За отриманими результатами експериментальних досліджень можливо визначити – на сучасних зернозбиральних комбайнах доцільно впроваджувати електричний привід з комп'ютерним регулюванням швидкості транспортування зерна як скребковим елеватором, так і зернотранспортною групою в цілому. Для зернозбирального комбайна КЗС-9-1 «Славутич» швидкість транспортування зерна може регулюватися в діапазоні 260…360 хв$^{-1}$ за умови збільшення величини сектору відцентрового розвантаження до 160°, що забезпечує більш плавний рух зернового потоку та зменшує його пошкодження.При цьому застосування електричного привода також вирішує технічну задачу заміни осьової бокової подачі зерна з нижнього зернового шнека молотарки комбайна на радіальну верхню подачу. Таке рішення зменшить руйнування зерна.
Ключові слова: *елеватор, зерновий потік, подрібнення зерна, сектор розвантаження, колова циркуляція.*

Ф. 4. Рис. 4. Табл. 1. Літ. 10.

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