Influence of the aging factor on the reliability of agricultural machinery

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Abstract. In the course of time a number of machine significant changes related to machine aging occur. The reasons for these changes are quite diverse. They are inevitable and irreversible in the time process of a gradual transition of the machine to a lower qualitative state. The article contains the data about the change in the indicators of no-failure and repairability of tractors (average restoration time) in the before-repair and between-repairs periods, which should be considered as a result of their aging. Data on the ratio of the lifetime of units and parts indicate the decisive role of the aging factor, but the lifetime can be strongly influenced by the assembly technology and the main thing - the run-in of parts. The degree of the aging of a machine can be estimated by reducing the lifetime of components, MTBF, machine productivity, etc., in the form of an aging factor, Kc. It shows how many times the lifetime of the part replaced in the machine is less than the nominal lifetime of the original part. The MTBF of the ageing machine is less than that of the new machine, or the labor input for the restoration of the old machine is greater than that of the new machine. By determining the aging rate of the parts to be replaced over the time interval under consideration, we constructed an aging function. The aging process of agricultural machinery was evaluated by the time and moment of resistance to unscrewing the uncoated threaded joints with a service life of 0.2 to 4 years. According to the obtained distribution functions, the average time increases with increasing service life, and the moment of resistance to unscrewing approaches the maximum values. With a service life of more than 4 years, the number of non-disassembled bolt connections, which break at the moment of unscrewing, increases, and the maintenance time also increases. The dynamics of the aging factors of threaded connections can be represented in the form of quadratic functions.

1. Introduction
The reliability of machines determines the volume of repair and maintenance work. In turn, the maintenance work serves as the initial characteristics for the formation of the repair-maintenance base of technical service of agricultural machinery. There also is the need for spare parts and human resources.

However, with the age of the machine there are significant changes associated with its aging; the reasons are very diverse. This is a process of a gradual transition of the machine to a lower qualitative state, which is inevitable and irreversible in time. In addition, the age has a great impact on the indicators of reliability, maintainability, service life of components and parts of the machine, which ultimately determines its performance.
The research objective is to quantify the aging process of agricultural machinery.

2. **Objects and methods**

We assume that the nature of the aging process in agricultural machinery is approximately the same and manifests itself primarily in the form of operating time to failure, service life of the machine or its individual components, labor and money costs to restore performance, etc. All these worsen with increasing service life and the ratios of these indicators to identical indicators of new (aging coefficients Kc) regardless of brand for the same periods of machine use will be the same. As a result, it seems possible to establish a unified pattern of aging of agricultural machinery, using the available data.

As the basic methods of research, we used observation directly in operating conditions of machinery, data from literary sources with the assessment of comparability of conditions. We also analysed the data of conducted experiments on determining the time of unscrewing and tightening torque of threaded connections M8, M10, M12 and M14, depending on the service life in the range of 0, 2 to 4 years. In our opinion, the process of tractor aging is characterized by changes in the reliability and repairability indicators (average recovery time) in the before-repair and between-repairs periods (Table 1).

3. **Research results**

From the observation data (Table 1) we can see that the MTBF and the average time to recover failure in the period between repairs have changed significantly compared to the pre-repair period, which, in our opinion, should be seen as a result of tractor aging [1].

| Tractor brand | Failure time, h | Average recovery time, h |
|---------------|-----------------|-------------------------|
|               | Before the repair period | Maintenance interval |
| K-700         | 125             | 3.05                    |
| K-700A        | 141             | 2.62                    |
| K-701         | 105             | 2.59                    |
| MTZ-80        | 160             | 1.97                    |
| K-700         | 76              | 3.19                    |
| MTZ-80        | 81              | 1.99                    |

The ageing factor in foreign machinery is similar. Thus, the average MTBF of tractor JOHN DEERE 7810 is equal to 482 engine-hours in the first year of operation, in the second - 450, in the fifth - 165 [2].

The change in the availability factor of tractors depending on the period of operation (Fig. 1) (the ratio of the number of serviceable to the listed number) [3] depends on their aging, and the obtained aging coefficients by years of operation can be used to form the aging function. It is clear that the user of the machine already from the second year of its operation can do little to ensure a high serviceability of the tractor. And from the 6th year of operation, the tractor aging factor plays a decisive role.

Table 2 shows the ratio of resources of KIROVETS tractors' components between overhauls to the pre-repair period. Figure 2 shows the change in the reliability indicators of combine harvesters [4].

The aging process of machinery is manifested primarily in the change of physical and mechanical properties of rubber and technical products, plastics, stability of threaded joints, etc. [4, 5]. At the same time, these circumstances are practically not taken into account in the process of operation of machinery, except, perhaps, for rationing the consumption of spare parts [6-8].
Figure 1. Dependence of the availability factor of K-700 tractors on the service life

Table 2. Correlation of resources of Kirovets tractors components between overhaul period and pre-repair period

| Tractor component                  | Tractor brand | K - 701 | K – 700A |
|-----------------------------------|---------------|---------|----------|
| Engine                            | 0.51          | 0.53    |
| Transmission                      | 0.49          | 0.56    |
| Leading axles                     | 0.67          | 0.74    |
| Leading Shaft of leading axles    | 0.60          | 0.68    |
| Fuel pump                         | 0.64          | 0.63    |
| Starter                           | 0.59          | 0.66    |

Figure 2. Changes in the reliability indicators of combine harvesters
The data on ratio of resources of components and parts indicate the decisive role of the aging factor, but the resources can be strongly influenced by the assembly technology and, the main thing, by the run-in of parts.

In radioelectronic equipment, the aging factor is usually taken into account by the change in the number of restorations from the operating time of the equipment. The Volterra equation of the second kind with a difference kernel \([9]\) is used to describe the process of restoration of product performance by preventive maintenance and replacement of aging elements:

\[
H(t) = F(t) + \int_0^t F(t - \tau)dF(\tau)d\tau
\]

where \(H(t)\) – the restoration function with prevention and replacement of aging parts;

\(F(t)\) – the resource allocation function of the parts to be replaced in the pre-repair period;

\(dF(\tau)d\tau\) – the resource allocation function of replaceable aging parts.

In spite of all subtlety of formula (1), where function \(dF(\tau)d\tau\) gives increment of the number of restorations as a result of product aging, in practice, as applied to agricultural machinery, it is very problematic to use it. It should consider the number of preventive maintenance (prevention is not failure), and on the other hand, preventive maintenance slows down the aging process to some extent. As a result we won't get the effect of aging on the number of restorations in its pure form.

B.V. Gnedenko suggested an approximate formula for the number of restorations for a long period of time \((t)\) \([10]\):

\[
H(t) \approx \frac{t}{t_{md}} + \frac{t^2}{2t_{md}^2} - \frac{1}{2},
\]

where \(t_{md}\) – average MTBF, hours;

The above dependence in principle satisfies the requirements of assessment of aging of agricultural machinery, but it requires a long time interval \((t)\) for observation and it is applicable only for a particular brand of machine, which narrows the possibilities of its use \([11]\). We propose quantitatively evaluating the aging process of the machine, as already noted above, by the ratio of resources of elements, operating time to failure, machine productivity, etc. in the form of the aging coefficient \(K_a\):

\[
K_a = \frac{t_{m}}{t_{j}}
\]

The aging coefficient shows how many times the resource of the part \(t_{m}\) replaced in the machine is less than the nominal resource of the original part \(t_{j}\). Or the MTBF of an aging machine is less than that of a new machine, or the labor intensity of restoration of an old machine is greater than that of a new machine \([12]\).

By determining the aging rate of the parts to be replaced over the time period in question, we can construct an aging function \(f(\tau)\).

In our opinion, the process of machine aging can be most fully and affordably characterized by the example of threaded connections. Fig. 3 shows characterizing the time of unscrewing threaded joints M8, M10, M12 and M14 (Fig. 3a) and the tightening torque of the same connections (Fig. 3b) depending on the service life from 0.2 to 4 years are plotted.

The distribution of the data obtained is in most cases subject to the normal law:

\[
f(t) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{(t-\mu)^2}{2\sigma^2}}.
\]

According to these points, the curves of change of the mentioned indicators from the service life are constructed. They are clearly described by quadratic functions (Fig. 3).
Threaded connections: O-M8, Δ-M10, □-M12 and M14

Figure 3. The time (a) and unscrewing torque (b) depend on the service life of the threaded connections.

Using these data, we have defined the aging coefficients as the ratio of the time or moment of unscrewing the threaded joint in the i-th year of operation of the machine to the new ones and plotted them in the graphs of Fig. 4.

Figure 4. Variation of the aging coefficient in terms of labor intensity (a) and stability of disassembly (b) of threaded connections as a function of service life.
As expected, the aging coefficients for all types of threaded connections are approximately the same and increase monotonically with increasing service life in terms of both unscrewing time and removal moments of threaded connections.

The obtained equations of changes in the aging coefficients ($K_a$) in this case can characterize the changes in the labor intensity of repair maintenance actions as a result of machine aging (Fig. 4a), as well as the costs of physical effort to perform them (Fig. 4b). On the other hand, what is the function of aging of machines in terms of reliability and durability, including foreign ones? Fig. 5 shows the values of aging coefficients of domestic and foreign tractors and combines, obtained by the reliability and durability indicators given above (Fig. 1, 2, tab. 3).

\[ y = 0.0675x^2 + 0.0435x + 1.3475 \]

\[ K_a \]

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**Figure 5.** Change in the ageing rate of tractors and combines as a function of service life (in terms of MTBF)

As can be seen from Fig. 5, the scatter of aging coefficients by service life of both domestic and foreign agricultural machinery is insignificant, and the obtained dependence quite correctly describes the calculated data.

### 4. Conclusion

Despite the existing seemingly insoluble difficulties in assessing the impact of the aging factor on indicators of technical condition of agricultural machinery both in theory and in practice, the obtained equations (Fig. 4, 5) of changes in aging indicators from the service life, nevertheless, can eliminate this gap. And it can serve as corrective dependences in assessing the technical condition of machines at a given period of their service life in the first approximation.

As a result of estimating the degree of the aging of machines according to our proposed coefficients of aging, it was found that they were approximately the same for machines of different brands for the same periods of their use and can be used in practice.
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