Systematization of Steam Cultivators and Structures Working Bodies

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Abstract. The main method of harvesting hay is its pressing, in which a mandatory requirement is to ensure constant conditioned humidity of the material. Compliance with such material parameters in the field is very difficult. Therefore, in order to achieve maximum efficiency when harvesting bulky, it is necessary to use various bioconservants and their uniform distribution over the surface of the selected roll. One of the conditions for the operation of the distribution system is the use of high pressure to crush a drop of a solution of a biological product, which negatively affects the effectiveness of the preservative. In the course of the work, the performance of the sprayer was studied depending on the pressure in the pneumatic system of the spraying device and the diameter of the feeding tube.

1 Introduction

According to the definition, cultivation is a method of continuous or inter-row tillage, with crumbling, loosening, partial mixing and leveling, as well as pruning of weeds.

When exposed to the soil during cultivation, the moisture and air permeability of the formation improves, which favor the activity of microorganisms and the growth and development of plants.

In addition, cultivation leads to an accelerated emergence of weeds, which are pruned during subsequent processing [1].

The increase in the production of agricultural crop production directly depends on the level of technology of the new generation. The high level of technology of the new generation is characterized by high productivity of the unit when meeting the agrotechnical requirements for a specific method of tillage.

The main requirements for carrying out such a tillage technique as cultivation are the following: loosening the soil without turning the formation; complete pruning of weeds; ensuring a finely lumpy structure of the treated layer; uniformity of the depth of loosening,

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compliance with the overlap between adjacent passages of the extreme working bodies; removal of the lower wet layer to the surface of the field is not allowed [2].

Steam cultivators, as a rule, also perform continuous pre-sowing tillage in accordance with current trends in the field of mechanical engineering in terms of the development of unified structures and universalization.

Thus, after the passage of the steam cultivator, the surface of the field should be leveled, with fully trimmed weeds, a finely lumpy soil structure with a compaction of the subsurface layer, which is achieved by rolling [3].

2 Materials and methods

The method of monographic examination of the structures of steam cultivators, both of the machine as a whole and separately of the main working bodies, was used on the basis of well-known scientific research and the results of state tests. Thus, the really working steam cultivators recommended for use in agricultural production were considered. In addition, the patented designs of the working bodies of steam cultivators were analyzed [4-7].

The following steam cultivators are considered and analyzed: KPPU-8, the KSOP family (KSOP-4, KSOP-5, KSOP-6N, KSOP-12), CD-720M, the K-720MK and K-12000MK families, the Altai KSU family (KSU-11, KSU-15), KPSH-9, the POLARIS family (POLARIS-4, POLARIS-4SK, POLARIS-8.5SK, POLARIS-8.5, POLARIS-12, POLARIS-12N), the CHECKPOINT family (CHECKPOINT-6, CHECKPOINT-8, CHECKPOINT-9, CHECKPOINT-12, CHECKPOINT-12V, CHECKPOINT-14.5), KShU-12M, KDK-4, KBM family (KBM-4.2NU, KBM-4.2NUS, KBM-8P, KBM-10.8P, KBM-11PSV, KBM 12-4K1, KBM-14.4PS), Combi 3, KPK family (KPK-12, KPK-4S, KPK-8C), KPS family (KPS-4U, KPS-5U, KSP-6-01), KP-12C, KP-12A, KP-15A, KPU-6, KPSH-7.2, KNK-7.2-01, KSHU-12N, KPM family (KPM-8U, KPM-10, KPM-12, KPM-14), KMP-14 Antares, KPO-13C, KSK-12, KM KPK-12, KS family (KS-8, KS-8M, KS-10, KS-12), KBP family (KBP 12-4 K1, KBP 8-4 K1), Stepnyak cultivator family (Stepnyak-5,6, Stepnyak-7,4, Stepnyak-10, etc.), KPI-3,8, TILLERMASTER family (TILLERMASTER-14000, TILLERMASTER-16000), JOHN DEERE 2210LL, KRISTALL 9/600K, CHALLENGER CH 5730, SALFORD models 580-40, CULTIMER L 4000, KUHN 5635, KORUND 8/750, VARIO 400, KRAUSE 5635-34, VERSATILE C600, Top Down TD700, RUMPTSTAD ZBC, etc.

The efficiency of steam cultivators was determined based on the results of state tests of the Volga, Northwestern, Siberian, Kuban, North Caucasian, Central Chernozem, Kirov, Vladimir MIS over the past 10 years [1].

3 Results

Currently, a number of steam cultivators of various designs are used [8].

In general, steam cultivators consist of a drawbar for attaching to a tractor, a frame for attaching working bodies, a hydraulic system, support and transport wheels.

Steam cultivators can be classified into 3 types:

- by type of main working organs (paws);
- according to the type of additional working bodies (rollers, harrows, rods);
- according to the type of connection to the tractor (trailed, mounted).

The authors [4] found that the hinged connection of a steam cultivator with a tractor, compared with a trailed one, makes it possible to increase the value of the coefficient of working strokes of the unit by an average of 8.5%, which will have a positive effect on productivity.

It is noted that due to the disadvantages of the design of steam cultivators in terms of the increased distance between the support wheel and the working bodies, the quality of soil cultivation deteriorates, in particular, uniformity in depth of travel [5]. Designs are being developed to ensure the stability of the steam cultivator without support wheels [6]. At the same time, mounted steam cultivators have less longitudinal stability during transportation [9].

The frame of a steam cultivator can be a universal hinge-sectional [8, 9], the length of which is determined by a given ratio in accordance with the required tractor power. At the same time, in order to meet the agrotechnical requirements for the uniformity of the loosening depth, steam cultivators must have certain dimensions [10]. The uniformity of the depth of tillage is regulated by setting the height of the support wheel relative to the frame of the steam cultivator.

Foreign cultivator designs may not be fully suitable for the soil and climatic conditions of southern Russia, especially in dry years, when soil hardness significantly exceeds the norm, and moisture reserves inside the reservoir are so negligible that when they are brought to the surface of the field during loosening, they will instantly lead to evaporation.

The analysis [11-16] showed that an increase in the grip width of steam cultivators from 4 to 16 meters leads to a sharp increase in weight (8 times), which has a direct impact on the growth of cost indicators and can cause excessive pressure on the soil, which is unacceptable.

The main working organs of a steam cultivator include paws. Depending on the clogging of the field and the physico-mechanical properties of the soil, the steam cultivator is equipped with paws containing knife-shaped (cutting), chisel-shaped and spear-shaped (loosening) elements.

The knife-shaped elements of the working body of the steam cultivator will allow you to cut weeds and loosen the soil. Chisel-shaped and spear-shaped elements on the working bodies of a steam cultivator are used when the field is poorly clogged to decompress the soil.

To destroy the crust on the surface of the field, often the main working organs of a steam cultivator are rotary working organs in the form of disks. However, disc working bodies can excessively spray the soil in arid conditions, which leads to increased erosion processes.

Thus, the main working organs of a steam cultivator can be cutting, loosening and universal, depending on the technological result.

The cutting working organs of a steam cultivator are mainly aimed at destroying weeds by pruning them, they function on the principle of sliding cutting, i.e. prolonged contact with the surface of the paw, therefore they are performed in the form of a plane cutter (one-sided or two-sided). Based on this, the double-sided plane cutter of the steam cultivator has a solution angle from 60-70 ° to 90 °. The planar cutter is characterized by a small crumbling angle (up to 18 °) and therefore is not quite suitable for soil decompression during steam treatment [17].

Loosening working bodies of a steam cultivator are used for decompression. The loosening working bodies of a steam cultivator can be chisel-shaped or spear-shaped, one-sided or reversible.

Universal working bodies are used for simultaneous pruning of weeds with loosening and decompression of the upper soil layer. The universal working bodies of a steam cultivator are characterized by a large crumbling angle (up to 30 °) compared to a plane cutter.

The universal working organs of a steam cultivator include pointed paws.

To copy the surface of the field, the arrow foot stand is pivotally connected to the tensioner spring bracket. However, the presence of cylindrical tensioner springs in the design increases the mass of the cultivator by 60 kg or more.

Therefore, improving the designs of steam cultivators to improve the quality and reduce energy consumption for tillage is impossible only in part of the main working bodies. The frame, the rack and the design of additional working bodies of steam cultivators are also being improved.

The curved shape of the cultivator's working body is also used to reduce soil resistance. The authors propose a design of pointed legs of a steam cultivator by hydrodynamic analogy based on bioforms moving in dense media. A special case of using a curved shape in structures is the crescent-shaped working body of a steam cultivator.

The pointed paws, the design of which is described in, are also made in a curved shape. At the same time, the cutting edge of the pointed paw is toothed, as in the working body having different angles of solution, which prevents the blade from being enveloped by weeds.

The design of the pointed foot presented in due to the serrated surface of the cutting edge contributes to less energy-intensive and higher-quality crumbling of the soil due to alternating deformations caused by the biconvex curvature of the surface of the working organ.

The design of the pointed foot is equipped with curved elements.

In order to ensure a leveled field surface after the passage of the pointed foot, the authors finalized its design by installing additional elements on the wings. At the same time, after the passage of the improved pointed foot, there is no furrow from the rack, and the soil is evenly distributed.

Placing a vertical knife-shaped element on a flat rack reduces sticking and clogging of the working body with soil.

To prevent the removal of moisture contained inside the formation to the surface of the field, the pointed paw of the steam cultivator is equipped with a plank with narals mounted behind the working body at the depth of loosening with the possibility of copying the relief and compaction of the lower soil layers. As additional elements to improve the quality of soil crumbling and the degree of pruning of weeds of the pointed paws of a steam cultivator, a disc knife attached to the front of the rack can also be used.

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To remove cut weeds from the surface of the working organ of a steam cultivator, additional elements are used in the design in the form of rods mounted directly on the ends of the paw or the end of the wing is bent according to a similar configuration.

The author, constructive solution, is aimed at improving the degree of pruning of weeds.

The authors proposed the design of an improved lancet foot with a variable crumbling angle and a transformed cutting edge, the use of which helps to reduce the traction

resistance of a steam cultivator by up to 7% and significantly improve the quality of crumbling.

According to the authors, the working body of a steam cultivator should be prefabricated, while approaching the pointed foot in shape. In this case, the working body must be transformable, used as a cutting, loosening or universal, depending on the degree of contamination of the field and the hardness of the soil.

The improvement of the main working organs of a steam cultivator can be carried out by radically modernizing the structure, completely abandoning pointed paws. Thus, the working body contains left- and right-cutting one-sided plane cutters mounted on a rack, offset from each other in the longitudinal direction. This design of the working body ensures complete pruning of weeds in the steam field.

Well-known research on steam cultivators can be classified into three main purposes:

- improving the operational reliability of working bodies;
- reduction of energy consumption;
- improvement of the quality indicators of the technological process of tillage with a steam cultivator.

The first set of tasks is combined to improve the operational reliability of the working bodies of a steam cultivator. This goal is realized by substantiating the strengthening modes and parameters, the choice of materials for the manufacture of working bodies of steam cultivators.

There are known studies on the basis of which the modes of thermal hardening are justified and a design with a self-sharpening cutting edge of the blade of the working body is developed.

The theoretical tasks of researching new working bodies are often solved through computer simulation.

Various methods are used in computer modeling: discrete and finite elements, hydrodynamic analogy.

The paper presents the results of modeling the working organ of a cultivator made of alternative materials (steloplastics), as a result of which a different course of the process of interaction with the soil was established. It was found that the working body of the cultivator, made of fiberglass, withstands a load 10 times greater than steel with equal strength.

Computer simulation using the above methods has the main drawback, which is that the properties of the processed medium do not coincide with the real ones.

The authors' research is aimed at increasing the life of the cutting edges of the cultivator working bodies and leveling for simultaneous wear of the entire structure. Analytical dependences of the parameters of the cultivator's working body with uniform wear are obtained.

The second target area of research on steam cultivators, according to the accepted classification, is to reduce the energy intensity of the working organs. Research in this area mainly boils down to parametric optimization of working bodies according to the criterion of the lowest traction resistance, provided that the energy facility is rationally loaded.

Thus, as a result of parametric optimization of the cultivator's working body, the traction resistance of the improved paw decreased by 9.5%, and the quality of soil crumbling increased by 10.7%.

The traction resistance of the working bodies is theoretically determined using the Goryachkin and Grandvoine-Goryachkin dependencies, and its components are based on the theory of dislocations.

For the most reliable result of modeling the working organ of a steam cultivator, it is necessary to consider the process in dynamics under the most stressful conditions.

Such conditions include the deepening of the working body of the steam cultivator to the required depth. At the same time, the transitional process of deepening and the stability of the course in depth of tillage with a steam cultivator are considered.

The problem of stability of the working bodies was determined by analyzing the differential equation of motion of the unit using the Lagrange equation of the second kind.

The dependencies characterizing the transient process of deepening the cultivator's working organs are given in.

The stability of the working bodies in depth is one of the most important qualitative indicators of the technological process of tillage with a steam cultivator.

Increasing the stability of the course in depth is included in the set of tasks of the next target area of research, which consists in improving the quality indicators of the technological process of tillage with a steam cultivator.

When developing the design of a new working body, a necessary condition for achieving and improving the quality of tillage with a steam cultivator is to determine the relationship of parameters with the indicators of the technological process.

Thus, the authors obtained dependences of the degree of pruning of weeds on the parameters of the working organ when working to a depth of up to 5 cm.

The relationship of the degree of pruning of weeds with the angle of solution of the cultivator's working organ in the absence of clogging and enveloping with cut mass is presented in.

An increase in the degree of pruning of weeds is possible if a sliding cutting condition is provided, which is achieved by optimizing the angles of the working body.

Another important qualitative indicator of the technological process of tillage with a steam cultivator is the quality of formation crumbling. The authors obtained expressions to determine the relationship between the angle of installation of the pointed foot to the bottom of the furrow and the size of the fractions obtained as a result of tillage, which characterize the quality of crumbling. The parameters of the working body are related to the quality of loosening in the work of the authors.

The authors analyzed the process of deformation of the soil with a pointed foot. There is a great influence of the rack on the process of loosening the soil along with the paw. The stress-strain state of the stand of the cultivator's working organ is presented.

4 Conclusions

1. In general, steam cultivators consist of a drawbar for attaching to a tractor, a frame for attaching working bodies, a hydraulic system, support and transport wheels.

2. Steam cultivators can be classified into 3 types: by type of main working bodies (paws); by type of additional working bodies (rollers, harrows, rods); by type of attachment to a tractor (trailed, mounted).

3. The hinged connection of the steam cultivator with the tractor in comparison with the trailed one allows to increase the productivity of the unit.

4. The disadvantage of disc cultivators is the poor quality of pruning weeds with high field contamination, due to the lack of paw working organs. In addition, they are not designed to work in conditions with a high probability of erosive processes and insufficient moisture, due to increased soil spraying by disk working bodies.

5. Universal structures capable of performing pre-sowing field treatment and steam care, as a rule, function most efficiently only at a depth of 11-12 cm, therefore they are not quite suitable for combating high contamination of fields, since they do not prune weeds in the upper soil layer.

6. Foreign cultivator designs may not be fully suitable for the soil and climatic conditions of the south of Russia, especially in dry years, when soil hardness significantly

exceeds the norm, and moisture reserves inside the reservoir are so negligible that when they are brought to the surface of the field during loosening, they will instantly lead to evaporation.

7. An increase in the grip width of steam cultivators from 4 to 16 meters leads to a sharp increase in weight (8 times), which has a direct impact on the growth of cost indicators and can cause excessive pressure on the soil, which is unacceptable.

8. The working bodies of the steam cultivator are mainly aimed at destroying weeds by pruning them, they function on the principle of sliding cutting. The planar cutter is characterized by a small crumbling angle and therefore is not quite suitable for soil decompression during steam treatment.

9. The improvement of the designs of steam cultivators to improve the quality and reduce energy consumption for tillage is carried out not only in terms of the main working bodies (paws). The frame in terms of the placement of the main working bodies, the rack and the design of additional working bodies of steam cultivators are also subject to improvement.

10. When using pointed paws, there is a large unevenness in the depth of the stroke of the working organs of the steam cultivator, the removal of wet layers to the surface of the field, sticking, the formation of ridges and furrows.

11. The working body of a steam cultivator must be prefabricated and transformable, used as a cutting, loosening or universal, depending on the degree of contamination of the field and soil hardness.

12. The improvement of the main working organs of a steam cultivator can be carried out by radically modernizing the structure, completely abandoning pointed paws.

13. Well-known studies on steam cultivators can be classified according to three main goals: improving the operational reliability of working bodies; reducing energy consumption; improving the quality indicators of the technological process of tillage.

14. The increase in operational reliability is realized by substantiating the strengthening modes and parameters, the choice of materials for the manufacture of working bodies of steam cultivators.

15. The traction resistance of working bodies is theoretically determined using the Goryachkin and Grandvoine-Goryachkin dependencies, and its components are based on the theory of dislocations.

16. When developing the design of a new working body, a necessary condition for achieving and improving the quality of tillage with a steam cultivator is to determine the relationship of parameters with the indicators of the technological process.

17. The theoretical tasks of researching new working bodies are often solved through computer simulation. Computer simulation has a major drawback, which is that the properties of the treated medium, represented by Bingham plastic soil and according to the modified Drucker-Prager model, do not coincide with the real ones.

References

1. Belousov, S. V. Explanation of the angle of sharpening of a plough cutting working body / S. V. Belousov, E. A. Saprykin, I. S. Karmazin // E3S Web of Conferences, Sevastopol, 09–13 of September 2019. Vol. 126. – Sevastopol: EDP Sciences, 2019. – P. 00025. – DOI 10.1051/e3sconf/201912600025. – EDN OCJGFB.
2. Belousov, S. V. On the problem of interaction of the tillage working body with the soil / S. V. Belousov, E. E. Samurganov // E3S Web of Conferences, Sevastopol, 2020. – Sevastopol, 2020. – P. 01062. – DOI 10.1051/e3sconf/202019301062. – EDN HHVTAF.

3. Parkhomenko, G. G. Qualitative Indexes of a Plane Cutter for Shallow Tillage with Optimized Parameters / G. G. Parkhomenko, O. S. Babenko, S. I. Kambulov [et al.] // E3S Web of Conferences, Krasnodar, 30–31 of May 2023 / Kuban State Agrarian University. Vol. 398. – Krasnodar: EDP Sciences, 2023. – P. 01030. – DOI 10.1051/e3sconf/202339801030. – EDN JHKJLU.
4. Belousov, S. V. Energy Assessment of Tillage Working Bodies / I. V. Bozhko, S. I. Kambulov, G. G. Parkhomenko, S. V. Belousov // AIP Conference Proceedings : INTERNATIONAL CONFERENCE ON MODERN TRENDS IN MANUFACTURING TECHNOLOGIES AND EQUIPMENT 2021, Sevastopol, 06–10 of September 2021. Vol. 2503. – Sevastopol: American Institute of Physics Inc., 2022. – P. 030044. – DOI 10.1063/5.0099966. – EDN HLWYHS.
5. Parkhomenko S.G., Parkhomenko G.G. Method of structural modeling of automatic control systems of operational modes of tillage units // Proceedings of GOSNITI. 2017. Vol. 126. pp. 55-61.
6. B. Talamini, Y. Mao, L. Anand, Progressive damage and rupture in polymers, Journal of the Mechanics and Physics of Solids, 111, 434-457 (2018) https://doi.org/10.1016/j.jmps.2017.11.013
7. Pakhomov, V. I. The Results of Studying Agronomic Indicators of the Demetra Selection Seeder / V. I. Pakhomov, S. I. Kambulov, I. V. Bozhko, G. G. Parkhomenko // Engineering Technologies and Systems. – 2022. – C.90–109. (DOI 10.15507/2658-4123.032.202201.090-109).
8. Rykov, V.B. Replaceable crawler engine and its interaction with the sup-porting base / V.B. Rykov, S.I. Kambulov // Achievements of science and technol-ogy of the agro-industrial complex. – № 9. – 2005. – P. 29-30.
9. Rykov, V.B. Development of efficient mobile technological units for conditions of the South of Russia / V.B. Rykov, S.I. Kambulov, E.I. Trubilin, N.V. Shevchenko. – Krasnodar: KubSAU, 2019. – 265 p.
10. V. Telichenko, A. Ter-Martirosyan, V. Sidorov, The rate of the pile settlement in clay soil with regard to its viscoelastic and elastic-plastic properties, Procedia Engineering, 165, 1359-1366 (2016) https://doi:10.1016/j.proeng.2016.11.865
11. 11.P. Panagos, P. Borrelli, J. Poesen, C. Ballabio, E. Lugato, K. Meusburger, L. Montanarella, C. Alewel, Environmental Science & Policy 54, 438-447 (2015) https://doi.10.1016/j.envsci.2015.08.012
12. A. Chappell, N. Webb, Aeolian Research 23, 63–78 (2016) https://doi.org/10.1016/j.aeolia.2016.09.006
13. I. Katra, A. Gross, N. Swet, S. Tanner, H. Krasnov, A. Angert, Sci. Rep. 6, 24736 (2016) https://doi.org/10.1038/srep24736
14. K. Adhikari, A.E. Hartemink, Geoderma 262, 101-111 (2016) https://doi.org/10.1016/j.geoderma.2015.08.009
15. V. Couvreur, J. Vanderborght, X. Draye, M. Javaux, Water Resources Research 50(11), 8891-8906 (2014) https://doi.org/10.1002/2014WR015608
16. Z. Sándor; M. Tállai; I. Kincses; Z. László; J. Kátai; I. Vágó, DRC Sustainable Future 1(1), 14-20) https://doi.org/10.37281/DRCSF/1.1.3
17. G.F. Botta, D.L. Antille, F. Bienvenido, D. Rivero, E.E. Contessotto, Engineer-ing for Rural Development. Jelgava, 22, 174-178 (2019) https://doi.org/10.22616/ERDev2019.18.N216