Correction of the inter-repair period of aggregates /nodes / of the machines

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Summary: *The stages of the life cycle of complex technical products, such as tractors and self-propelled agricultural machinery, are examined. The need to correct /extend/ the period between repairs of individual aggregates and nodes is justified.*
For this purpose, a corrective expression was derived for determining the economically expedient extension of the between-repair period of the machine elements, 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 aggregates.
KEYWORDS*: LIFE CYCLE, MAINTENANCE PERIOD; ECONOMIC EFFECT; EXTENSION.*

Agricultural machinery, as well as all other machines, from the beginning of their development to the end of their use, goes through a number of stages, united under the so-called life cycle. This concept is used for complex, knowledge-intensive production.
A life cycle according to ISO 9004-1 is a set of processes carried out from the moment of the emergence of needs for a certain product, to the moment of facilitating these needs and disposal of the product/machine.
Fig. 1 shows the main stages of the life cycle of a technical product related to the manufacturer and its user.

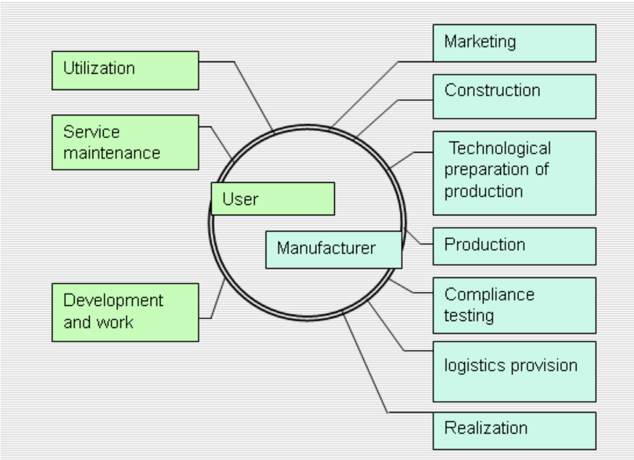

Fig.1 *Life cycle of tractors and self-propelled agricultural machinery*

The longest period of the agricultural machinery life cycle is the period of operation. The specificity of agricultural production implies several months of intensive use of the predominant part of the equipment and a long period of storage. Because of this, a situation often arises when the operating time of individual units of the machines or entire machines has to be extended, i.e. to increase their inter-repair period.
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.
For definiteness, let us assume that the initial value of the failed unit or node is C. Then the economic effect obtained as a result of extending the inter-repair period of the unit for the time.

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

Where : C is the initial price of the unit;
α - the proportionality factor characterizing the economic effect of extending the maintenance period [1].
But for the purchase of a certain number of spare parts for the unit (node), for the prevention and elimination of failures during operation, costs are necessary, which for the time t will be

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

Where : $K_p\,/t/$ is the upper confidence limit of the volume of spare parts, which is determined with a given probability $P\ (0< P_3 <1)$;

C_o - the adjusted value of the unit taking into account the operating costs in the conditions of the extension of the repair period $(t > 0)$.

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

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

Where : t > 0.

And since $Kp/t/$ as a function of t is monotonically increasing with an increase in t, then at $t<\Delta\tau$ the economic effect of extending the maintenance period 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 $\Delta\tau$ is the rational instant at which $E^{+}/t/ = E^{-}/t/$.

If we shorten both sides of the expression (1) by $t>0$, we get

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

whence it follows that in order to solve equation (1) for t it is necessary to determine in explicit form the expression for $Kp/t/$, i.e. the expression for the upper confidence limit of the replenishment volume of spare parts to maintain the operability of the machine unit.
For this we use the following ratio from [2]:

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

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:

$$\text{(3)} \qquad P[\nu(\tau+t)-\nu(\tau)\le H(\tau+t)-H(\tau)+\beta]\ge\beta^2/[\beta^2+\sigma^2(\nu(\tau+t)-\nu(\tau))],$$

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

To calculate $H(z)$ we use the following relation [2]:

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

Where: ξ is the residual work starting from time z until the next failure.

We assume that the replacement of the failed unit with a standing unit is instantaneous, i.e. replacement time is negligible.

Then, using the expression (4) we easily obtain that

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

From where we can 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 replenishment of the stock of spare parts, the average residual resource does not change.

Substituting (6) into (3), we get that

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

For calculation σ^2 [.] we use the expression [2]:

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

Where 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 apparent 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 where, taking into account the 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 get

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

Further, if we equate the right-hand side to the set value of the confidence probability P_3, we get

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

where the value of β is determined by the condition

$\beta^2/(\beta^2+t/\bar{t}_o)=P_3$ и

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

Substituting the expression (9) into (8) we get 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, in order to determine the rational moment t_0, it is necessary to replace the expression (10) in the 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 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, in general, we suggest that the rational between repair period be extended 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 defined by the formula (11) for the *i-th* aggregate;

n is the total number of machine units,

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

where *Co* are the costs of purchase, prevention and elimination of failures of the i-th unit.

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

In this way, taking into account the dependence (11) in (12), we will finally get the following expression for the extension of the machine maintenance period:

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

Conclusions:

1. An expression has been derived for determining the economically expedient extension of the inter-repair period of aggregates/nodes/ of the machines and for development and making justified management decisions in agriculture.
2. The expression for correcting the inter-repair period of aggregates/nodes/ of the machines takes into account the economic effect of its extension, the relative share of costs for the purchase of aggregates for replacement and the set value of the confidence probability of the resource of the aggregates.

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