About rational number of spindles on drums of cotton harvester

A. A. Rizaev[1*], *D. B.* Alimova[1], *N. N.* Omonov[2], and *I. A.* Mamatmurodov[2]

[1]Institute of Mechanics and Seismic Stability of Structures named after M.T. Urazbayev of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
[2]Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan

Abstract. The technological process in a cotton harvesting machine is carried out mainly with the help of spindle drums, doffers, and mechanisms that set them in motion. The contact of the spindles in the drums with the open bolls of the cotton during the harvesting process is due to the quality of the harvest and the full set of parameters of the drums, which should be paid attention to: diameters, the number of spindles in them, kinematics, the size of the open bolls and the size of the cotton. The article presents the analytical expression linking the parameters of the drum and the open bolls of cotton based on the analysis of the results of studies conducted in this direction and experiments. The graphs were constructed that reveal the essence of this connection, and their analysis was given. The article presents the results of comparative experiments on the example of a vertically-spindle cotton harvester with two pairs of sequentially arranged spindle drums with 12, 14, and 15 spindles on each drum with the same diameter kinematic mode of its operation. The results of theoretical and experimental studies have allowed us to conclude that an increase in the number of spindles in front paired drums contributes to an increase in the completeness of cotton harvesting from open cotton bolls.

1 Introduction

When harvesting cotton, our republic's clusters and farms use modern horizontal and vertical spindle cotton harvesters. Technological processes in spindle cotton harvesters, especially ensuring the rational parameters of the drums, are of great practical importance for high-quality and efficient harvesting. In this direction, it is appropriate to highlight the work of specialists from Uzbekistan, the USA, Australia, Israel, China, India, and Turkey.

The better preservation of the natural quality of harvested cotton is provided by spindle cotton harvesters. In practice, both horizontal and vertical spindle sweepers are used. They consist of drums on the periphery of which there are vertical spindles with teeth, or cassettes with horizontally arranged console tooth spindles [1-11]. During the cotton harvesting, the teeth, sticking into the cotton, wrap it around the spindle, and the latter, rotating together with the drum, moves towards the doffer, where the doffer releases the spindle from wrapping and throws it to the receiving chamber of the apparatus. The airflow

*Corresponding author: rizayev52@mail.ru

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

carries the cotton to the bunker of the machine. In this technological cycle, the efficiency of cotton harvesting depends on the number of spindles on the drum.

It is known that harvesting in one pass by machines that ensure the opening of cotton bolls by 90% or more leads to high efficiency. In this case, research work is known from the literature to determine the optimal value of the number of spindles (cassettes) in the previous drums of the typesetting device to improve their construction and technologies of the manufacturer [7-12]. Especially in the design of the horizontal spindle apparatus, the front drum has 16 pieces, and in the rear drum, cassettes with 12 spindles were placed in John Deere cotton pickers belonging to Case and CRCHI [13-15]. At the same time, recently, the drums of a multi-row machine of apparatuses have been unified, having 12 spindle cassettes [16].

If in the first experimental designs of a vertical spindle cotton harvester, the spindle drum was equipped with 36 spindles, the designers later reduced them from 24 to 15 pieces. In the early 70s of the XX century, the drum with a diameter of 292 mm was equipped with 12 spindles with a diameter of 24 mm. [16-18]. As a unified series of harvesting apparatus, this version of the spindle drum is produced by production. But in the well-known researchers of scientists, designers, and testers of machines in Uzbekistan, considering the technological load of paired spindle drums of the apparatus, recommendations were developed on equipping them with the same number of spindles [18]. But as it is known, the technological load (harvest by opened bolls) on spindle drums arrives unevenly. This factor on the horizontal spindle apparatus was solved by increasing the diameter and number of spindle cassettes of the first drum [2-5, 9].

There are similar solutions from Chinese manufacturers of cotton harvesting equipment [9, 15]. Further American researchers and machine manufacturers followed the path of unification of the design of the front and rear drums, as well as differentiated operation regimes based on Information Technology and hydraulic drives of working units [4]. With a simpler mechanical drive of the working organs and a unified design of the spindle drums of the apparatus, the rationale for the number of spindles on the drums remains relevant for the vertical apparatus, and the article is devoted to this issue.

2 Materials and methods

Based on the theoretical and experimental work, analytical analyses were carried out, and their solutions are presented in histograms. Following the methods presented in the Theory of cotton harvesters, a mathematical connection was obtained representing the interaction of the spindle drum and the smallest open bolls, graphs were constructed linking them with the parameters, and their analysis was carried out. Theoretical researchers were the basis for creating a harvesting machine with a different number of spindles on a drum with one specific diameter and conducting comparative experiments in the field of cotton harvesting machines. The tests followed Uzbekistan State Standard 3225-2017 “Testing of agricultural machinery. Cotton harvesting machines. Test methods”.

3 Results and Discussions

Based on the tests carried out, it was found that the vertical spindle in the first pair of spindle drums, with an increase in the working clearance of the spindle from 32 mm to 52 mm, the completeness of the spindle picking decreased from 79.5% to 57.6%; as a result, the picked cotton with the next pair of working clearance of 32 mm reached 22%, while the third pair of picked cotton, with a working gap of 28 mm, the completeness of the picking increased from 4.6% to 9.2%, according to a study by the Institute of Mechanics [16].

The total amount of cotton harvest was 90-92%. The identical design and operating mode of the drums arranged in two pairs, as well as the completeness of the picking when the working slot in the rear pair remained constant at 28 mm, were presented in Figure 1 based on our analysis of the values of the cotton change recruited by the drum spindles located in front and back.

The diameter of the picker consisting of a pair of drums is $D = 292\ mm$, the diameter of the spindles is $d = 24\ mm$, the number of 15 pieces, the number of open bolls is 60...90%, and the productivity is 23.4...25.8 c/ha in experiments conducted in the laboratory field conditions with a harvesting machine, the average amount of picking at the first pass is 74.1...78.2%, at the second pass is 7.8...9.0% and at the third pass is 2.2...2.6%, this was previously known by employees of the Head Special Design Bureau of the "Agromash" Joint Stock Company [1, 15-19].

As can be seen from this, the amount of harvesting, which is typed using spindle drums in the first pair of a typesetting device equipped with three pairs, has changed to 60...80% and, depending on the working slot, this pair is from 2.0 to 7.5 times compared to subsequent pairs, and on a device equipped with a drum device with two pairs of spindles, this parameter is 5.5...19.0.

Increasing the loading of the first pair of drums led to the fall of cotton on the ground from 1.4 to 2.7 times. Therefore, researchers have proposed several technical solutions for the rational distribution of the amount of cotton harvesting to the next pair of spindle drums of the first pair.

Especially in this research, we will focus on the theoretical and experimental work at the Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan.

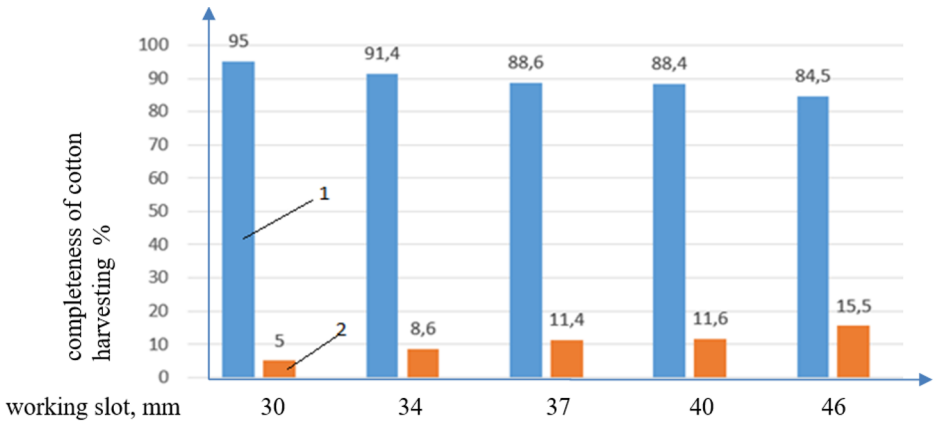

Fig. 1. Amount of picked crops by harvesters with two paired spindle drums column 1 is front pair, column 2 is rear pair

According to the results of research conducted in the harvesting machine, the number of spindles in the drums of the previous pair, when the diameters of the drums and spindles arranged in pairs of spindles are at the same values is 1.2 compared to the pair on the reverse side. If the amount of picking is increased by 1.2...1.3 times, then we additionally see an increase of 3...4% [17-20].

The diameter of the spindle $d = 30mm$, and the number of teeth of the cross-section is 5 pieces, and the drums of both pairs are also assembled by a machine equipped with a harvesting machine with 14 spindles installed in each of them; the amount of cotton

harvesting was 2.5...3.5% increase recorded in comparative tests by researchers of the Institute of Mechanization of Agriculture of the Republic of Uzbekistan [18, 19].

At the same time, it should be noted that even in comparative field tests conducted by specialists of the Certification and Testing Center for Agricultural Machinery and Technologies with researchers from the Institute of Mechanics and Seismic Stability of Structures in 2018-2020, this legislation was repeated for the MX-2.4 semi-trailer machine with 14 spindles installed on it. Now let's look at the calculation scheme in Figure 2, devoted to the analysis of this position from the theoretical side.

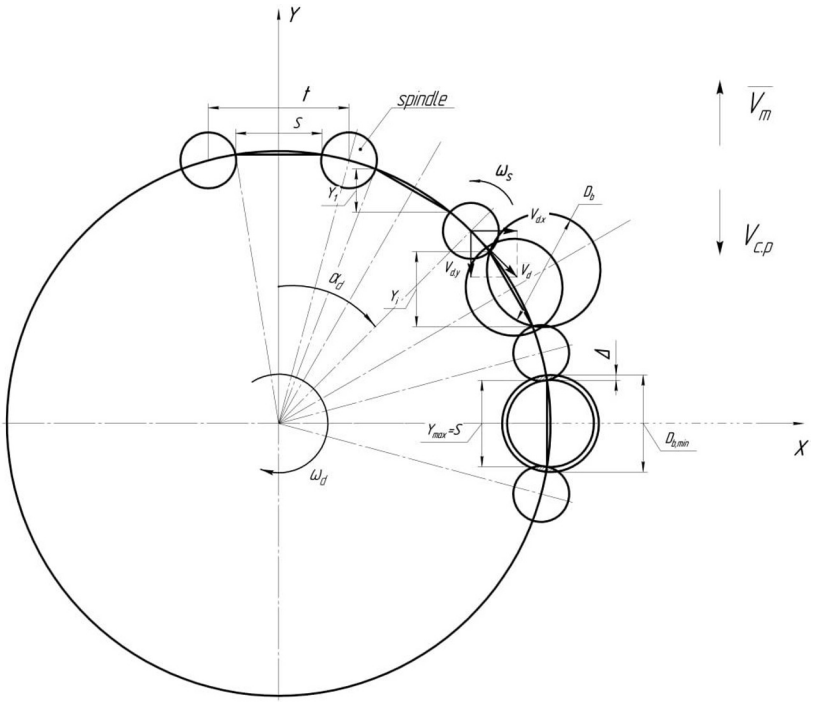

Fig. 2. Connection between side spindles in drum with open cotton boll.

The figure shows the spindles located side by side in the spindle drum between the axes have t (step), the surfaces between them, the angle of rotation of the drum α_d and the rotation speed ω_d, the minimum diameter of the opened cotton boll, which can be placed between a pair of spindles, is $D_{b\min}$ (conditionally considered a sphere), its deformation 2 Δ and the speed of the machine V_m (the speed V_P at which it enters the reverse working slot of the cotton).

When cotton enters vertically into the working chamber, the projection of the linear velocity vector V_d of the drum on the OY axis is equal to the speed of the machine V_{dy} and is directed to the opposite direction, i.e., $V_m = -V_{dy}$ the effective execution of the picking process in the working chamber is known from research. From the diagram in Figure 2, we can write the following equality:

$$Y_i = D^1_{b\min} \cdot \sin\alpha_d \qquad (1)$$

or side by side with spindles, an open cotton boll is the ratio of the smallest diameter; the probability of covering this boll with spindles can be expressed as follows:

$$P = \frac{Y_i \cdot K_i}{S} = \frac{K_i \cdot D^1_{b\min} \cdot \sin\alpha_d}{S} \qquad (2)$$

here $D^1_{b\min}$ is the smallest conditional diameter of the opened boll, mm;

S is the distance between the surfaces of adjacent spindles, mm;

K_i is coefficient of variation of the distance between the surfaces of the spindles;

This coefficient is related to the absorption coefficient of the drum as follows:

$$K_i = \frac{V_d}{V_m} = K_O \qquad (3)$$

here α_d is the angle of inclination of the drum relative to the OY axis, rad (deg)

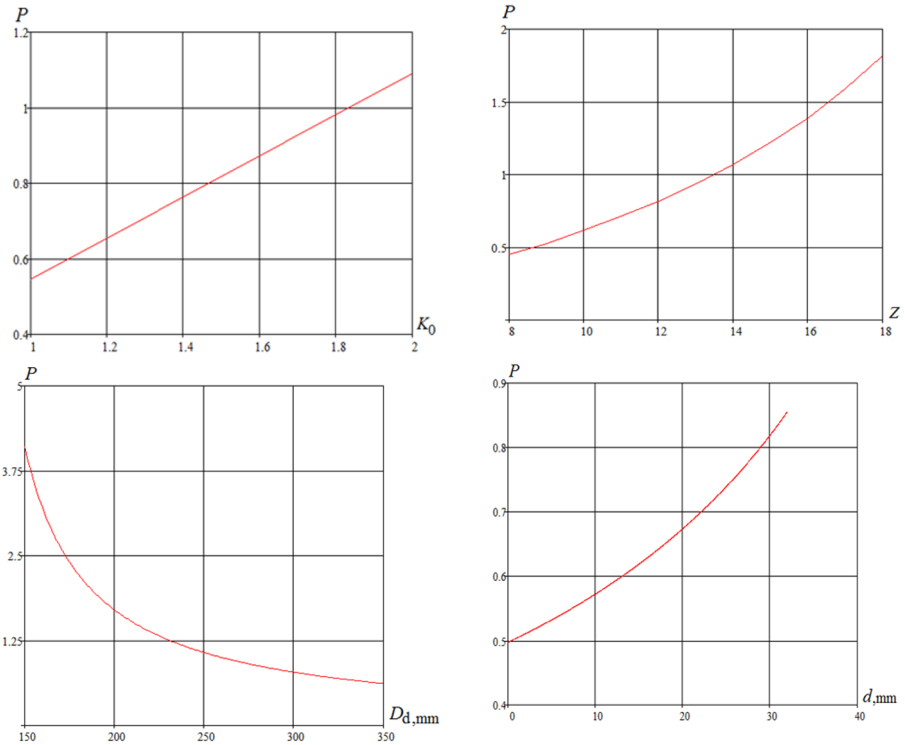

Fig. 3. Graphs of influence of smallest diameter of open boll, drum, parameters spindle on influence of P harvesting.

If the distance between the surfaces of the spindles is equal to the diameter of the drum - D_d, the spindle - d, the number of spindles in the drum - Z, then

$$S = \frac{\pi \cdot D_d - Z \cdot d}{Z} \tag{4}$$

substituting (4) and (5) into (2)

$$P = \frac{Z \cdot K_O \cdot D^1_{b\min} \cdot \sin\alpha_d}{\pi \cdot D_d - Z \cdot d} \tag{5}$$

here $D^1_{b\min} = D_{b\min} - 2\Delta$, $\alpha_d = \arcsin\frac{1}{K_O}$

(6) the expression correlates the parameters of the drum with the smallest open diameter $D^1_{b\min}$.

Our research shows that while the spindle is active, for the cotton fibers to catch in the boll, it is necessary to seal it with teeth at a certain deformation [20]. These expressions are given (1), (2), and (6) taken into account.

Using expression (6), the following initial values were taken to formation diagrams of the arguments contained in it, which each represents its influence on P: here before $D_d = 292\ mm$, $d = 30\ mm$, $K_O = 1.5$, $D_{b\min} = 46\ mm$ we accept this and create our next calculations. Based on expression (6), showing without changing the other parameters P, in which the smallest diameter of the opened cotton boll $D_{b\min}$, the coefficient of overtaking of the drum K_O, the influence of changes in the number of spindles of the drum, changes in the diameter of the drum and changes in the diameter of the spindle, graphs were constructed using the software package MathCAD 15.

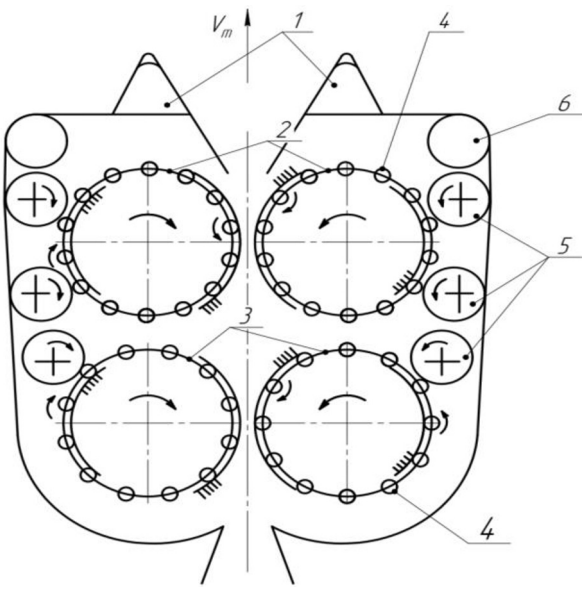

Fig. 4. Scheme of harvesting machine with 14 spindles in front pair and 12 spindles on rear pair of drums: 1 is brush lift, 2 is front pair of drums, 3 is rear pair of drums, 4 is spindles, 5 is doffers, 6 is receiving camera of the apparatus.

In the graphs in Fig. 3, the increase in the value $D_{b\min}$ from 30 mm to 50 mm was indicated as linear to $P(D_K)$, the change in the value K_O from 1 to 2 was also linear to $P(K_O)$, the effect of Z, D_d and d, K_O, it was indicated that has a value $P(Z), P(D_d)$, $P(d)$ following curvilinear laws.

It became known from them that with the smallest diameter of the open boll, the overtaking of the linear speed of the drum relative to the speed of the machine, the number of spindles, and an increase of the diameter increases the probability of picking open bolls of the spindle drum. Still, the diameter of the drum has the opposite effect on this indicator.

The analytical expression (6) and the graphs constructed based on it provided that $P \geq 1$ producing harvesting machines with 14 and 15 spindle drums were possible. Figure 4 shows a schematic diagram of the apparatus, in which the front pairs of drums are equipped with 15 (or 14) spindles and the rear ones with 12 spindles. Vertical spindle machines according to drum schemes 15-12 and 12-15 (front pairs with 12, and rear with 15 spindles) were installed on 4-row cotton harvesters 14KHV-2.4 for row spacing 60 cm and KHNP-1.8 for row spacing 90 cm.

Table. Quantitative indicators of operation of devices at a one-time assembly with various schemes of arrangement of spindle drums.

Technological scheme	Harvested cotton, %	Clogging of harvested cotton, %	Cotton losses on the ground, %
Cotton harvesting machine 14KHV-2.4			
12-12 (production scheme)	88.77	5.9	5.09
15-12	91.66	5.2	3.63
12-12	87.05	6.1	4.09
12-15	86.91	6.3	4.81
Cotton harvesting machine KHNP-1,8			
12-12	87.50	7.3	2.04
15-12	91.71	7.9	1.65

Similar schemes of devices were previously tested in JSC “BMKB-Agromash”, but the requirements of unification and universalization of components and parts of the device in the field of production, as well as the lack of a theoretical basis, did not allow them to be used in mass production. Similar schemes of devices were previously tested in Joint Stock Company “Head Specialized Design Bureau – Agromash”, but the requirements of unification and universalization of components and parts of the device in the field of production, as well as the lack of a theoretical basis, did not allow them to be used in serial production.

To determine the efficiency of the proposed device schemes with a production scheme of 12-12 (12 spindles on the front and rear drums), tests were carried out in real field conditions. The test procedure is based on the normative materials adopted in Uzbekistan. The table shows the results of the experiments.

It can be seen from the table that with the same parameters ($D_d = 292mm$, $d = 30mm$, $K_O = 1.5$) and kinematic regimes of operation of the machine ($n_d = 106\min^{-1}$, $V_m = 1.05m/s$), the scheme of the apparatus 15-12 is more effective both in picking cotton from open cotton bolls (by 2.89% more) and in cotton loss on the ground – 1.46%. The

clogging of the harvested cotton has practically remained at the same level. The scheme's effectiveness 15-12 was manifested on the KHNP-1.8 machine. The harvesting increased by 4.21% due to reduced losses on the ground and cotton bushes.

Similar comparative tests were conducted based on projects of the Ministry of Innovative Development of the Republic of Uzbekistan from 2016 to 2020. Their results are given in our work [18-20], based on the data of comparative tests conducted at the center for certification and testing of agricultural machinery and technology of the Ministry of Agriculture of the Republic of Uzbekistan [19].

4 Conclusions

It follows from the above graphs that the probability of capturing P the open cotton boll with spindles depends on the diameter of the open boll $D_{b\min}$, the coefficient of overtaking of the drum K_O, the directly proportional diameter of the spindle - d and the diameter of the drum - D_d and the number of spindles with a curved (paraboloid and hyperboloid) connection. According to the results of theoretical and experimental researchers, it can be concluded that an increase in the number of spindles in the front pair of the vertical spindle apparatus compared to the rear pair of drums increases the efficiency of the cotton harvester.

References

1. Matchanov R.D. Combined cotton picker with interchangeable devices IOP Conf. Series: Earth and Environmental Science Vol.677 p. 052021 (2021)
2. Patent. Johansen et al. US 2009/0000261A1. High speed cotton picker drum. Pub. Date: Jan. 1, (2009).
3. Teng, L. I., Fuping, H. A. O., Zengde, H. A. N., Xianfa, F. A. N. G., Zhaohui, H. A. O., & Yunqiang, L. I. U. Design and Test of Horizontal Spindle Picking Head with High Efficiency. Nongye Jixie Xuebao/Transactions of the Chinese Society of Agricultural Machinery, 50(12). (2019).
4. Patent application. US 2015234374 dated 02.10.2015. Cotton processing system with mechanical sequencing. author of the Weber, Scott D. The applicant is Deere & C.
5. Carlson B.C. Patent US 2021015043 (A1). Cotton harvesting machine with automatically variable drum and spindle speed. (2021).
6. Li, H.Y.; Fu, X.Q.; Wang, H.B.; Zang, H.W.; Gu, Y.Q.; Du, X.T.; Tao, Y.C.; Li, J. Research on the wear characteristics of the Hook Teeth of cotton Pickers. Coatings Vol.12, p.762. (2022).
7. WuJ.S.; Chen, X.G. Present situation, problems and countermeasures of cotton production mechanisation development in Xinjiang Production and construction crops Trans.Chin. Soc. Agric. Eng. 31.5-10. (2015).
8. Li, W.C.; Qiao, Y.Y.; Deng, Y.M.; Liu, X.M.; Zhang, H.W. Evaluation and analysis of hook tooth wear for cotton picker spindle. Journal China. Agric. Mech. Vol. 39, pp. 11-14. (2018).

9. Haiyang Li. Analysis and experiment of dynamic picking process of spindle of cotton picker. Agriculture, Vol.12, 1346. pp. 1-12. (2022).
10. Baker K.D.; Delhom C.D.; Hughs, E. Spindle diameter effect for cotton pickers. Trans. ASABE 33, 321-327. (2017).
11. Baker, K.D.; Hughs, E.; Foulk, J. Spindle speed optimization for cotton pickers. Trans. ASABE 31.217-225. (2015).
12. Zang, Y. Q.; Wang, W.; Liao, J.A. Wear failure analysis on spindle of cotton picker. Trans. Chin. Soc. Agric. Eng. 33., 45-50. (2017).
13. Deere and Company. Products: CP690 Cotton picker. (2014).
14. Rizaev A.A. Research and construction of working units of cotton picking machine with high efficiency, Tashkent (2017).
15. Rizaev Anvar. Bench-scale study of centrifugal fan parameters. IOP Conf. Series: Materials Science and Engineering. (2021).
16. Rizayev, A. A., Khakimov, M. A., Usarov, S., and Akhmedov, S. H. A. Development of the four-row cotton harvester for one-time cotton picking. In AIP Conference Proceedings, Vol. 2637, No. 1, p. 060005. (2022).
17. Protocol №16-2020. (MB Atex – 2018+BV-Atex-2018-13) of preliminary tests of the MX – 2.4 cotton harvester. P. 24. (2020).
18. Rizaev Anvar. Cotton harvesters for one-time cotton-picking. IOP Conf. Series: Materials Science and Engineering. (2021).