Harmonization of maintenance systems for agrorobots and aggregated equipment

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Abstract: *The paper presents an analysis of the maintenance system of the powertrain component of the Omni Power agrorobot and the Seed Master seeder, which is aggregated. It is shown that the specified equipment has different maintenance systems, the regulations of which are inconsistent with each other. The results of the calculations of forces in the moving connections of the seeder in the case of the use of carbon-plastic parts are presented. It is indicated that carbon-plastic details have a safety margin coefficient of 4.2 to 6.5 under different operating conditions. The results of field tests of the seeder, equipped with experimental parts developed at the Dnipro State Agrarian and Economic University, are presented. It is shown that the use of such parts does not require maintenance, and their replacement is advisable when the seeder works for 3500 hours. Thus, if the developed parts are used in the equipment that will be aggregated with the Omni Power agrorobot, the harmonization of the maintenance systems of the energy part of the agrorobot structure and equipment will be achieved.*
KEYWORDS*: AGROROBOT, AGGREGATION, CARBON FIBER COMPOSITES, TECHNICAL SERVICE.*

1. Problem Statement

Problem Statement. Ukraine is one of the most heavily mined countries in the world. On the de-occupied lands of Chernihiv, Kyiv, Kharkiv, Kherson, and Mykolaiv regions, on 2022, cases of injury and death among machine operators due to detonations caused by mines, shells, grenades, and other explosive devices were still recorded even in 2024. There is no absolute guarantee of safety when working in such fields. Although the State Emergency Service of Ukraine issues permits for agricultural use of land after demining, there remains a threat of intentional mining by enemy drones or the fall of downed missiles and UAVs containing explosives. At the same time, modern trends in the agricultural sector aim to reduce human involvement by implementing robotic technologies. Agrorobots will become essential in Ukraine for performing technological operations across large areas of demined land. This is necessary to preserve the health and lives of machine operators and to save human resources. The concept of introducing agrorobots into production also includes extending their operating time without operator intervention. That is, agrorobots should be capable of performing assigned technological tasks over extended periods, with minimal downtime for refueling and maintenance. However, this contradicts the traditional design of agricultural implements, which typically have limited operational intervals between maintenance cycles.

For example, the world's first agricultural robot DOT (Fig. 1), created by Seed Master, had exactly one of the following concepts: designed to perform technological operations autonomously, but it has limitations on the terms of service of the systems with which it is aggregated. DOT was equipped with a 163 hp diesel engine that transmits energy to 4 wheels using a hydraulic drive. All four wheels have a turning angle of 90 degrees, changing the direction of movement of the unit and perpendicular directions. Maximum speed up to 20 km/h. The structural and conceptual disadvantage that limited the autonomy of the agrorobot was the discrepancy of the periodicity of the maintenance of the power part (motor, hydraulic system) and the working bodies of the machines: moving connections of the seeder sections, etc.

Fig. 1*-The world's first autonomous agricultural robot DOT (before CNH's purchase).*

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1. Hinged connections of the seeder frame – every 50-100 hours of operation.

2. Coulters and seeding discs – check and lubricate every 100 hours or earlier in case of heavy pollution.

3. Roller bearings and support wheels – lubrication every 100-200 hours (depending on the operating conditions).

4. Chain drives (if used) – lubrication every 50 hours or if necessary.

In graphical interpretation, this combination looks like this

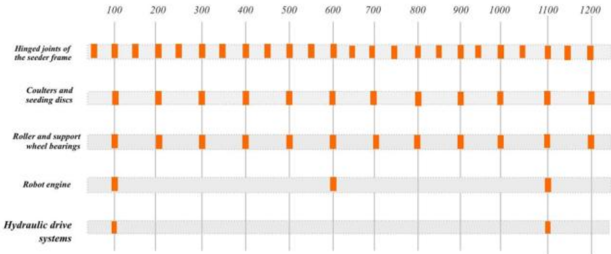

Fig. 2 *- Maintenance interval scale for agrorobot components (4, 5) and Seed Master seeder components (1–3), aggregated with it.*

A clear imbalance exists between the maintenance systems of the agrorobot and the seeder it is aggregated with. From Fig. 2, it is evident that the seeding agrorobot equipped with a standard seeder must stop for scheduled maintenance every 50–100 hours.

SeedMaster seeders are designed to work with traditional tractors. Therefore, the maintenance system is designed for the presence of the operator. But in aggregating Omni Power, the seeder limits its autonomy, requiring lubrication every 100 hours. But the agrorobot must work for a much longer time without human intervention.

Therefore, the purpose of the work is to develop maintenance-free friction elements of seeders intended for use with Omni Power agrorobots.

To achieve this goal, the following tasks must be completed:

1. Analyze publications on the subject.
2. Assess the load levels on the seeder's hinge joints.
3. Justify the selection of materials suitable for use in hinges (tribological pairs) in order to comply with the "free maintenance" principle.

2. Analysis of Recent Research and Publications

Certain aspects of automation in technical maintenance, the use of new materials, and the optimization of machinery design, including agricultural equipment, are discussed in [1, 2]. The articles present conclusions indicating that a primary issue in agricultural machinery is the disparity in reliability between the powertrain components of robots (engine, hydraulics) and the attached implements (seeders, fertilizer spreaders, etc.). The frequency of maintenance of the working parts of traditional agricultural equipment, which are aggregated with autonomous platforms, creates additional idle units. Prospective solutions for improving the use of platforms are proposed. These are the application of artificial intelligence, machine learning, sensors for failure prediction, as well as the use of materials that do not require frequent maintenance [3]. In the paper [4], the authors also provide an overview of new materials to reduce the need for maintenance. Self-lubricating polymers (e.g. fluoroplastic) are proposed for use, which significantly reduces the need for lubrication of working units. It is shown that the use of hard lubricating coatings (MoS_2, graphite coatings) allows to extend the service life of bearings and hinges in difficult conditions [5, 6]. Ceramic bearings have higher wear resistance and can work without maintenance up to 5 times longer than traditional metal [7]. Also, the use of new alloys (aluminum and titanium composite materials) allow to reduce the weight and increase the durability of the units used in autonomous machines [8, 9]. This analysis of the publications showed that the problem of compatibility of maintenance systems for energy units of agricultural robots and equipment is unresolved. One approach to harmonizing systems is to extend the periodicity of equipment maintenance. This periodicity should be coordinated with the periodicity of the maintenance of the engine and hydraulic systems. The paper [10] presents the results of studies aimed to increase the durability of the parallelogram mechanism of the Turbosem II 19-48/60 seeder (Ukraine) by using parts made of carbon fibers, mainly of the CPA-6-30 brand. However, the paper investigated the durability of metal parts in the tribosystem and carbon fibers. It has been established that carbon-plastic parts can significantly increase the durability of parts and increase the frequency of maintenance. But the amount of filling polyamide with carbon fibers, which are the most expensive in the structure of the production of parts, was not substantiated.

It follows from the above that in order to increase the autonomy of agrorobots, it is necessary to create an equipment design, the maintenance systems of which would be harmonized with the maintenance system of the agrorobot. In our opinion, there may be at least three such approaches.

1. Optimize power units (for example, the use of electric motors or hybrid systems).

2. Use automatic maintenance systems, including automatic lubrication systems.

3. Apply maintenance-free systems, or with a long frequency (up to 500...1000 hours of operation).

Obviously, the research of foreign scientists is also aimed at solving the problems of increasing the level of autonomy robots. However, the specified papers have not yet reflected an analysis of how much time is lost, for example, on carrying out routine maintenance of trailed tools, how they affect the pace of work of agricultural robots.

3. Objectives

The aim of the paper is to enhance the autonomy of agricultural robots by employing tribological units of the "Free Maintenance" type.

4. Main Material

Consider the classic design of triboconjugation of moveable connections of precision seeders (Fig. 3). The accuracy of the depth of seed laying is ensured by a parallelogram mechanism that works in tandem with the spring mechanism. The stiffness of the spring is regulated and this determines the level of force with which the coulter presses on the ground. Moveable connections of this mechanism significantly reduce its reliability, and durability should be ensured in the case of systematic maintenance with a short frequency. During maintenance, the seeding unit does not work.

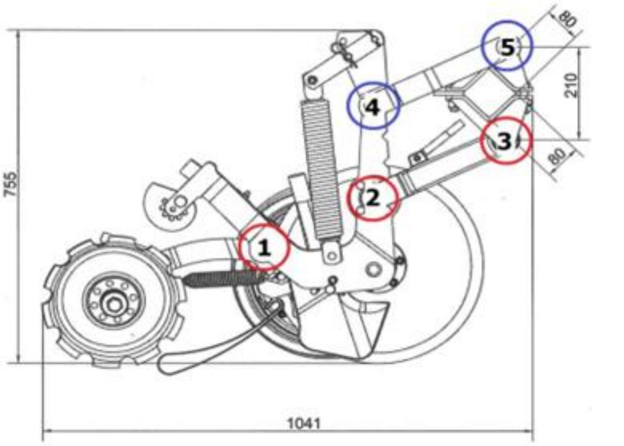

Fig. 3 *– Classic design of a precision seeder row unit (example: Turbosem II 19-60). 1–5 – service points with a maintenance interval of 48….100 hours.*

Moveable connections include parallelogram mechanisms (2-4), levers of rolling wheels (5) and other mechanisms. The classic design of the triboconjuction of the moveable joints of the seeders in question has the form (Fig. 4), except that a self-lubricating bush 1 made of polymer-composite material. In the calculation schemes, the inner diameter of the bushing is 32 mm, and its length is 30 mm. The thickness of the part will depend on the operating conditions and design features of a particular seeder. Taking into account the active loads (dynamic and static), it is necessary to justify the use of a particular material, considering its physical and mechanical properties.

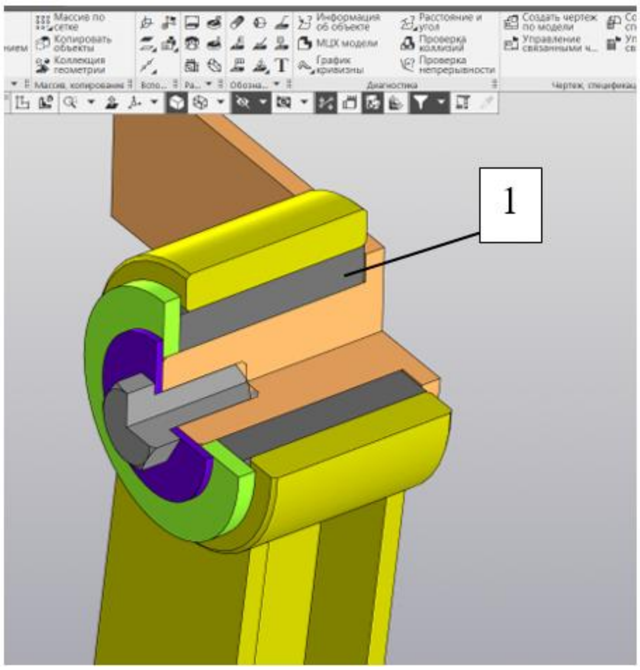

Fig. 4 *- Tribological pair scheme recreated by using a SolidWorks.*

As in the research presented in [2], the authors have also chosen the use of self-lubricating polymer composites as a concept to increase the autonomy of agrorobots. For instance, [2] proposes using PTFE (fluoroplastic-4) in tribological joints. However, force calculations for coulter sections [10] showed that the maximum load in joints such as the parallelogram mechanism of the wide-seeding Turbosem II 19-60 reaches 2377 N, especially when hitting an obstacle, such as a 100 mm clod of black soil. Assessing the experience of operation of seeders equipped with the Precision Planting system, it was found that the coulters overcome the soil resistance within 230...2000 N. These data, obtained experimentally (Fig. 5), are comparable to the calculated data. For the manufacture of part 1 (Fig. 4), several brands of polymer-composite materials can be used: fluoroplastic-4, carbon fibre based on polyamide-6 and others. Let's look at some examples.

Fluoroplastic-4. Friction coefficient f = 0.05...0.09; compressive strength σ = 20...50 MPa. The material is characterized by low mechanical strength.

Using the known calculation methods, we will determine what is missing in the proposed triboconjugation, which will be operated under the operating conditions defined in [10].

We present the results of the calculations.

Fluoroplastic-4 has the following characteristics:

- Compressive strength: 30-50 MPa
- Tensile strength: 20-35 MPa
- Shear strength: 4-6 MPa

When such a polymer and metal come into contact, a pseudo-rigid state occurs, in which the contact area between the working surfaces of the parts will be within 60...150 mm^2.

In this case, the classical calculation of the stress that will occur under such conditions will be in the range of 39.6...15.8 MPa. Under such dynamic operating conditions, plastic deformation or part extrusion is possible. Parts made of fluoroplastic-4 will not be able to ensure the functioning of the hinge joints of the seeder.

Carbon fibre plastics based on aliphatic polyamides. The laboratory of polymer composites produces CPA-6-15, CPA-6-20 and CPA-6-30 carbon fibre-reinforced plastics. These are carbon fibre-reinforced plastics based on aliphatic polyamide 6 with carbon fibres in the structure of 20 %, 30 %, and 40 % by weight, respectively. The chaotic arrangement of carbon fibres in the polymer matrix ensures the isotropic properties of the resulting parts, high tribotechnical, physical and mechanical characteristics (Table 1).

Given the characteristics (Table 1) of the developed carbon fiber composites and the operating conditions described in study [4], it is known that the contact strip width of the part with CPA-6-30 will range from 3 to 4 mm. This results in the following stress values in the tribological contacts: 26.4 MPa for a contact strip width of 3 mm and 19.8 MPa for a width of 4 mm.

Table 1 *- Some characteristics of carbon fibre-reinforced plastics developed in the polymer composites laboratory*

Parameter	Type of carbon fibre reinforced plastic		
	CPA-6-15	CPA -6-20	CPA -6-30
Compressive strength limit σ_{cs}, MPa	110	117	128
Impact strength ρ, kJ/m²	41	42	47
Fluidity limit σ_f, MPa	81	82	86
Density, g/cm³	1,19	1,21	1,23

The results obtained (Table 2) indicate a sufficient strength margin of the parts.

Table 2 *– Results of the operability calculations of developed carbon plastics in seeding machine friction units*

Material	Compressive strength limit, MPa	Factor of safety under tribological contact stress of 26.4 MPa	Factor of safety under tribological contact stress of 19.8 MPa
CPA -6-15	110	4,2	5,6
CPA -6-20	117	4,4	5,9
CPA -6-30	128	4,8	6,5

Testing the actual forces on each coulter of the John Deere 7200 seeder, with the Precision Planting equipment installed, was carried out in the field when sowing corn. It has been established that when the seeder is working, the value of this indicator is quite highlighted and is within 0...204 kg (0...2044 H) (Fig.4). The value "0" indicates that the coulter dived to a given sowing depth without the additional force of the hydraulic cylinder, and therefore the reactions in the hinges were insignificant. The maximum force was recorded - more than 204 kg in the area of significant soil compaction by engines of industrial equipment (highlighted by an oval). That is, in this zone, the coulters were forcibly immersed in solid ground by hydraulic cylinders of the Precision Planting system.

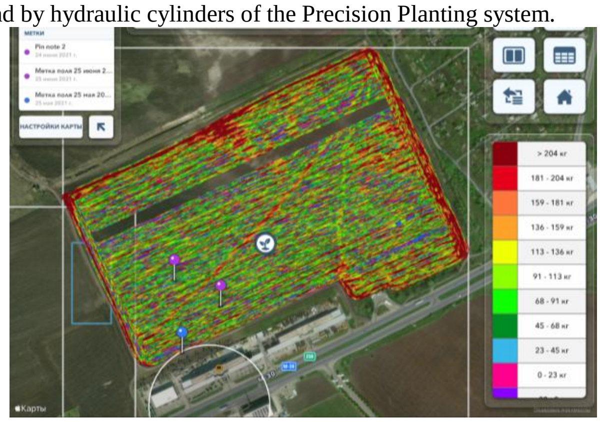

Fig. 5. *Map of actual forces in each individual hydraulic cylinder of the seeder equipped with the Precision Planting system*

Thus, any of the developed carbon plastics can be applied in the seeder's hinge joints – the parts possess sufficient strength margins.

By the now, there are no SeedMaster seeders available in Ukraine, which are used in aggregation with the Omni Power agricultural robot. Therefore, experimental parts were manufactured for the hinges of the Turbosem II 19-60 seeder levers. According to the manufacturer's maintenance system, these hinges should also be serviced every 48...100 hours of operation. The regulation provides for lubrication with plastic lubricants and backlash control. The seeder, equipped with experimental parts, worked for 400 hours (sowing was performed on an area of 1932 hectares), after that an assessment of the technical condition of the tribocouting was carried out (Fig. 6). It was established that the wear of the working surfaces of the parts with the CP did not exceed 0.1 mm, with a permissible 0.8 mm. The metal conterbodies had a polished working surface without burrs and damage. The wear was less than 0.01 mm, it was not controlled by the internal gauge. After analysing the technical condition, the experimental parts were left for further testing and reached production when the seeder worked out 17251 hectares or 3586 hours. At the same time, agrotechnical standards for sowing quality and the technical condition of the sowing sections were controlled. During the operation of experimental parts, their maintenance was never carried out.

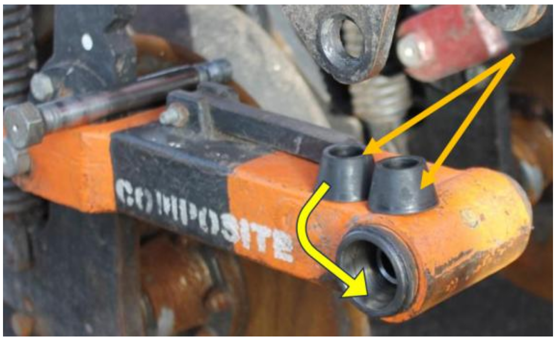

Fig. 6 *- Experimental parts 1 made of carbon plastic after inspection at 400 hours of operation.*

It was established that the developed parts meet the criteria for the technical condition of the parts as "Free Maintenance." Thus, it was possible to avoid at least 35 maintenance services which would have to be done according to the regulations when using serial parts.

5. Conclusions

On the basis of the analysis of the problem and conducted research work, the following conclusions can be drawn:

1. An analysis of scientific publications revealed that current research efforts are focused on finding technical solutions and

scientific approaches aimed at increasing the maintenance intervals of equipment components aggregated with agrorobots.

2. It was established that the manufacturer of the Omni Power agrorobot has not provided synchronization between the maintenance systems of the robot itself and the equipment that operates in conjunction with it.

3. Specific components of seeders were identified whose maintenance significantly increases agrorobot downtime during seeding operations. The average load on a single triboconjuction is approximately 2377 N.

4. The optimal carbon plastic composition for the manufacture of tribo-coupling parts in seeders was justified—CPA-6-30, which contains 30 wt.% of carbon fiber within the polymer composite structure. It was shown that carbon plastic parts used in seeder joints provide a safety factor in the range of 4.2 to 6.5.

5. Field tests of the seeding unit equipped with experimental parts demonstrated that carbon plastic components do not require maintenance (free maintenance), and their service life is approximately 3500 hours. This allows avoiding 35 to 70 maintenance services. Therefore, these materials should be recommended for implementation in equipment aggregated with agrorobots such as Omni Power.

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