Improving the reliability and efficiency of tillage machines

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Abstract. Increasing the efficiency of diesel equipment operation is primarily associated not only with increasing the reliability of its main components, assemblies, joints and details, but also with reducing costs and fuel consumption during production processes. At the same time, operating experience shows that a significant share of the operating time of the equipment is not fully loaded, often up to 40...50%. The transient and unsteady modes that arise in this case, as well as the design features of the fuel equipment of domestic diesel engines, lead to an excessive consumption of fuel and a significant increase in the unevenness of fuel supply through the engine cylinders up to 26...38%. To ensure a minimum clearance in the plunger pair, it is proposed to apply a diamond-like thin film coating based on silicon oxycarbide onto the working surfaces of the details, which has high microhardness, low friction coefficient, and prevents the setting of contact surfaces by final plasma hardening. After applying the technological operation of hardening the working surfaces of the details by forming a thin film coating, the distribution of the parts over the time of crimping changed so that 82% of the experimental plunger pairs have a hydraulic density exceeding \( t = 45.7\) s with an average value of \( 46.7\) s with a mean square deviation \( \sigma = 1.05\) s. The results obtained during the tests showed that at the nominal speed of rotation of the cam shaft, the cyclic feed of the produced plunger pairs decreased by 2.8%, while in the experimental ones, the decrease in fuel supply was 1.3%, the uneven fuel supply in both cases did not exceed 2%. The predicted resource of the experimental plunger pairs will be 9000 hours, which is 2.25 times longer the resource of serial plunger pairs.

1. Introduction

Operations related to tillage are important and most labor-intensive in the production of agricultural products. The quality of these operations depends on the parameters and condition of the working bodies of agricultural machines and equipment. The operation of the working bodies of tillage machines is carried out in conditions of constant abrasive and impact-abrasive wear. Therefore, 70-80% of faults occur in the wear of the working body, and the remaining 20-30% are in their deformation. The ploughshare is one of the most responsible and quickly wearing parts of the plow, the average mean time before failure (MTBF) of which, depending on the type of soil, varies from 2 to 20 ha [1, 2]. The effectiveness of the technological process of plowing and the cost of resources will be determined by the specific tillage implement, i.e., to what extent the quality of work performed by the tillage implement corresponds to agrotechnical requirements, as well as what would be the financial cost. Therefore, the issue of reducing costs and increasing the efficiency of the process will ultimately come down to improving parameters, form, material, manufacturing technology, manufacturing costs of elements or details of a tillage implement. In our case, it is the plow of a share.
- mould-board plough, on which the energy and quality indicators of the technological process, i.e., operational and technological indicators of the arable unit operation, mainly depend.

2. Materials and methods
The main ways to increase the resource of working bodies are presented in Figure 1.

![Diagram of ways to increase the resource](attachment:image.png)

**Figure 1.** Ways to increase the wear resistance of ploughshares.

The introduction of alloying elements into steel was studied in the work [75]. The results of the experiments allow to make a conclusion that the wear resistance of steels for ploughshares can be increased by 30–50%, increasing them from 1.5 to 2% C; from 6 to 12% Si and with the introduction of up to 1.5–2% Cr and V. However, the use of these elements as alloys entails a significant increase in steel prices, which is not economically feasible.

The use of cast iron for the manufacture of shares makes it possible to produce finished products for the shortest cycle: liquid metal is a finished product. Research on the use of ductile iron for the manufacturing of plowshares was carried out in three directions:
- obtaining a three-layer ploughshare with a bleached surface, a bleached blade and with a viscous core in a raw (without annealing) condition;
- obtaining a ploughshare with through bleaching, subsequent annealing of the back and preservation of the bleached blade;
obtaining a ploughshare by annealing the entire bleached casting with hardening of the blade.

According to the first option, a bleached wear-resistant crust was obtained, the thickness of which from 1.0–1.5 mm in the upper part increased to 3.0–3.5 mm in the direction toward the blade. The blade itself had a through whitening. However, a three-layer cast iron ploughshare during field tests did not show either the required strength or high wear resistance.

The second option is casting a ploughshare with through bleaching and subsequent annealing of its fixing part - the back. In this case, the attachment point is viscous, and the working part - the blade - is hard and wear-resistant with the rational use of the initial hardness of the casting. Field tests showed low strength of these shares.

The third option involved casting plowshares with continuous whitening, by heat treatment, a pearlitic structure was obtained by quenching the blade. Tests of these shares have shown satisfactory results.

Analyzing the materials and technologies used for the manufacture of shares, we can make a following conclusion. The main material for the manufacture of plowshares are iron-carbon alloys - steel and cast iron. To increase their wear resistance and strength, they are alloyed with various chemical elements. High prices for high alloy steels and complicated ploughshare manufacturing technologies that require the use of special expensive equipment are the basis for the search for new technological solutions for making cheap ploughshares.

3. Results

To assess the operational properties of the deposited plowshares, their field tests were carried out in the farms of the eastern zone of the Stavropol Region. In the experiments, six types of ploughshares were compared. Serial trapezoidal ploughshare (No. 1) was compared with ploughshares: the ploughshare PLZH-31702 “Rubtsovsk plug” (No. 2), the ploughshare P-702 manufactured by “Svetlogradagromash” (No. 3), the ploughshare sintered with powder based on cast iron shavings (No. 4), the share, hardened by manual arc welding with Sormite powder (No. 5) and the ploughshare branded “VOGEL & NOOT” (No. 6.) (Fig. 2).

Figure 2. Types of shares passed the tests: a - serial trapezoidal ploughshare; b - the ploughshare PLZH-31702 “Rubtsovsk plug”; c - the ploughshare P-702 manufactured by “Svetlogradagromash” sintered; d - the ploughshare manufactured by “Svetlogradagromash” sintered with powder based on cast iron shavings; e - the share, hardened by manual arc welding with Sormite powder; f - ploughshare branded “VOGEL & NOOT”.

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Before testing, the primary examination of the working bodies was carried out for their compliance with the drawings and technical requirements, for which a 100% control of the ploughshares was carried out according to all dimensional parameters, material hardness and blade sharpening geometry. The initial technical examination of the working bodies was carried out according to OST 10.2.1-97 for the subsequent determination of the amount of wear.

On the marked field, the results of processing the field with worn and new shares were compared. At the same time, the exact time of work with worn and new shares was recorded for subsequent control of fuel consumption in the dispatch center.

The obtained data on the depth of plowing were processed using methods of mathematical statistics and a computer program. As a result, histograms and distribution polygons were constructed, as well as curves of the accumulated experimental probabilities of the depth of plowing of worn-out (Fig. 3) and new (Fig. 4) shares, which give a visual representation of the experimental distribution of the reliability of the plowing process.

![Figure 3. Scheme of experimental distribution of plowing depth of worn shares.](image)

![Figure 4. Scheme of experimental distribution of the plowing depth of new shares.](image)
Table 1. Indicators of operational tests of ploughshares.

| Option No. of the working body | The average value of the resource, ha | Average wear rate by weight kg / ha | by the width of the blade, mm / ha | by height, mm / ha |
|-------------------------------|--------------------------------------|-----------------------------------|---------------------------------|------------------|
| 1                             | 7.4                                  | 0.092                             | 0.98                            | 2.82             |
| 2                             | 10.2                                 | 0.08                              | 0.6                             | 2.66             |
| 3                             | 22.0                                 | 0.048                             | 0.56                            | 2.54             |
| 4                             | 24.7                                 | 0.045                             | 0.52                            | 2.36             |
| 5                             | 25.3                                 | 0.04                              | 0.45                            | 2.18             |
| 6                             | 52.1                                 | 0.024                             | 0.2                             | 1.8              |

From the data in table 1 it can be seen that the resource of the serial ploughshare produced by Svetlogradagromash when tilling sandy soils with a hardness of 2.0 MPa and a moisture content of 10-15% was 7.4 ha, with an average wear rate of 0.092 kg / ha. “VOGEL & NOOT” shares have the highest resource of 52.1 ha, with an average wear rate of 0.024 kg / ha. The ploughshares No. 3, 4 and 5 showed approximately the same results, and their resource was 22 ... 26 ha with an average wear rate of 0.04 ... 0.048 kg / ha. The results of the comparative assessment are presented in Figure 5.

Figure 5. Indicators of a comparative assessment of ploughshares operating tests.

4. Discussion of the results

Figure 3 shows that the spread of the experimentally established values of the depth of plowing was within 15.3 ... 24.4 cm. With a probability of 0.95 it was found that the average value of the depth of processing was 18.5 cm with a confidence interval of 17.8 ... 19, 1 cm, the standard deviation was $\sigma = 2.2$ cm. The total length of the interval was 9.1 cm. The diagram additionally indicates the tolerances of the processing depth for agricultural requirements $\Delta_{agr:req}$ and the maximum possible expansion interval of this range $\Delta_{ad}$ taking into account the evenness of the agro-landscape. The integrated depth distribution curve for worn plowshares $F(t)$ made it possible to determine the percentage ratio of the depth of plowing satisfying the established requirements $\Delta_{ad}$. 

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It can be seen from the diagram that 77% of the processing depths were below the set limit $\Delta_{\text{low}}$, and 3% exceed the set limit $\Delta_{\text{up}}$. And only 20% of the processing depths were within acceptable limits. By dividing the integral curve $F(t)$ to the left of the lower tolerance limit $\Delta_{\text{low}}$ into sections, you can set the percentage ratio of the depth of plowing in each interval.

Unlike worn out for new shares (Fig. 4), the total length of the interval of distribution of the depth of plowing was 2.8 cm, and the spread of experimentally established values is in the range of 20.2 ... 23.0 cm. The average value of the processing depth was 21.2 cm with a confidence interval of 21.0 ... 21.4 cm. The standard deviation was $\sigma = 0.65$ cm. The diagram shows that 96% of the processing depths satisfy the specified conditions and only 4% exceed the upper limit $\Delta_{\text{up}}$. In comparison with the operation of worn shares, the length of the interval of spread in the values of the processing depth in this case decreased for 3.8 times. A comparative assessment showed that, despite the fact that the largest resource have the “VOGEL&NOOT” shares, which amounted to 51.6 hectares, the most preferred ploughshares are the ones sintered with powder based on cast iron waste, the average resource of which amounted to an average of 24.7 hectares, but the technical and economic indicator for their operation is 276 rub/ha, which is 25% lower than the share of “VOGEL&NOOT” firm. The high technical and economic indicator of the “VOGEL&NOOT” branded shares is explained by the high selling price of the shares, which amounted to 3042 rubles. The cost of the “VOGEL&NOOT” ploughshare is 9.5 times higher than the serial trapezoidal share and 4–7 times higher than the other shares [3, 4, 5].

“Svetlogradagromash” production ploughshare sintered and “Sormait” powder hardened ploughshares showed good production in comparison with serial trapezoidal ploughshares and approximately the same production as “Svetlogradagromash” ploughshare sintered with powder based on cast iron waste, but they have a higher technical and economical index.

Taking the results of the comparative assessment into account, the “Svetlogradagromash” production shares sintered with powder based on cast iron waste are perspective and having a lower technical and economic indicator.

5. Conclusions
Thus, in spite of the high resource share of VOGEL&NOOT shares, which amounted to 52.1 ha, the most preferred shares are those deposited with powder based on cast iron alloyed with boron and manganese in an optimal ratio, the average resource of which is 24.7 ha, but the technical and economic indicator of their operation amounted to 276 rub / ha, which is 25% lower than the share made by “VOGEL&NOOT”.

References
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