Methodology for technical and economic assessment of the overhaul period of tractor units and self-propelled agricultural machinery

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Summary: The stages of the life cycle of complex technical products, such as tractors and self-propelled agricultural machinery, are considered. The need for adjusting /extending/ the repair interval of individual units and assemblies is justified.
A methodology for the technical and economic assessment of the repair interval of tractor units and self-propelled agricultural machinery has been developed, which takes into account the economic effect of extending the repair period, the relative share of the costs of purchasing replacement units and the set value of the confidence probability of the resource of the units.
Keywords: life cycle, unit, resource repair interval; economic effect.

Tractors and self-propelled agricultural machinery, as well as all other machines from the beginning of their development to the end of their use, go through a number of stages, united in the so-called life cycle. This concept is used mainly for complex, science-intensive production.

The life cycle of any technical product is a set of processes carried out from the moment a need arises for it, to the moment this need is satisfied and the product/machine is disposed of.Fig. 1 shows the main stages of the life cycle of a technical product /tractor, self-propelled agricultural machinery/ related to its manufacturer and user.

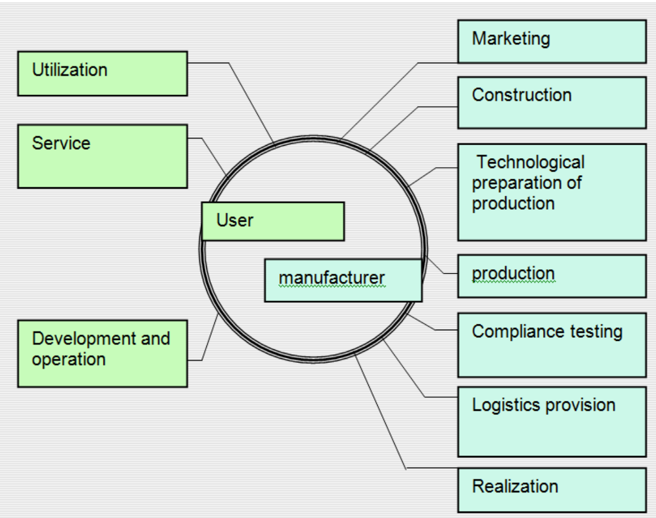

Fig.1 *Life cycle of tractors and self-propelled agricultural machinery*

The longest period of the life cycle of agricultural machinery is the period of operation, [3]. The specificity of agricultural production implies several months of intensive use of the predominant part of the equipment and a long storage period. Therefore, a situation often arises when the operating time of individual machine units or entire machines needs to be extended, i.e., their maintenance interval needs to be increased.

When using the aggregate-nodal form of repair, replacing the failed aggregate (node) with a new or repaired one, we increase the level of reliability of the machine and extend the originally determined interval between repairs.

Let us assume for certainty that the initial value of the failed unit or unit is C. Then the economic effect obtained as a result of extending the maintenance interval of the unit for the time

$$E^{+}/t/=\alpha.C.t,$$

where: C is the initial price of the unit;

α - the proportionality coefficient characterizing the economic effect of extending the repair interval [1].

But to purchase a certain number of spare parts for the unit (unit), for prevention and elimination of failures during operation, costs are required, which for time t will be

$$E^{-}/t/ = C_0\, t\, K_p/t/,$$

where: $K_p/t/$ is the upper confidence limit of the spare parts volume, which is determined with a given probability $P\ (0<P_з<1)$;

Co - the adjusted value of the unit taking into account operating costs in the conditions of an extended maintenance period $(t > 0)$.

The proposed method for determining the period of extension of the unit's repair interval $\Delta\tau_0$ consists in the fact that the magnitude of $\Delta\tau_0>0$ is determined by the condition of equality of the effect of the extension and the costs (losses) resulting from the purchase of spare parts, prevention and elimination of failures, i.e.

(1) $$\text{Co}\ t\ K_p/t/ =\alpha\ t\ C,$$

Where: t > 0.

And since $Kp/t/$ as a function of t is monotonically increasing with increasing t, then at $t<\Delta\tau$ the economic effect of extending the maintenance interval is equal to $E^{+}/t/$ and will be greater than the costs $E^{-}/t/$, and vice versa, at $t>\Delta\tau$ the costs $E^{-}/t/$ will be greater than the economic effect $E^{+}/t/$.

Therefore, the time Dt is the rational moment at which $E^{+}/t/ = E^{-}/t/$.

If we reduce both sides of expression (1) by $t>0$, we will obtain

(2) $$\text{Co}\ Kp/t/ = \alpha C,$$

from which it follows that in order to solve equation (1) with respect to t it is necessary to determine in explicit form the expression for $Kp/t/$, i.e. the expression for the upper confidence limit of replenishment of the volume of spare parts to maintain the operability of the machine unit.

For this we use the following ratio from [2]:

$$P[X\leq M(x)+\beta] > \beta^2/(\beta^2+\sigma^2(x))$$

where: $\beta > 0$ is a random number;

$M(x)$ and $\sigma^2(x)$ are the mathematical expectation and variance of X.

We place $X=\nu(\tau+t)-\nu(\tau)$,

where: $\nu(z)$ is the number of replacements for time z and we get

(3) $$P[\nu(\tau+t)-\nu(\tau)\leq H(\tau+t)-H(\tau)+\beta]\geq\beta^2/[\beta^2+\sigma^2(\nu(\tau+t)-\nu(\tau))],$$

where: $H(z)=M[\nu(z)$ is the average number of substitutions over time z.

is the average number of substitutions over time [2]:

(4) $H(z) = 1/\bar{t}_o\,[t+M(\xi_z) + z-\bar{t}_o]$,

where: ξ is the residual production, starting from time z until the next failure.
We assume that the replacement of the failed unit with a working one is carried out instantly, i.e. the replacement time is negligible, [4].
Then, using expression (4) we easily obtain that

$$H(\tau+t) - H(\tau) = 1/\bar{t}_o\,[t+M(\xi_{\tau+t}) - M(\xi_\tau)],$$

whence, if we assume that

(5) $M(\xi_{\tau+t}) = M(\xi_\tau)$,
then
(6) $H(\tau+t) - H(\tau) = t/\bar{t}_o$.

According to expression (5), as a result of replenishing the spare parts stock, the average residual resource does not change.

Taking into account (6) in (3), we obtain that

$$P[\nu(\tau+t) - \nu(\tau) \le t/\bar{t}_o + \beta] \ge \beta/[\beta^2 + \sigma^2(\nu(\tau + t) - \nu(\tau))].$$

To calculate the σ^2 [.] we use [2]:

$$\sigma^2[\nu(t)] = 2\int_0^t H(t-x)dH(x)+H(t)-H^2(t),$$

from which we get that

(7) $\sigma^2[\nu((t)] = t/\bar{t}_o$,

because according to the formula (6) $H(t)=t/\bar{t}_o$ и $H(t-x)dH(x)=t^2/2\bar{t}_o^{\,2}$.

If we analyze the obvious ratio

$$\sigma^2[\nu(\tau+t)]=\sigma^2[\nu(\tau)]+\sigma^2[\nu((\tau+t)-\nu(\tau)],$$

We get that:

$$\sigma^2[\nu(\tau)-\nu(\tau)]=\sigma^2[\nu(\tau+t)]-\sigma^2[\nu(\tau)],$$

from which, taking into account expression (7), we obtain that

$$\sigma^2[\nu(\tau+t)-\nu(\tau)]=t/t_0.$$

Therefore, taking into account the last equality in expression (7), we obtain

$$P[\nu(\tau+t)-\nu(\tau)\le t/\bar{t}_o+\beta]\ge\beta^2/(\beta^2+t/\bar{t}_o).$$

Further, if we equate the right-hand side to the given value of the confidence probability P_3, we will obtain

(8) $P[\nu(\tau+t)-\nu(\tau) \le t/\bar{t}_o+\beta]\ge P_3$,

where the value of β is determined by $\beta^2/(\beta^2+t/\bar{t}_o)=P_3$ и

(9) $\beta = [tP_3/(\bar{t}_o\,(1-P_3))]^{1/2}$.

We substitute expression (9) into (8) and obtain that

$$P[\nu(\tau+t)-\nu(\tau) \le Kp(t)]\ge P_3,$$
where

(10) $Kp(t)=t/\bar{t}_o+[tP_3/(\bar{t}_o\,(1-P_3))]^{1/2}$.

Then, to determine the rational moment t_0, it is necessary to substitute expression (10) into equation (2) and we get

$$C_0(t/\bar{t}_o)++[tP_3/(\bar{t}_o\,(1-P_3))]^{1/2}=\alpha C.$$

Or, if we solve the last equation we will get the desired value

(11) $\Delta\tau=\bar{t}_o/2[P_3/(1-P_3)\,(1+\sqrt{1+4\alpha C(1-P_з)/C_oP_з}) + 2\alpha C/C_0]$

Or if we assume that $(1-P_3)/P_3=\kappa$; $C/C_0=\gamma$, then

(11′) $\Delta\tau=\dot{t}_o/2[1/k(1+\sqrt{1+4\alpha k\gamma})+2\alpha\gamma]$.

Thus, the rational extension of the service life (τ) will be $\Delta\tau$, determined by the formula (11).

For the machine as a whole, we propose to extend the rational maintenance interval by $\Delta\tau$, which we will determine by the formula

(12) $\Delta\bar{\tau}=\sum_{i=1}^{n} q_i\Delta\tau^{(i)}$,

where $\Delta\tau^{(i)}$ is determined by formula (11) for the *i-th* aggregate;
n is the total number of units of the machine,

$$q_i=C_0^{(i)}/\sum_{i=1}^{n}C_o^{(i)},$$

where C_0 are the costs for purchasing, preventive maintenance and troubleshooting of the *i-th* unit.

Formula (12) is interpreted as a weighted average value of the rational repair interval of the machine units.

Thus, taking into account the dependence (11) in (12), we will finally obtain the expression for the extension of the repair interval of the machine, the following expression:

$$\Delta\bar{\tau}=\sum_{i=1}^{n} q_i\bar{t}_{oi}/2.[k^{-1}(1+\sqrt{1+4\alpha_{ii}k\gamma_i})+2\alpha_i\gamma_i].$$

Conclusions:

1. The stages of the life cycle of complex technical products, such as tractors and self-propelled agricultural machinery, have been examined. The need for adjusting /extending/ the repair interval of individual units and assemblies has been substantiated.

2. A methodology has been developed for the technical and economic assessment of the repair interval of tractor units and self-propelled agricultural machinery, which takes into account the economic effect of extending the repair period, the relative share of the costs of purchasing replacement units and the set value of the confidence probability of the resource of the units.

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