Development of methods for increasing the technical and economic efficiency of the application of hardening technologies for flat working bodies of tillage machines

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Abstract. The questions of strengthening of details of tillage machines are considered. A method for improving technical and economic efficiency is developed based on determining the zones of preferential hardening of dumps based on finding the local coefficients of the wear rate and developing technologies for strengthening the selected zones that ensure the achievement of the specified coefficients. The durability of reinforced parts that have passed full-scale tests in the farms of the Kaluga region has increased by 1.8 times.

When carrying out technological operations in agricultural production, thin flat parts in the form of working bodies of tillage machines (ploughshares, landside, mouldboard) are widely used. These parts work under conditions of abrasive wear and significant static and dynamic loads [1, 2]. The resource of plough components a large extent determines productivity and agro-technical terms. Hardening of parts by quenching for hardness 48 ... 52 HRC does not allow to achieve a significant increase in their wear resistance [3]. Thus, the wear of the working edge of the breast of the mouldboard plow of the EurOpal company (figure 1) can reach 15-20 mm.

Figure 1. Wear of working edge of the breast of the mouldboard plow of the EurOpal company
a) new breast of the mouldboard plow; b) worn of the mouldboard plow.

Mouldboards are subjected to intense wear, up to perforating abrasion (figure 2).
Figure 2. Perforating abrasion of the EurOpal mouldboard plow.

The wear of the dumps and the resulting loosening of the bolt fasteners can lead to the formation of cracks (figure 3).

Figure 3. Worn plow parts. a – wear of hidden bolt heads in the area of attachment of the Kverneland plow blade to the body; b – a transverse crack in the bow of the Kvernerland plow blade.

A lot of attention is currently being paid to the study of the wear characteristics of the parts of tillage machines and the development of technologies for their hardening [4, 5]. Lind, an American company, has proposed Wear-TUFF to protect working bodies from wear when working in highly abrasive environment [6]. The coating is applied by pouring or spraying followed by heat treatment. It is noted that the coating increases the product's service life by two to three times. The coating hardness is 56-60 HRC. This company also offers the technology for hardening the working bodies of agricultural machines using wear-resistant linings and plates made by applying Wear-TUFF wear-resistant coatings with hardness up to 60 HRC to soft steel surfaces. Wear-resistant plates are attached to the working bodies of agricultural machines using bolted connections.

The Hungarian company "Innoveld" has developed a technology for strengthening working bodies with a hard alloy of the "Elkefem" family using induction heating [6]. As noted, the use of this technology can increase the service life of working bodies by 3.5-4 times. Other methods of surfacing with wear-resistant materials are also used [7].

However, the use of all these technologies is associated with an increase in material and labor costs. At the same time, as shown in figures 1-3, the wear of parts is extremely uneven, and their performance is limited by the state of a very limited number of edges and surfaces. This circumstance is explained by the fact that the location of the wear zones is determined by the trajectory of movement and the pressure of the soil layer. In this regard, it seems appropriate to develop a methodology for improving the technical and economic efficiency of the application of hardening technologies by minimizing the areas of parts to be hardened, as well as choosing a rational technology for strengthening these according to the "cost-wear resistance" criterion. In this paper, as a hardening technology, we studied the arc surfacing with non-overlapping rollers

It is proposed to determine zones with different requirements to the hardening technology based on measurements of the wear of the used blade and the calculation of the wear intensity coefficient [8].
where \( K_w \) is the amount of wear at the measuring in the i-th point; \( W_{aw} \) average wear of the entire surface.

The value of \( W_{aw} \) is proposed to be calculated by the expression

\[
W_{aw} = \frac{\sum W_i}{N},
\]

where \( N \) is the number of measurement points.

The physical meaning of the proposed coefficient is that in order to ensure equal wear resistance of the entire part, it is necessary to strengthen the zones for which \( K_w > 1 \), i.e. the wear intensity exceeds the average value. To perform the calculations according to formulas (1) and (2), thickness measurements were carried out at 20 dumps with an operating time of 100 ... 200 ha after plowing on sandy and sandy loamy soils.

The thickness was measured (figure 4) along seven horizontal lines (I – VII) located at a distance of 30 mm and in three at a distance of 60 mm from each other. On the chest of the blade, measurements were taken at a distance of 30 mm from each other, and on the wing and the working surface of the blade at a distance of 60 mm from each other. The dimensions of the coordinate grid were set more frequently in the most loaded zones.

![Figure 4. The scheme for measuring blade thickness.](image)

For further studies, 4 areas were identified in which the wear rate was within the range: region I - 2.00 or more, region II - from 1.50 to 2.00, region III - from 1.00 to 1.50, region IV - less than 1.00.

We set the requirements for hardening technologies for each of zone I, II, and III. With "spotted" hardening, the area of the deposited surface \( S_{st} \) in each zone is less than the total area \( S \) of the zone to be hardened. Near the rollers of the deposited metal in the zones of thermal influence (HAZ) there is a partial softening of the base metal. With this in mind, the average wear resistance of each zone of the hardened surface \( U_{st} \) can be estimated by the dependence

\[
U_k = k_{tech} \left( U_{in} \cdot \eta_{in} + U_{st} \cdot \eta_{st} + U_{HAZ} \cdot \eta_{HAZ} \right),
\]

where \( U_{in}, U_{st}, U_{HAZ}, \eta_{in}, \eta_{st}, \eta_{HAZ} \) is wear resistance and the proportion of the surface area of the blade not subjected to changes in the structure, subjected to surfacing and subjected to partial softening in the near-seam zone, respectively; \( k_{tech} \) is coefficient taking into account the influence on \( U_{st} \) other indicators of surfacing technology, such as the scheme for applying welds, the height of the weld beads, etc.

The increase in wear resistance of the hardened surface will be evaluated by the coefficient of hardening.
Substituting (4) in (3) after transformations is obtained
\[ k_h = k_{tech} \left( \eta_{st} + r_{HAZ} \eta_{HAZ} \right), \]
where \( r_{st}, r_{HAZ} \) is relative wear resistance of weld metal \((r_{st}>1)\) and partially released base metal in the near-shore zone \((r_{HAZ}<1)\).

We assume that the area of the released surface is proportional to the area of the deposited metal. Then
\[ \eta_{HAZ} = \zeta_{HAZ} \cdot \eta_{st}, \]
where \( \zeta_{HAZ} \) is the proportionality coefficient.

Substituting (6) into (5) and, as a first approximation, assuming \( k_{tech} = 1 \), we obtain
\[ k_h = \eta_{st} \left( r_{st} - 1 - \zeta_{HAZ} \left( 1 - r_{HAZ} \right) \right) + 1. \]  

Thus, by changing the volume of surfacing \( \eta_{st} \), it is possible to control the amount of hardening \( k_h \) and reduce the volume of surfacing in areas with a lower value \( K_w \). Approximation to the case of equal wear resistance of the product is achieved when \( k_h \rightarrow K_w \) the entire working surface.

Table 1 shows experimentally determined coefficients of local wear intensity for the initial and hard-surfaced non-overlapping roller blade of the EurOpal plough.

| Local coefficient of the wear rate | Mouldboard surface area | Average value |
|-----------------------------------|------------------------|--------------|
|                                   | I         | II         | III        | IV   |               |
| for initial mouldboards           | 2.05     | 1.68       | 1.18       | 0.58 | 1.37         |
| for hardened mouldboards          | 1.53     | 1.37       | 1.07       | 0.79 | 1.19         |

The data in table 1 show a decrease in the coefficients of local wear intensity in the hardened areas (I, II, and III) with a simultaneous increase in the coefficient of local wear intensity in the non-hardened areas (IV). The coefficient of local wear intensity approaches one over the entire surface of the blade, which indicates an increase in the uniformity of wear of the entire working surface of the blade. The durability of the mouldboard, which was hardened by surfacing, increased to 1.8 times.

The economic feasibility of strengthening the part is estimated as follows. Let the service life of a base, non-hardened part be \( T_{in} \).

Then for some time \( T_p \) it is necessary to make \( n_{in} \) replacements of the part:
\[ n_{in} = \frac{T_p}{T_{in}}. \]  

During the service life of the hardened part \( T_h \), the required number \( n_h \) of replacements will be
\[ n_h = \frac{T_p}{T_h}. \]  

Denote the cost of the initial part by \( C_{in} \). The cost of a hardened part \( C_h \) can be represented
\[ C_h = C_{in} + C_{st}, \]
where \( C_{st} \) is the cost of strengthening the base part.

The cost of acquiring basic parts \( E_{in} \) over a period of time \( T_t \) will amount to
\[ E_{in} = n_{in} \cdot C_{in}. \]  

The cost of acquiring hardened parts \( E_h \) for the same period \( T_p \) will be
\[ E_h = n_h \cdot C_h. \]  

Reducing the cost of purchasing parts in the case of their hardening is estimated by the coefficient \( K_R \).
Taking into account dependences (8-13), we obtain

\[ \frac{K_R}{E_h} = \frac{E_{in}}{E_h}. \]  

(13)

Let us also assume that the cost of hardening the base part \( C_{st} \) is determined primarily by the area \( S_{st} \) of surfacing. Then we can write

\[ C_{st} = \eta_{st} \cdot S \cdot P_h, \]  

(15)

where \( \eta_{st} \) is the fraction of the area of the weld surface to the total area \( S \) of the working surface of the part; \( P_h \) is the cost of surfacing per unit surface area of the part.

Let's introduce the coefficient of hardening of the entire part

\[ h_{in} = K_{TP} \cdot \frac{C_{in}}{S}. \]  

(16)

Then, taking into account equations (15) and (16), expression (14) takes the form

\[ \eta_{st} \cdot P_h < \left( \frac{K_h - 1}{S} \right) \cdot \frac{C_{in}}{S}. \]  

(17)

Thus, the method proposed in this paper to increase the technical and economic efficiency of the application of hardening technologies for flat working bodies of tillage machines includes two main stages:

The first is micrometering of the worn part, calculation the local coefficients of the wear rate and determination of the required hardening for different areas of the wear surface;

The second is development of hardening technologies for the selected areas of the hardened surface, ensuring the achievement of the specified hardening coefficients and the calculation of the economic feasibility of applying the developed technology of hardening the parts.

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