OPTIMIZATION OF THE FREQUENCY OF THE TECHNICAL SERVICE OF MACHINES WITH RELIANCE OF RELIABILITY

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Abstract: A key element in the machinery management policy is its rational use by optimizing the periodicity of maintenance and repairs. The influence of the numerical characteristics and parameters of the reliability indicators distribution on the optimal periodicity of the maintenance has been investigated. Analytical dependencies for determining the complex reliability indicators of the objects at the optimal periodicity of the prophylactics are proposed.

Key words: STANDARDS, ASSET MANAGEMENT, MAINTENANCE, FAILURE, SERVICEABILITY, COST.

The structure and nature of the machine maintenance and repair process is determined by the adopted usage strategy, which in its broadest form is a set of principles and rules that provide a defined management of the process of maintaining and restoring machine performance by maintaining an optimal operation of the machinery and prescribing the maintenance and repair work in accordance with its technical condition.

Therefore, the aim of this work is to study and optimize the periodicity of machine maintenance, taking into account their reliability characteristics.

The object of the study is the self-propelled agricultural equipment, and the subject of research is a mathematical model for optimizing the periodicity of its maintenance.

For companies and business organizations, whose the machine-tractor park failures lead mainly to a decline in their economic indicators, the optimization of the prophylactic actions should be done on the basis of the criterion “specific aggregate costs minimum” (C) [1]:

\[ C = C(\tau) = C(\tau)/t = \{C_o(\tau) + C_p(\tau)\}/t, \]

where \( C_o(\tau) \) is the function of the cost of restoring the facility's operational capacity due to a failure;
\( C_p(\tau) \) - the function of costs for conducting planned preventive actions.

The cost of restoring the work capacity of the site due to a failure \( (C_o(\tau)) \) and the costs for conducting planned preventive actions \( (C_p(\tau)) \) can be determined by the following relations:

\[ C_o(\tau) = C_0 H_0(t); C_p(\tau) = C_p H_p(t), \]

where \( C_o, C_p \) are the cost averages, respectively, for the removal of one failure and for a planned repair action to be carried out;
\( H_0(t); H_p(t) \) - the flow characteristics of the failures and the planned repairs.

If \( z \) is the work between the moments of restoration of the facility's working capacity, then \( \{z_k\} \) forms a recurrent flow of restoration of the functionality of the objects \([2, 3]\) with an average number of failures for a particular work \( m=M(m_0) \), where \( m_0 \) is the number of restorers of the facility's performance in the range \((0, t)\).

In [4] using the full probability formula, the following expression for \( m_0 \) is obtained:

\[ m_0 = \int_0^t [1 - F(t)]dt + t_p F(t) + t_p [1 - F(t)]. \]

The expected number of restorers of the facility's performance within the range \((0, t)\) for each stationary process is proportional to \( t \), i.e. \( H(t)=t m_0 \).

Then, taking into account that the two types of actions (due to a failure and planned) form a complete set of events, we get

\[ H(t) = M(m_0) = H(t), F(t); \]

\[ H(t) = M(m_0) = H(t), [1-F(t)]. \]

If in (1) we substitute (2), (3), (4) and (5) with their equals, than

\[ m_0 = \int_0^t [1 - F(t)]dt + t_p F(t) + t_p [1 - F(t)]. \]

To optimize the periodicity of planned actions, it is necessary to differentiate (6) and equalize the derivative to zero.

Then \( \omega(\tau)\{[1 - F(t)dt + p] - [F(\tau) + C_p/(C_o + C_p)]\} = 0, \)

where \( p=(C_{0,P},-C_{0,P})/(C_o + C_p) \).

In this case, if the density of distribution of work until failure (the resource) is by Weibull distribution

\[ f(t)=(b/a)t^{a-1}exp\{-t/a\b\}; \]

then \( \int_0^\infty [1 - F(t)]dt = \tilde{\Gamma}\{[\tau, \Gamma(1+1/b)/\tilde{\Gamma}], (1+1/b) + \tau.\exp\{-\tau / a\}^b\}, \)

where \( a, b \) are the parameters of the Weibull distribution;
\( \tilde{\Gamma} \) is the average value of work until failure (the resource) of the object;
\( \Gamma(z;x) \) - the incomplete gamma-function of the arguments \( z \) and \( x [5] \).

Taking into account (7), we may get for (6) and (7) specific expressions, i.e.:

\[ \omega(\tau)\{[\tilde{\Gamma}(z;x) + \tau.\exp\{-\tau / a\}^b + t_p F(t) + t_p [1 - F(t)]\}; \]

\[ \omega(\tau)\{[\tilde{\Gamma}(z;x) + \tau.\exp\{-\tau / a\}^b + p] - [F(\tau) + C_p/(C_o + C_p)]\} = 0. \]

It follows from the analysis of (6) that the value of C is dependent on the costs \( C_o, C_p \) the parameters of the work distribution law to the failure \( F(t) \) and the periodicity of the planned maintenance \( \tau \). The study was conducted for Weibull and normal distribution of the work until failure, and the graphical interpretation of the results is given in Figure 1-4, where \( \tau / t \) is the variation of the periodicity of the planned actions compared to the average work until failure; \( \kappa=C_p/C_o \) is the cost-reduction ratio for planned repair actions, and the \( C/C_o \cdot \tau \rightarrow \infty \) ratio characterizes the change in the relative costs of scheduled maintenance services relative to relative costs without planned maintenance actions \( (\tau \rightarrow \infty) \).
The analysis of the results obtained shows that the effectiveness of management of the level of reliability depends on the periodicity of the prophylactic actions. By decreasing the ratio $k$ outlines more clearly the extremum of the function $C=f(\tau)$, the achievement of which can be ensured by increasing the frequency of planned repairs. Therefore with the decrease of $k$ due to the increase of $C_0$, the need to carry out planned preventive actions, even at an invariable level of $\omega(t)$ of objects, will grow.

**Figure 1.** The nature of the relative cost variation according to the periodicity of the planned actions in Weibull distribution of the work to the failure of the object: a) with a cost-reduction ratio for planned repair actions $k=0,2$; b) with a cost-reduction ratio for planned repair actions $k=0,6$.

**Figure 2.** The nature of variation in relative costs depending on the periodicity of planned actions under normal law of distribution of workmanship to refusal of the object: a) with a cost-reduction ratio for planned repair actions $k=0,2$; b) with a cost-reduction ratio for planned repair actions $k=0,6$.

**Figure 3.** Influence of the cost-reduction ratio for planned repair actions ($k$) on the optimal periodicity of the planned service ($\tau$) in Weibull distribution of the work to a failure.
The reduction of $C$ in conducting prophylactic maintenance with optimal frequency compared to the use of objects until failure may be significant, for example from 80% ($k=0.02; b=2.4$) to 2% ($k=0.6; b=2.4$). The rate of change of $C$ largely depends on the parameter of the form $b$ and in case of small values of $b$ the implementation of the planned preventive actions from an economic point of view is meaningless, because in this case the distribution is close to the exponential distribution of the work until failure.

The expression (6) allows to investigate from another direction the influence of $b$ and $k$ on $\tau_{opt}$. Therefore, in Figure 3 and Figure 4, the change of function $\tau_{opt} = f(b;k)$, is shown. From the analysis of graphical dependence, it follows that the nature of the change in the $\tau_{opt}$ in the relation to the parameter $b$ has a non-linear character, which confirms the economic efficiency of the organization of the prophylactic service of the technique with optimal frequency. Moreover, regardless of the value of $k$, when $b \rightarrow 1(V=1), \tau_{opt} \rightarrow \infty$, and this means that it is effective to use objects until failure and not to carry out scheduled maintenance service actions.

To evaluate the level of reliability of the managed objects by optimizing the periodicity of prophylactic actions we use the complex indicators:

standby ratio

$$K_g = (t - t_p m_p - t_p m_o)/t_p m_p,$$

and a technical utilization ratio

$$K_g = (t - t_p m_p - t_p m_o)/t.$$

Conclusions:

- The influence of the numerical characteristics and the parameters of the distribution of the reliability indicators on the optimal periodicity of the prophylactic actions was investigated.
- Analytical dependencies are proposed for determining the complex reliability of the objects at the optimal periodicity of conducting the prophylactic actions.

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