Technological, cycle and actual productivity of the surfacing process in the restoration of parts of forest machines

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Abstract. Most forestry machines and mechanisms operate in adverse conditions: an abrasive medium at low temperatures, which impede lubrication of parts and components of mechanisms and affect the mechanical characteristics of metals; under significant loads caused by working conditions in the forest. Therefore, the issues of operation and repair of precisely logging machines are most relevant. Scientific research and best practices of repair enterprises currently have a significant number of studied methods for building up worn parts in the recovery process. Scientific research and best practices of repair enterprises currently have a significant number of studied methods for building up worn parts in the recovery process. The requirement to ensure high productivity of the extension operation is relevant and important. The most high-performance methods are metallization, casting, electro contact, surfacing. But the first two methods do not provide guaranteed adhesion to the base metal. When applying metal to a worn surface by surfacing, good adhesion and the possibility of obtaining a wear-resistant surface are ensured. When floating metal overhead, technological work is performed, which means "work to change the shape, properties, condition and position of the subject of labor. "Productivity of the equipment is determined by the amount of technological work performed for a certain period of time.

1. Introduction
One of the main tasks of the development of repair production is a constant and significant increase in the productivity of technological processes, including in restoration operations. Without considering productivity, it is impossible to correctly carry out a technical and economic assessment of the method of restoration. Labor productivity in the performed operations of the technological process cannot be considered according to the achieved values but should be evaluated by a system of indicators characterizing, in addition to the costs of living labor, the costs of social, past labor. The efficiency of the process with enough fullness can be determined by indicators: 1) equipment performance; 2) the complexity, energy intensity and metal consumption of the process. To determine the effect of various factors on productivity, consider technological, cyclic and actual performance.

2. Technological productivity
The productivity of the possible, clean operation of the equipment, or the productivity of continuous technological work, without any time expenditures for auxiliary operations, idling, preparatory and final operations.
In general

\[ \Pi_T = A \cdot V = K \cdot N_c \]  

where \( A \) – load indicator; \( V \) – process speed indicator; \( K \) – process speed indicator; \( N_c \) – power consumption.

Cyclic performance is considered taking into account the time losses in the cycle:

\[ \Pi_{\text{U}} = \Pi_T \cdot \eta_t \]  

where \( \eta_t \) – cycle time utilization.

Actual performance is considered taking into account all time losses, including off-cycle:

\[ \Pi_o = \Pi_T \cdot \eta_t = \eta_t \cdot K \cdot N_c \]  

where \( \eta_t \) – the total time utilization.

Surfacing technological productivity is estimated by the amount of deposited metal per unit time. Can record:

\[ \Pi_T = F_{np} \cdot V_{np} \cdot \eta_n \]  

or

\[ \Pi_T = 0.785 \cdot d_n^2 \cdot V_n \cdot \eta_n \]  

where \( \eta_n = 1 - \psi \).

In the expression (5), there are no electrical parameters, it is understood that the power source provides the melting of the entire amount of wire supplied (the performance of the metallization apparatus does not depend on the current, but on the wire feed speed and its diameter) [80].

Thus, the limiting values of technological productivity of the surfacing installation are limited:

1) The power of the power source;
2) The feed rate and the cross-section (diameter) of the electrode wire (Figure 1).

![Figure 1. \( \Pi_T \) limitation by diameter and electrode wire feed speed.](image-url)

3. Cycle performance

When surfacing a part, in addition to the main technological operation, it is necessary to perform a number of auxiliary operations that ensure the performance of the main technological work. The cycle time consists of the main technological time \( t_T \) of the auxiliary time \( t_a \), and the coefficient of utilization of the cycle time.
\[
\eta_v = \frac{t_f}{t_r + t_u}
\] (6)

The auxiliary time consists of: time for installation and removal of the part \(t_1\), time for turning on and off the equipment \(t_2\), time for clogging the oil channels of the part to protect against welding \(t_3\), transition time \(t_4\), time to clean equipment parts (for example, from metal spatter) \(t_5\), time to control \(t_6\). In determining \(t_u\), it is necessary to consider the possible combination of time. To determine the technological time, the expression

\[
t_r = \frac{V_T}{K_v \cdot N_c}
\] (7)

Where \(V_T\) – is the volume of metal growth.

The volume of metal growth can be represented

\[
V_T = \pi \cdot d \cdot l \left( \delta_1 + f \right)
\] (8)

where \(d, l\) – dimensions of the deposited area; \(\delta_1\) – amount of wear; \(f\) – machining allowance.

Then

\[
t_r = \frac{\pi \cdot d \cdot l \left( \delta_1 + f \right)}{K_v \cdot N_c}
\] (9)

To determine \(t_r\), a nomogram is proposed as Figure 2 was used to determine \(t_r\), the volume of metal growth.

To identify the nature of the change in the utilization of the cycle time, we accept: \(d = 30-110\) mm; \(l = 50-300\) mm; \(\delta_1 = 1.0\) mm; \(K_v = 9.7\) cm²/MJ; \(\eta = 0.5\); \(I_H = 150-400\) A. The calculation results are presented in Table 1.

**Figure 2.** Nomogram for definition \(t_r\). For \(d_{np} = 2.0: 1.2; 3.4; 5.6; 7.9; 11\) cm. For \(d_{np} = 1.2: 8.9; 10; 11; 12; 13; 14; 15\), respectively \(V_{np} = 2.3; 2.9; 3.8; 4.8; 6.0; 7.9; 11.0; 12.6\) cm/s.
**Table 1.** The size of the deposited area both in diameter and in length.

| Plotsize $$(d \times l, \text{cm}^2)$$ | $t_T$ | $t_s$ | $t_u$ | $\eta_{t_u}$ |
|--------------------------------------|-------|-------|-------|-------------|
| 1                                    | 20    | 3.0   | 0.93  | 3.93        | 0.76        |
| 2                                    | 50    | 5.4   | 0.98  | 6.38        | 0.85        |
| 3                                    | 80    | 6.7   | 1.03  | 7.73        | 0.87        |
| 4                                    | 110   | 7.5   | 1.08  | 8.58        | 0.87        |
| 5                                    | 140   | 8.1   | 1.13  | 9.23        | 0.88        |
| 6                                    | 170   | 8.5   | 1.18  | 9.68        | 0.88        |
| 7                                    | 200   | 8.8   | 1.23  | 10.63       | 0.88        |
| 8                                    | 230   | 9.1   | 1.28  | 10.38       | 0.88        |
| 9                                    | 260   | 9.2   | 1.33  | 10.53       | 0.88        |
| 10                                   | 290   | 9.3   | 1.38  | 10.68       | 0.88        |

Table 1 shows that with an increase in the size of the deposited area both in diameter and in length with a simultaneous increase in arc power $\eta_{t_u}$, when surfacing on small surfaces is 0.76-0.85. But later it stabilizes with value 0.85-0.9. At a constant arc power, which is typical for surfacing surfaces of the same diameter, but of different lengths, a change in a wider range should be expected, which is confirmed by the data in Table 2 (Accepted: $d = 5.0$ mm; $l = 50-300$ mm; $I_{A} = 180$ A; $\delta_{s} = 1$ mm; $f = 0.3-1.2$ mm).

**Table 2.** The section length for each indicator.

| Indicators | Section length (mm) |
|------------|---------------------|
|            | 50  | 75  | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 |
| $t_T$ (min.) | 2.86| 4.28| 5.72| 7.14| 8.56| 10.0| 11.43| 12.85| 14.3 | 15.72| 17.15 |
| $t_s$ (min.) | 0.93| 0.98| 1.03| 1.08| 1.13| 1.18| 1.23 | 1.28 | 1.33 | 1.38 | 1.43 |
| $t_u$ (min.) | 3.79| 5.26| 6.75| 8.22| 9.69| 11.18| 11.18| 14.13| 15.63| 17.10| 18.58 |
| $\eta_{t_u}$ | 0.75| 0.81| 0.85| 0.87| 0.88| 0.89 | 0.9 | 0.91 | 0.92 | 0.92 | 0.92 |

The utilization rate of the cycle time direct welding of the considered size intervals is 0.75-0.92; Cycle throughput will be calculated according to Equation 10.

$$II_{hl} = (0.75-0.92) II_T$$

(10)

4. Actual performance

When surfacing parts, the time is inevitable for preparatory and final operations, downtime and other time losses for various organizational and technical reasons, i.e. only an hour of shift work time is spent on the main and auxiliary operations of the work cycle - cycle work. The value of out-of-cycle time losses per shift can be characterized by the coefficient of time use as Equation 11.

$$\eta_t = \frac{\sum t_u}{\sum t_u + \sum t_n}$$

(11)

where $\sum t_u$ – cycle time per shift; $\sum t_n$ – time spent on off-cycle losses.

When surfacing operation:
\[
\sum t_n = T_n + T_{\text{доп}} \cdot n
\]  
(12)

Where \( T_n \) is the preparatory-final time for a batch of parts (it is assumed that a batch of parts is fused for a shift), consists of time for: receiving a task, a tool, preparing and cleaning a workplace, installing and removing tools and devices, setting up and adjusting equipment, commissioning finished products; \( T_{\text{доп}} \) – time for maintenance of the working bridge and natural necessities, etc.; \( n \) – is the number of parts per shift.

Coefficient \( \eta_t \) can be represented in Equation 13.

\[
\eta_t = \eta_{t_a} \cdot \eta_{t_b} \cdot \eta_{t_o}
\]  
(13)

where \( \eta_{t_a} \) – coefficient taking into account the loss of time on the preparatory-final operations; \( \eta_{t_o} \) – coefficient taking into account the loss of time for organizational and technical reasons.

Otherwise

\[
\eta_t = \frac{t_T \cdot n}{(t_T + t_a + t_o) \cdot n + T_n}
\]  
(14)

Then the actual performance of the surfacing installation was confirmed using either one of the Equation as below:

\[
\Pi_o = K_v \cdot N \cdot \eta_{t_a} \cdot \eta_{t_b} \cdot \eta_{t_o}
\]  
(15)

or

\[
\Pi_o = K_v \cdot N \frac{n \cdot t_T}{n(t_T + t_a + t_o) + T_n}
\]  
(16)

or

\[
\Pi_o = F_{np} \cdot V_{np} \cdot \eta_n \frac{n \cdot t_T}{n(t_T + t_a + t_o) + T_n}
\]  
(17)

Actual productivity is directly proportional to the technological productivity of the equipment and the overall coefficient of use of time \( \eta_t \), which increases with a decrease in the size of the batch of parts (per shift) and with a decrease in out-of-cycle. Performing actions by the operator on the surfacing installation combine the work of a locksmith and a welder. Combined work on the management of the machine and its maintenance: removal and installation of parts, cleaning parts of the equipment from splashes, setting up the machine for preset modes, etc.

We accept that \( t_{o6c} \) includes time elements on: care of equipment, working bridge; elimination of minor problems; regulation of the regime; turn on, turn off, power on the installation; layout and cleaning of tools; cleaning equipment from metal spatter.

5. Methodology of experimental-design studies of energy intensity

From the expression of the specific and hourly productivity (5) it can be seen that they depend on the amount of wire fed \( F_{np} \), \( V_{np} \), Coefficient of performance \( \eta \) installation; arc power \( N_o \); spray coefficient \( \psi \) at the optimal values of the remaining parameters of the mode. At \( F_{np} = \text{Const} \) according to the experimental \( I_H \) can be expressed by \( V_{np} \) by an equation of the type \( y = k + bx \) (under conditions of self-regulation of the arc). Coefficient of performance. \( \eta \) installation, summarizes Coefficient of performance of all hotel consumers of the installation, the greatest losses occur in the power source. Differentially experimentally investigated \( \eta \) and Coefficient of performance. \( \eta_i \) source in the download area 0,1-0,9 (\( K_i = 0,1-0,9 \)), which takes place during surfacing of restored parts.

Productivity was calculated as the amount of deposited metal to the total energy consumption of the installation. The coefficient \( \psi \) in the calculations is adopted (according to the results of experiments) 7%, the transfer coefficient is \( \eta_n \) is 0.93, respectively. For a comparative analysis, the performance is calculated and graphically shown for the converter and rectifier, with respect to only 1.6 and 2.0 mm
wires, when determining the graphical dependence of energy consumption, we considered differentially for technological, cyclic and actual performance. The utilization factors are times: cyclic and total - calculated on the basis of reference materials, as applied to the polygons of the distribution of parts by diameter and length.

Research results $\eta$ and $\eta_u$ in depending on $K_3$ (Figures 3, 4) for Power Supply 1 and Power Supply 2.

![Figure 3. Dependence $\eta$, $\eta_u$ on $K_3$ (Power Supply 1).](image1)

![Figure 4. Dependence $\eta$, $\eta_u$ on $K_3$ (Power Supply 2).](image2)

Given different values of $I_{Ht}$, we calculate the specific productivity of surfacing installations from power supplies 1 and 2. The graphical dependence is presented in Figure 5.

![Figure 5. Actual installation performance: 1 - Power supply 1; 2 - Power Supply 2.](image3)

6. The results of experimental-design studies of energy intensity
The $K_v$ indicator gives a specific assessment, characterizes the energy excellence of the installation at various load factors, indicates the rational area of use of the installation according to $K_3$. The $\Pi_{Ht}$ and $\Pi_0$ values are much smaller, which is explained by the low values of time coefficients. With regard to repair of parts, the ratio and nature of the change in $\Pi_{Ht}$ and $\Pi_0$ was shown in Figure 6.
Figure 6. The nature of the change in $\Pi_{li}$ and $\Pi_s$ depending on $l$ of the site.

Low $Kv$ values at low $K_i$ load factors are explained by significant energy losses in the surfacing installation itself.

7. Conclusions
1. The expressions obtained show that the work of applying a metal coating to a unit of consumed energy is determined by: 1) the cross section of the electrode wire and its feed rate; 2) the efficiency of the installation and use of metal; 3) the energy consumption of the arc. You can increase the value of $Kv$ by increasing: 1) wire cross-section; 2) wire feed speed; 3) set the efficiency. Increasing the value of the arc power during $F_{pr} \cdot V_{gh} = Const$ will reduce the specific productivity of the installation. It is necessary to use the minimum arc power, which provides satisfactory melting of the feed wire.
2. The technological productivity of the surfacing installation is determined by the amount of wire that can be supplied and is limited by the power of the power source.
3. By reducing the amplitudes of fluctuations in the electrical parameters during periods of microcycles, it is possible to increase $\Pi_T$ by 5-10%.
4. The actual productivity is 30-50% of $\Pi_T$ and can be improved by reducing all kinds of time losses.
5. The main factors of actual performance is: time; specific productivity; power.

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