Improving the reliability of machine and tractor units in technological processes

P A Lebedev, A T Lebedev, R V Pavlyk, A V Zakharin

Stavropol State Agrarian University, 12, Zootekhnicheskiy lane, Stavropol, 355000, Russia

E-mail: zoya_lebedeva@mail.ru

Abstract. The paper describes a method for improving the reliability of a machine-tractor unit in technological processes. Two approaches aimed at improving the reliability of the least reliable elements are analyzed. To improve the reliability of power units, it is proposed to spray SiO$_2$-based thin-film coatings on the working surfaces of plunger pairs. The calculations show that an increase in the service life of the plunger pairs is 2 ... 2.5 times higher than that of the serial ones. To improve the reliability of working machines, an example of the improved reliability of cultivator paws due to the modernization of their design is provided. Results of the comparative tests showed that the solutions make it possible to reduce the traction resistance when performing field works. In addition, it is possible to replace a nose of the cultivator paw.

1. Introduction

Agricultural producers strive to improve the quality of the final product using new technologies and fertilizers. It is important to reduce production costs. In the structure of agricultural production in Stavropol Territory, up to 50% of all costs are costs for fuel and lubricants and equipment maintenance. To produce high-quality products and preserve them, it is necessary to use fertilizers and plant protection agents; this accounts for 25 ... 40% of the total cost.

A high share of costs for fuel and lubricants is due to the poor reliability of machine and tractor units. The machine-tractor unit consists of two subsystems: an energy source (tractor) and a working machine (plow, cultivator, seeder, harrow, etc.). Each subsystem has its own less reliable units and parts, which affect the overall fuel consumption. For a power plant, fuel equipment is less reliable, in particular, injectors and plunger pairs, whose wear causes a loss of power, increased fuel consumption and exhaust smoke. The reliability of working machines depends on working bodies (plowshares, cultivating shares, openers, seeding discs, etc.), whose wear can deteriorate the quality of technological operations.

A poorly performed technological operation entails either a decrease in the number of final products or repeated execution of a technological operation, which entails financial costs for fuel and lubricants. In most cases, a deterioration of the quality of technological operations is due to the lack of criteria for rejecting working bodies and means for monitoring the technical condition of parts.

2. Materials and methods

Currently, there are various methods aimed at improving the reliability of machine and tractor units,
but they are related to each other, since their application is implemented at the design, manufacturing stages, as well as in various technological processes. An analysis of the methods aimed at improving the reliability of machine and tractor units showed that they can be used at three life stages of products (Figure 1): design, manufacture and operation.

The methods for improving the reliability of machines at the design stage involve optimizing the design of units and elements, ensuring and creating favorable operating conditions for rubbing working surfaces, creating an optimal lubricating medium for contacting parts and surfaces.

At the manufacturing stage, the methods can be used to improve the reliability: selection of optimal materials, increasing the wear-resistant ability of parts, improving the quality of production of the most critical parts, creating an improved microgeometry of the working surfaces of parts, improving control of assembly operations for units and machine parts, implementing the latest nanotechnologies.

During the execution of technological operations, to improve the reliability of machines and units, optimal conditions for loading and machine-tractor units are created, the size and nature of the load of agricultural machinery is controlled. It is important to attract highly qualified workers, as well as to use modern diagnostic and repair equipment, the latest lubricants and additives.

In the real conditions, the structural, technological and operational measures help to achieve the desired reliability; it is necessary to use measures aimed to reserve less reliable systems and parts.

![Methods for improving the reliability of machine and tractor units](image)

**Figure 1.** Directions for improving the reliability of machine and tractor units

Reservation is a method for improving the reliability, involving the use of additional means and capabilities in order to preserve the operability of an object in the event of a failure of one or more of its elements or a breakdown in connections between them.

Analyzing the existing reservation methods, we can conclude that they do not increase the reliability of agricultural machines and aggregates due to the lack of electronic information communication between the elements.

In this case, the reservation of agricultural machines, units and their elements involves the methods aimed at increasing the reliability through functionality. The reservation of the least reliable elements, systems and assemblies can be used both during the production and operation of these elements. The use of such elements as part of the technical system complicates the design, but it is necessary to increase the likelihood of system's trouble-free operation. The use of the elements will not improve the reliability indicators, since it is necessary to implement special technological measures aimed at expanding and increasing functionality.

It is necessary to control the technological process of the mobile power plant and the working machine. To ensure the operational control, functional reservation of properties of working surfaces can be used. It is aimed at maintaining the required level of reliability of the most critical parts that are responsible for the efficiency and quality of the technological processes.

### 3. Results

The research experience has shown that 90% of agricultural machines and units have significant changes in the requirements of technical conditions. Approximately 20% of the machines and assemblies were produced with violations of geometric dimensions. The tests showed that 70% do not meet the reliability standards. The problem of ensuring the reliability of the existing fleet of machines
is aggravated by the fact that the spare parts are initially either defective (up to 40%) or have an underestimated resource.

The consequence of using spare parts with lower reliability is breakdowns and failures that arise during technological operations. When eliminating the failures, the load on other machines increases financial losses occur. The idle time of equipment can lead to crop losses, changes in the soil background and an increase in the fuel consumption.

The largest number of energy failures is due to the breakdowns in the fuel system. The least reliable elements of high pressure fuel pumps are precision parts. The technical condition of precision parts is determined by the gap between the parts. It is technically difficult to determine this gap, therefore, a complex indicator is used. An analysis of new precision parts for high-pressure fuel pumps showed that 86% of new precision parts have a pressing time of no more than 45.7 seconds. The data obtained indicate that the new plunger pairs have lower reliability indicators and a reduced service life. It can be concluded that there is an increased gap between the contacting parts [1, 2].

To improve the reliability of the high-pressure fuel pump and the energy facility, it is necessary to use the reservation methods, in particular, the functional reservation of properties of the working surfaces of plunger pairs, by applying SiO$_2$-based thin-film coatings on the working surfaces of parts (Figure 2).

![Figure 2. The distribution of hydraulic density of plunger pairs with a thin-film coating](image)

The resulting distribution indicates a decrease in the gap between the working surfaces of the parts. The compensating layer with a high microhardness makes it possible to increase the wear resistance of the plunger and sleeve. Comparative laboratory studies on the wear rate of serial and experimental plunger pairs showed that the wear rate of serial plunger pairs is $\beta_1 = 2.01 \, \mu m / h$ ... $\beta_2 = 2.7 \cdot 10^{-3} \, \mu m / h$, and for experimental parts it is $\beta_1 = 0.41 \, \mu m / h$ ... $\beta_2 = 0.63 \cdot 10^{-3} \, \mu m / h$.

Based on the experimental data on the wear rate, the service life of serial and experimental plunger pairs was predicted (Figure 3).
During the technological operations, the energy device is aggregated with a working machine (plow, seeder, cultivator, etc.); therefore, the improved reliability of the working bodies will affect the efficiency of the technological operation [3, 4]. The quality of the operation depends on the quality of the working bodies (plowshare, cultivator share, opener, etc.), but all the necessary parameters of the parts must be controlled when manufacturing tillage machines. The working bodies can be used according to their functional purpose, but the effectiveness of application is decreasing [5–7]. For example, the cultivator paws are used until “wings” are worn out, which creates soil areas that are not exposed to loosening and destruction of weeds. Under operating conditions, the wear of “wings” occurs much later than the wear of the nose part (Figure 4) [8–10]. Abrasion of the nose part does not affect the main indicators of the cultivation process, but determines the effectiveness of this process. Changing the shape of the nose of the cultivator share increases the traction resistance, which increases the fuel consumption. A similar situation occurs with other working bodies of the tillage machines.

In order to increase the reliability of the working bodies and efficiency of the technological processes, the method of rejecting the working bodies can be changed with the help of indirect indicators indicating the wear of working bodies due to an increase in the traction resistance. To
increase the reliability of the cultivator tines, the modernized tines with a replaceable nose can be used.

The proposed modernized cultivator share has the following parameters (Figure 5):
- the length of the bow \( e \) is 34 mm;
- the angle of attack of the nose is \( \beta = 28...30^\circ \);
- the bow has a rounded shape and is equal to \( L = 2.1 \) mm;
- the overhead part is made in such a way that its angle is equal to the paw angle \( \alpha = 2\gamma = 75^\circ \);
- the overhead part has a width of \( R_1 = 90 \) mm.

Structurally, the overhead part is made with two holes for fixing. The lower hole is intended for attaching the overhead part only to the paw, with the help of the upper one fixation to the paw and the supporting beam takes place. In the manufacture of prototypes, the inclined elements were made of steel 45, and their hardness was 45 ... 48 HRC.

![Figure 5. The replaceable nose](image)

When conducting comparative studies of the modernized and standard duckfoot paws, two cultivators KRN-5.6 were used: one cultivator with a modernized working body and other cultivators with standard working bodies. The type of technological operation for both cultivators was continuous cultivation on the Ciscaucasian low-leached chernozem. The moisture content at a depth of 10 cm was 9.5%; with an increase in depth to 25 cm, the moisture content did not exceed 24%. When conducting comparative tests, the main indicators were monitored: thickness of the treated layer, grinding or lump formation by fractional composition, surface roughness, and traction resistance. Traction resistance was monitored using strain gauges. DASEL TS21-T5 was used to read the indicators. The data were process using the KYOWA strain gauge station. The results are shown in Tables 1 and 2.
Table 1. The main agrotechnical indicators of the modernized lancet paws

| Controlled characteristics | Results |
|----------------------------|---------|
| Speed during treatment, km / h | 18      |
| Thickness of the layer: |         |
| - average value, cm; | 6.5     |
| - parameter fluctuation, % | 16.9   |
| Grinding, %, lump formation by fractions, mm: | |
| - not less than 10 | 47.4     |
| - 10-15 | 62.5     |
| - 15-20 | 16.7    |
| - 20-25 | 7.4     |
| over 25 | 19.1    |
| Surface roughness, cm | 3.1     |
| Traction resistance, N | 5156    |

Table 2. The main agrotechnical indicators of standard lancet paws

| Controlled characteristics | Results |
|----------------------------|---------|
| Speed during treatment, km / h | 18      |
| Thickness of the layer: |         |
| - average value, cm; | 3.4     |
| - parameter fluctuation, % | 19.2   |
| Grinding, %, lump formation by fractions, mm: | |
| - not less than 10 | 51.3     |
| - 10-15 | 61.3     |
| - 15-20 | 16.8    |
| - 20-25 | 11.2    |
| over 25 | 4.4     |
| Surface roughness, cm | 2.9     |
| Traction resistance, N | 7360    |

4. Conclusion
The redundancy methods can improve the reliability and efficiency of tractors in the technological processes.

References
[1] Khokhlov A, Golubev V, Khokhlov A, Marin D, Golubev S 2019 Decreasing the wear of precision pairs of fuel injection equipment in diesel engines IOP Conference Series: Earth and Environmental Science 403(1) 012101
[2] Lebedev A, Lebedev P, Zakharin A, Maryin N, Zhevora Y 2019 Improving the reliability of plunger pairs of diesel engines IOP Conference Series: Earth and Environmental Science 403(1) 012058
[3] Lebedev A, Lebedev P, Zakharin A, Maryin N, Zhevora Y 2019 Improving the reliability and efficiency of tillage machines IOP Conference Series: Earth and Environmental Science 403(1) 012059
[4] Fanigliulo R, Biocca M, Pochi D 2017 Evaluation of traditional and conservation tillage methods for cereal cultivation in central Italy Chemical Engineering Transactions 58 211-216
[5] Bobobee E Y H, Gebresenbet G 2007 Effect of cutting edge thickness and state of wear of ploughshare on draught force and heart rates of Sanga oxen in Ghana Soil and Tillage Research
[6] Zhang S, Wu Z, Chen J, Song Z, Mao E et al 2020 Control method of driving wheel slip rate of high-power tractor for ploughing operation Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering 36(15) 47-55

[7] Zeng Z, Thoms D, Chen Y, Ma X 2021 Comparison of soil and corn residue cutting performance of different discs used for vertical tillage Scientific Reports 11(1) 2537

[8] Eremeev A V 2013 Wear factors of tillage machines working tools Applied Mechanics and Materials 379 32-35

[9] Singh J, Chatha S S, Sidhu B S 2021 Abrasive wear characteristics and microstructure of Fe-based overlaid ploughshares in different field conditions Soil and Tillage Research 205 104771

[10] Lemecha M, Napiórkowski J, Konat Ł 2021 Analysis of wear and tear of working elements with a replaceable cutting edge in an abrasive soil mass Tribology 273(3) 101-109