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ANALYSIS OF METHODS OF TESTING CABINS OF GRAIN HARVESTING COMBINERS

https://doi. **10.5281/zenodo.15427439**

УДК 621.891

Syman I.V. ***Analysis of methods of testing cabins of grain harvesting combiners***

Abstract. *The article examines and analyzes the existing methods of testing cabins for durability and methods of evaluating the visibility of cabins. The national standard of Ukraine DSTU ISO 5700:2004 establishes the static load test method and the conditions for acceptance of protective structures (cabins or frames) of wheeled combines for agriculture and forestry. The national standard of Ukraine DSTU ISO 3463:2015 establishes the method of dynamic testing, the conditions of acceptance of protective structures for protection during overturning (cabin or frame) of agricultural and forestry wheeled combines. Practical testing using various stands, taking into account the requirements of regulatory documents for the characteristics of the impact of testing equipment on the protective structure, allows you to check theoretical patterns, assess the compliance of the cabin design, establish the actual value of absorbed energy from the applied load, work out the stages of applying loads in practice and check the accuracy of the measurement system. Visibility from the operator's workplace" establishes requirements, test methods and acceptance criteria for the operator's visibility. The design and equipment of the harvester must ensure the appropriate visibility of the operator when driving on public roads and when performing fieldwork. Visibility is considered appropriate if the operator is provided with at least partial visibility of each front wheel or wing when moving in a straight line and with a track width that corresponds to the total width of the combine with single wheels no more than 2.55 m.*

Key words: *protective structure, statistical load, dynamic load, visibility, testing.*

Симан І.В. ***Аналіз методів випробування кабін зернозбиральних комбайнів***

Анотація. *В статті розглянуто та проаналізувато наявні методи випробування кабін на міцність та методи оцінки оглядовості кабін. Національний стандарт України ДСТУ ISO 5700:2004 установлює метод випробування статичним навантаженням та умови приймання захисних конструкцій (кабін чи каркасів) колісних тракторів для сільського господарства та лісогосподарства. Національний стандарт України ДСТУ ISO 3463:2015 установлює метод динамічного випробування, умови приймання захисних конструкцій для захисту під час перекидання (кабіна чи каркас) сільськогосподарських і лісогосподарських колісних комбайнів. Практичне виконання тестувань за допомогою різних стендів з урахуванням вимог нормативних документів до характеристик впливу випробувального обладнання на захисну конструкцію дозволяє перевіряти теоретичні закономірності, оцінювати відповідність конструкції кабіни, встановлювати фактичне значення поглиненої енергії від прикладеного навантаження, опрацьовувати етапи прикладання навантажень на практиці та перевіряти точність системи вимірювань. Оглядовість з робочого місця оператора» встановлює вимоги, методи випробувань та критерії приймання оглядовості оператора. Конструкція і обладнання комбайна повинні забезпечувати відповідну*

оглядовість оператора при русі по дорогах загального користування і при виконанні польових робіт. Оглядовість вважається відповідною, якщо оператору забезпечена як мінімум часткова видимість кожного переднього колеса або крила при русі по прямій та при ширині колії, яка відповідає загальній ширині комбайна з одинарними колесами не більше 2,55 м.

Ключові слова: *захисна конструкція, статистичне навантаження, динамічне навантаження, оглядовість, випробування.*

Introduction

Combine harvesters are important vehicles for agriculture. During operation, these vehicles usually overcome terrain obstacles, work on slopes. Such conditions create a high risk of instability and overturning. For the operator, this threatens serious consequences – receiving serious injuries or fatalities. To increase the safety of the driver, all combines and combines must have a protective structure.

Along with the requirement to equip combines with protective structures against overturning, developers face the optimization task of ensuring safety criteria and minimum material consumption of the structure. The task became the subject of numerous scientific studies, experiments and tests [1].

Since 80% of the information about the operation of the machine is obtained by the operator as a result of visual observation, it is extremely important to ensure full visibility from the cab not only forward, but also so that he can observe the work process, working bodies, and vehicles moving nearby. Ensuring visibility from the operator's workplace is included among the main ergonomic requirements, as well as the most important operational indicators of combine harvesters [2].

Analysis of recent researches

The national standard of Ukraine DSTU ISO 5700:2004 establishes the static load test method and the conditions for acceptance of protective structures (cabins or frames) of wheeled combines for agriculture and forestry [3]. The national standard of Ukraine DSTU ISO 3463:2015 establishes the method of dynamic testing, the conditions of acceptance of protective structures for protection during overturning (cabin or frame) of agricultural and forestry wheeled combines (4). DSTU ISO 5721:2012 "Agricultural combines. Visibility from the operator's workplace" establishes requirements, test methods and acceptance criteria for the visibility of the operator of agricultural combines [5]. Researchers are guided by the requirements of these documents when conducting tests [6-18].

The aim and objectives of research

To consider and analyze the existing methods of testing cabins for strength and methods of evaluating the visibility of cabins.

Research results

Reproducing the conditions of a combine overturning with the help of test equipment requires obtaining the maximum reliability in order to make a conclusion about the conformity of the protective structure. At this time, the main methods of testing the operator's protective structures – static and dynamic – have been approved.

According to DSTU ISO 5700:2004 [3], horizontal loading tests and compression tests are carried out.

The test method involves the sequence of loading the protective structure of the operator on the stand - from the side, back, front and top.

The test must be carried out in accordance with the procedures in the following sequence:

1) The first longitudinal loading (for a combine with at least 50% of the weight on the rear wheels, the longitudinal load must be applied from the rear, for other combines, the longitudinal load must be applied from the front);

2) The first compression test (the load during the first compression test must be applied to the edge of the protective structure to which the first longitudinal load was applied;

3) Loading from the sides (in the case of a displaced driver's seat or a protective structure of asymmetrical strength, the loading from the sides occurs on the side of the most likely violation of the free space zone);

4) The second compression test (must be carried out on the side of the protective structure, opposite to the one to which the first longitudinal load was applied);

5) Second longitudinal load (the second longitudinal load is applied in combines manufactured with an open protective structure, only if the longitudinal force, according to 1), was not applied in the direction in which the protective structure is thrown).

There is a wide variety of structural schemes of frames and cabs, separate nodes and parts of protective devices, fastening of frames and cabs to the frame of the combine, which dampen the dynamic loads of the devices. Despite the great variety, all basic schemes of protective frames are classified according to the design and number of vertical power elements. Protective devices can be divided into two types: two-post and multi-post frames, which are built into the cabin or surround it along its contour [1].

The purpose of the research of the group of researchers of DNU "UkrNDIPVT named after L. Pohorily [1] was the development of technical support for tests of cabins or frames of wheeled combines with a static load.

The main purpose of the protective structure of the operator is to maintain the zone of free space for the operator during the absorption of external energy in the event of a rollover, therefore it is necessary that the materials, equipment and fasteners ensure the rigid fixation of the protective structure of the operator, mounted on the basis of the combine frame with a suspension system, and all the energy applied from the loading equipment was perceived only by the cabin and its rigid elements.

The impact of test equipment on cabins or frames is determined by the design of loading devices, the essential requirements for which are specified in the normative document on the test method [3], which served as a task for the development of technical support.

The developed and manufactured technical tool for testing the protective structures of wheeled combines with a static load is designed to carry out the following types of tests in accordance with DSTU ISO 5700:2004 [3]:

- Horizontal load test – application of horizontal load at the back, front and side of the protective structure;
- Compression test – application of a vertical load through a beam located on top of the upper part of the protective structure (1).

Technical characteristics of the developed UkrNDIPVT named after L. Pogorily stand for tests of cabins and frames of wheeled combines with static load is given in Table 1.

Further practical testing with the help of this stand, taking into account the requirements of the method for the characteristics of the impact of the test equipment on the protective structure, will allow to check the theoretical laws, evaluate the compliance of the cabin structure, establish the actual value of the absorbed energy from the applied load, work

out the stages of applying loads in practice and check the accuracy of the measurement system.

Table 1

Technical characteristics of the stand

No	The name of the indicator	The value of the indicator
1	The range of height change of the horizontal loading device, mm	100-3400
2	The range of height changes of the vertical load bar, mm	1500-2620
3	Means of creation of efforts	High pressure hydraulic cylinders
4	Energy source	Hydro station
5	Effort range, kg: - horizontal - vertical	 0...30160 0...21300
6	The number of tensometric links	3
7	Electric signal converter	Complex "Spider-8"
8	Device for processing information	Personal computer
9	Software	Microsoft Excel, Catman Express 4.5

The purpose of another study of the UkrNDIPVT named after L. Pohorily [3] determined cabin deformation indicators using standardized methods and developed technical means.

The tests were carried out in accordance with the methods specified in DSTU ISO 5700:2004 withusing a load stand, pressure and displacement sensors, a Spider 8 digital measuring amplifier and a laptop.

The protective structure AI.209.45.011.OO of the cabin of combines type C25 "Slobozhanets" was provided for testing.

Before conducting the tests, the dimensions of the protective structure of the cabin were measured and recorded. During the first longitudinal load, the load was applied to the upper transverse element of the protective structure from the front to the right. The point of application of the load was at a distance of 260 mm from the outer corner of the edge of the protective structure. Uniform distribution of the load in the direction perpendicular to the direction of action and along the loading beam was ensured using a sealing element. The value of the energy absorbed by the protective structure was 13100 J (required energy – 12586 J) with a maximum applied force of 82 kN and a displacement of 340 mm. During the first and second compression test, the structure was loaded vertically with a force of 180 kN along the front and rear upper transverse elements of the protective structure, withstanding the indicated force for 5 s. The side load was applied horizontally to the upper right longitudinal element of the protective structure at a distance of 85 mm forward from the control point of the driver's seat. The length of the loading beam was 600 mm. The value of the energy absorbed by the protective structure was 17,000 J (required energy – 15,732 J) with a maximum applied force of 80 kN and a displacement of 290 mm. After carrying out all stages of the tests, the front extreme point of the protective structure experienced the largest movement back – 70 mm, the front left point – 35 mm. The rear extreme points in the rear direction were also accommodated by 45 mm – right and 30 mm – left. In the lateral direction, the front right extreme point moved forward by 15 mm. After the tests, the free space zone was not violated.

The methods and technical means used during the tests make it possible to determine the amount of applied forces and deformation with the necessary accuracy and reliability.

During the compression tests, the values of the test force (180 kN) were reached, and during the application of horizontal loads – the energy absorbed by the protective structure (13100 J – longitudinal load and 17000 J – lateral load).

The protective structure at the front extreme point experienced the greatest final deformation – 70 mm, under such conditions, there was no violation of the driver's free space zone by the elements of the protective structure.

Therefore, the protective structure AI.209.45.011.00 of the cabin of combines type C25 "Slobozhanets" passed static tests for compliance with DSTU ISO5700.

In another [7] study, the static load test of combine cabs is modeled by the finite element method in accordance with the standardDSTU EN ISO 3471:2014 Earth-moving machines. Overturn protection devices. Technical requirements and laboratory tests (EN ISO 3471:2008, IDT). The analysis was carried out using software based on the principle of operation of the load-carrying mechanism in order to simulate test loads. The finite element model is constrained by the connection points of the frame, and deformations are investigated for three loading conditions.

Before the physical tests, a finite-element model of the cabin was prepared and an analysis was carried out. In this way, precautions were taken on areas that could cause problems during testing and time was saved.

The national standard of Ukraine DSTU ISO 3463:2015 establishes the method of dynamic testing, the conditions of acceptance of protective structures for protection during overturning (cabin or frame) of agricultural and forestry wheeled combines [4]. The standard applies to combines with at least two axles, equipped with wheels with pneumatic tires, both with and without tracks, with a total mass between 600 kg and 6000 kg. The minimum track width of the rear wheels should normally be more than 1150 mm.

The standard provides impact tests (front and rear impact tests, side impact tests) and crumple tests.

Test methodology. Combines with less than 50% of the mass on the front axle must be tested in the following sequence:

- blow from behind;
- crumpling of the rear part of the structure for protection during overturning;
- impact from the front;
- side impact;
- crumpling of the front part of the structure for protection during overturning

Testing of combines. In which 50% or more of the mass is on the front axle, it is necessary to perform in the following sequence:

- hit from the front;
-sideswipe;
- crumpling of the rear part of the structure for protection during overturning;
- crumpling of the front part of the structure for protection during rollover.

It is not permissible to repair or straighten any structural elements in the period between tests.

The induced energy absorbed by the overturning protection structure during the test is recorded and calculated, in joules, by the formula:

$$E=19.6\,N, \quad (1)$$

where N is the lifting height of the pendulum shock block.

The seat reference point (SCP) must be determined in accordance with ISO 5353.

In the case of a sprung seat, the shock absorbers must be adjusted according to the seat manufacturer's instructions. If there are no such instructions, the seats are fixed in the middle of the stroke of the shock absorbers.

After installing the seat on the combine, the CTS becomes fixed in relation to the combine and does not depend on the horizontal and vertical adjustments of the seat.

The zone of free space is determined with respect to the reference plane and the CTS. The reference plane is a vertical plane that is usually located along the combine and passes through the CTS and the center of the steering wheel. Usually the plane coincides with the longitudinal plane of symmetry of the combine. This plane is horizontal when the seat or steering wheel is moved during loading, but remains perpendicular to the combine or the base of the structure for rollover protection.

A rollover protection structure can be adopted only if the following requirements are met:

- no parts of the combine should penetrate into the zone of free space. No parts of the combine must touch the seat during the test. In addition, the free space zone must not be disturbed by external elements of the rollover protection structure.

- the structure for protection during overturning and the combine after each test must be visually inspected for cracks and tears. The following conditions must be met:

a) there should be no cracks in structural elements, fastening elements and parts of the combine that provide structural strength for protection during overturning;

b) there should be no cracks in the welded joints, which ensure the strength of the structure for protection during overturning, or in its fastening elements;

c) energy-absorbing gaps in the metal sheets of the structure are acceptable provided that, according to the testing laboratory, they do not have a significant effect on reducing the deformation resistance of the structure for protection during overturning.

During the test, the elastic deformation shall not exceed 250 mm in the horizontal plane which coincides with the upper bounding surface of the free space zone.

Visibility is an important characteristic of cabins— objective ability to see road conditions from the place the driver.

DSTU ISO 5721:2012 "Agricultural combines. Visibility from the operator's workplace" establishes requirements, test methods and acceptance criteria for the visibility of the operator of agricultural combines [5].

The design and equipment of the combine must provide the operator with adequate visibility when driving on public roads and when performing field work. Visibility is considered adequate if the operator is provided with at least partial visibility of each front wheel or wing when moving in a straight line and with a track width that corresponds to the total width of the combine with single wheels of no more than 2.55 m.

Shading zones should not be more than 700 mm, it is permissible to have shading zones of no more than 1500 mm, if the structural elements that create them cannot be of a different shape and cannot be placed in a different way.

If the combine has a windshield, it must be equipped with one or more mechanically driven windshield wipers.

The following methods of visibility (front field of view) tests are regulated.

Visibility check. The combine must be placed on a horizontal surface. On the horizontal stand, which is placed at the level of the operator's eye point, two point light sources are placed, which are placed symmetrically with respect to the base point at a distance of 65 mm from each other. It is necessary that the stand can rotate around a vertical axis that passes through the base point. When measuring shading zones, the stand must be turned so that the line that connects the point light sources is perpendicular to the line that connects the element that obstructs the view and the point of placement of the operator's eyes.

It is also necessary to conduct additional tests if there are design features. From the previous position, the light sources are shifted to the side, first to one side, then to the other, until the shadowed area from each structural element that interferes with the view becomes the smallest on the semicircle of view. Areas determined in this way are taken as shading zones. It is also possible to carry out a mathematical calculation of shading zones (instead of the described tests). With binocular examination and the distance between the eyes equal to 65 mm, the size of the shading zone x, mm, is calculated by the formula:

$$X = [(b - 65) / a] \times 12000 + 65, \quad (2)$$

where *a* is the distance between the structural element that obstructs the view and the operator's eye placement point, measured along the line of sight that connects the operator's eye placement point, the center of the element, and the perimeter of the viewing semicircle, mm;

b – the width of the structural element that obstructs the view, measured in a horizontal plane perpendicular to the line of sight, mm.

Acceptance criteria for testing are:

- the distance between the centers of the shading zones, measured along the chord of the viewing semicircle, should not be more than 2500 mm;
- on combines with a maximum design speed of ≤25 km/h, shading zones should not exceed 5500 mm and the distance between shading zones should $b_e \geq 1300$ mm;
- on combines with a maximum design speed >25 km/h, shading zones should not exceed 4500 mm and the distance between shading zones should $b_e \geq 1300$ mm;
- the distance between the vertical transverse planes that pass through the extreme front point of the combine chassis or radiator grille and through the center of the steering wheel, or in its absence through the base point >3500 mm.

The rear lateral field of vision must provide visibility of at least flat horizontal areas on both sides behind the combine at a height of 1 m above the level of the supporting surface, 5 m wide from a plane parallel to the vertical longitudinal plane of the combine and passing through the extreme lateral point starting behind 30 m behind the point of the operator's eyes.

Visibility of the area on both sides of the combine at a height of 1 m above the level of the supporting surface, from a plane that is parallel to the vertical longitudinal plane of the combine and passing through the extreme lateral point that begins 4 m behind the vertical transverse plane, must also be ensured. What passes through the point of placement of the operator's eyes.

The lateral field of view must provide visibility, at least, of flat horizontal areas at a height of 1 m above the level of the supporting surface, which are limited by:

- a plane that is parallel to the vertical longitudinal plane of the combine and is at a distance of 0.5 m from its extreme side point;
- a plane that is parallel to the vertical longitudinal plane of the combine and is at a distance of 2 m from its extreme side point;
- a plane that is parallel to the vertical transverse plane that passes through the point of placement of the operator's eyes and is 1.75 m behind this plane;
- a plane that is parallel to the vertical transverse plane that passes through the point of placement of the operator's eyes and is 1 m ahead of this plane.

Methods of side and rear field of view tests.

Conditions for checking the side and rear field of view.

The combine must be placed on a horizontal surface. On the horizontal stand, which is installed at the level of the operator's eye placement point, two point light sources are placed, which are installed symmetrically with respect to the operator's eye placement point at a distance of 65 mm from each other. It is necessary that the stand can rotate around a vertical axis. What passes through the point of placement of the operator's eyes. To determine the

blackout zones, the stand must be turned in such a way that the simultaneous or alternating switching on of the light sources allows to determine the blackout zones in the field of view that is checked, at a height of 1 m from the supporting surface. It is allowed to shift the stand with light sources to the left or right by a distance of no more than 170 mm. Checking the field of view can be carried out, for example, by moving the mirror at a height of 1 m over the entire field of view to be checked. The mirror should be turned so that the light sources are visible in it.

Acceptance criteria of the field of direct view. When conducting the described tests, there should be no darkening zones at a height of 1 m from the support surface in the field of view that is being checked. When performing lateral field of vision tests, the areas of shading must not exceed 10% of the field of vision tested on each side of the combine, and the 300 mm diameter test object must not be completely covered by each area of obscuration in each field of vision tested.

In work [9]a system for measuring the visibility of agricultural combine operators was developed and evaluated according to ISO 5006 and ISO 5721 standards, and a blind spot diagram around the test combine was created.

Two light bulbs were used to simulate the eyes of the operator, they were attached to a beam with a supporting frame. A wooden frame was used to determine the position of the supporting point of the seat. The 12 m visibility test circle was divided into six viewing sectors, and the test combine was placed in the center of the circle. Artificial light was provided in a darkened environment, and shadow or masking effects were measured manually at a distance of 12 meters around.

Results: When the bulbs were placed at the operator's eye level, forward visibility was good; no dimming was detected in the field of view "A", but larger widths of dimming were detected in the fields of view "B" and "C". As the blackout width exceeded 700 mm, additional tests were performed, such as moving the light sources to either side of the operator's eye level. Less than six dimming effects were detected in the semicircle of front view, and more than one dimming effect was detected in the "B" and "C" fields of view. A diagram of blind spots and specular visibility was created to determine the exact nature.

In work [2], a method of obtaining experimental data was developed, which allowsto obtain accurate results of the study of shaded viewing areas when designing a combine cabin at the stage of developing a layout, without making prototypes in kind and conducting experimental studies aimed at the feasibility of using the cabin that is being developed.

Conclusions

1. The biggest hazard for vehicles used in agricultural land is rollover. The requirements approved by regulatory documents provide that all combines must have a protective structure. Technical support for tests of protective structures of the operator (cabin) in case of overturning within the scope of the distribution of regulatory documents, which define the method of static testing and the method of dynamic testing, can be implemented by various technical solutions.

2. Visibility assessment is an effective way to ensure proper and safe work for combine drivers. Incorporating visibility tests into the overall testing process can help combine manufacturers design safe and ergonomic cab designs.

3. This analysis will be used in the further planning and development of parameters and modes of testing of the protective structures of the operator (cabins) and the development of improved methods for assessing the visibility of the cabins.

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