Using Statistical Methods for Assessment of Wear Product 
Content Limits of Engine Oils Used in Agriculture

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Abstract. Currently, the quantitative assessment of wear product content in oils is becoming 
more relevant due to the introduction of diagnostic and maintenance methods based on the 
current condition of machinery in the agricultural sector. The changes in the physical and 
chemical properties of engine oils and the accumulation of wear products in them during 
operation help diagnose the technical condition of the key component of tractors, the engine. 
At the same time, it allows for the assessment of the state of the oil itself. The use of spectral 
analysis for the assessment of metal content in oils helped to significantly increase the speed of 
wear product content identification with sufficient accuracy. This diagnostic method stipulates 
that apart from the spectral analysis, it is necessary to conduct laboratory tests of the physical 
and chemical properties of oils. Any of the measured properties of engine oils can be used as a 
diagnostic parameter to be used for the assessment of engine condition without disassembling 
and the possibility of its further fault-free use for a specific time. That being said, the accuracy 
of the diagnostic forecast using the wear parameters depends on the accuracy of these 
parameters. Wear depends on a large number of factors, the majority of which are randomly 
manifested throughout the operation of the machinery, and the changes in the parameters can 
be assessed using statistical methods. At the same time, labeling some of the engine 
components as faulty or non-faulty depends on the accuracy of the “reference standard”, which 
we understand as the limit value for the wear product content in oil. This article aims at 
determining the limit value for the wear product content in oil using statistical methods.

1. Introduction
The quantitative assessment of wear product content in oils is becoming more relevant due to the 
introduction of diagnostic and maintenance methods based on the current condition of machinery in 
the agricultural sector [1.2.3].

Following the spectral analysis procedure, sampling for the analysis of wear product content in the 
oboil is carried out over a set period, and additional oil samples are taken if faults occur, and fault types 
are recorded in a log [4.5.6].

To assess the technical condition of the machine using the content of wear products in the oil, it is 
necessary to determine the complete list of controlled parameters to assess the operation of specific 
components and the engine as a whole using the design documentation. The condition assessment is 
based on the comparative analysis of rated (limiting) and actual parameter values characterizing the 
time indicators of operation accuracy and reliability that ultimately determine the probability of the
operable state. If the current parameter value exceeds the rated one, the engine is labeled as faulty [7.8.9].

The majority of currently available assessment methods for the maximum content of wear products are based on two parameters: mathematical expectation and dispersion applied to the normal distribution law for controlled parameters [10.11,12]. Since the type of distribution determines the quantitative parameters of good/faulty state thresholds, the creation of a control system and the identification of rated values of controlled parameters require a more rigorous approach to the assessment of distribution parameters for the indicators used. Therefore, experimental data processing and analysis, apart from the parameter mathematical expectation and dispersion of the controlled parameter, should also consider distribution moments, as well as asymmetry and excess coefficients.

This article aims at the development of methods to determine the limit value for the wear product content in oil using statistical methods.

2. Objectives and methods

The results of statistical monitoring of the dynamics of wear product accumulation in oil are a key instrument for the assessment of oil quality, and the state of specific components and parts that can be used as the basis for the assessment of the maximum content of products impacting the wear. To perform statistical monitoring, we determined the following parameters [13.14.15]:

- we determined the list of wear products impacting the wear of engine components;
- we assumed that the controlled wear products are independent random values with normal distribution;
- the accuracy of factor determination is so high that the can be considered non-random;
- the dispersion is homogeneous and only determined by the accuracy of measurement and the impacts of uncontrolled parameters.

The materials obtained as a result of statistical monitoring are processed as follows [16,17,18]:

- for each of the wear products, the analyses are divided into two groups: those of non-faulty engines and those of faulty engines;
- we only considered the faults of the components where the specified wear product indicates wear;
- we performed the typological grouping of the data in each of the groups and constructed histograms;
- we selected the probability distribution law for the parameter in question.

Use $S_\lambda^{(1)}$ to express the maximum value of wear product i in oil and $S^{(i)}$ to express the parameters characterizing the actual content of wear product i in oil.

Apart from that, we identified the following:

$$f_1(x_i) = N(m_{sn}, \sigma_{sn})$$

– the probability density of the maximum value of wear product i in oil;

$$f_2(x_i) = N(m_s, \sigma_s)$$

– the probability density of wear product i in oil;

$m, \sigma$ is the mathematical expectation and the root-mean-square deviation of the distribution.

Parameters $S_\lambda^{(1)}$ and $S^{(i)}$ are considered as random values with distribution laws $f_1(x_i)$ and $f_2(x_i)$ respectively,

where $x_i (i = \text{Num})$ are the numerical values of controlled parameter i.

The deviation between the values of rated and actual wear product i content is $\Delta = S^{(i)} - S_\lambda^{(1)}$. 
where $\Delta$ is a random value formed as a composite of random values $S^{(i)}$ and $S_{pr}^{(i)}$.

In this case, the deviation of mathematical expectation is

$$\Delta m = m_s - m_{sn},$$

and the deviation of dispersion is

$$\Delta D = D_s - D_{sn}.$$ 

The probability of random value $S^{(i)}$ being greater than $S_{\lambda}^{(i)}$ is determined using the following formula:

$$P(S^{(i)}>S_{pr}^{(i)}) = P(\Delta>0) = \frac{1}{\sqrt{2\pi}\Delta\sigma_1} \int_0^{\infty} e^{-\frac{(x_1-\Delta m)^2}{2\Delta^2}} dx_1,$$

or

$$P(S^{(i)}>S_{pr}^{(i)}) = N(x) = N\left(\frac{m_s-m_{\lambda}}{\sigma^2+\sigma_{pr}^2}\right),$$

where $N(x)$ is the value in point $x$ of the random value distribution function following the law with parameters $(0,1)$.

We used the statistical decision method to find the difference between the rated and controlled values of wear product $i$ content in oil. Assessment $S_{\lambda}$ and $S$ is carried out against background noises, which can be integrated as measurement error, characterized by probability densities $f_1(x_1)$ and $f_2(x_1)$ respectively.

To create a control system for the technical state of machinery, it is necessary to solve the problem of justification and identification of the rated values of controlled parameters that should be used in the assessment of component or unit operability at different stages of operation:

- monitoring frequency;
- error-free identification of the amount of correctly determined states (faulty or non-faulty) in the total number of states determined;
- the statistical models of the complex assessment of the technical state of the unit during the analysis of the content of wear products in oil can be constructed based on the study of distribution laws for numerical values of controlled parameters (CP) obtained in experiments.

Use the reference $S_{\lambda}^{(i)}$ and indicators $S^{(i)}$ to characterize the content of wear products in the oil. In this case,

- $f_1(x_1) = N(m_{s3},\sigma_{s3})$ is the probability density of the maximum value indicator.
- $f_2(x_1) = N(m_{s},\sigma_{s})$ is the probability density of the controlled oil quality indicator.

Parameters $S_{\lambda}^{(i)}$ and $S^{(i)}$ are considered as random values with distribution laws $f_1(x_1)$ and $f_2(x_1)$ respectively,

where $x_1(\bar{i} = \bar{T}n)$ are the numerical values of controlled parameter $i$.

The difference between the rated and analyzed parameter values is $\Delta = S^{(i)} - S_{\lambda}^{(i)}$, where $\Delta$ is a random value determined as a composite of random values $S^{(i)}$ and $S_{\lambda}^{(i)}$.

In this case, $m_{\Delta} = m_{s}-m_{s3}, D_{\Delta} = D_s - D_{s3}.$

The probability of random value $S^{(i)}$ being greater than $S_{\lambda}^{(i)}$ is determined using the following formula:

$$P(S^{(i)}>S^{(i)}_{\lambda}) = P(\Delta>0) = \frac{1}{\sqrt{2\pi}\sigma_{\Delta}} \int_0^{\infty} e^{-\frac{(x_1-m_{\lambda})^2}{2\sigma_{\Delta}^2}} dx_1,$$

or

$$P(S^{(i)}>S^{(i)}_{\lambda}) = N(x) = N\left(\frac{m_s-m_{\lambda}}{\sigma^2+\sigma_{\lambda}^2}\right),$$

where $N(x)$ is the value in point $x$ of the random value distribution function following the law with parameters $(0,1)$. 

To obtain the differences of the quality indicator (QI) between a parameter nominal value and a controlled one, one can use the statistical decision method. Assessment $S_3$ and $S$ is carried out against background noises, which can be integrated as measurement error, characterized by probability densities $f_1(x_i)$ and $f_2(x_i)$ respectively.

Note the threshold value $m_3 < x_{0i} < m_3$ on the axis and assume that the proper domain of one indicator $0 < x_i < x_{0i}$, and another $x_{0i} < x_i < \infty$ or $x_{0i} < x_i < x_{f}$, where $x_i$ is some different limit (Figure 1).

\[
\begin{align*}
&\text{Figure 1. The distribution density for parameter } x_i \text{ is the component content in oil expressed in percent.} \\
&\text{Determine the probability of identification error for the two classes where the percentage content of wear products does not exceed the maximum value (non-faulty) and exceeds the maximum value (faulty).} \\
&\text{The identification value can be expressed as the following law:} \\
&P(S_{z}) \int_{0}^{x_{0i}} f_2(x_i)dx_i + P(S) \int_{x_{0i}}^{x_i} f_1(x_i)dx_i,
\end{align*}
\]

where $P(S_{z})$ and $P(S)$ are probability densities for the emergence of $S_{z}$ and $S$.

Assuming $\lambda_0 = P(S)/P(S_{z})$.

$P(S)$ is faulty, $P(S_{z})$ is non-faulty

If $P(s_{z}) = P(S) \lambda_0 = 1$

i.e., the abscissa of the intersection points of curves $f_1(x_i)$ and $f_2(x_i)$

The reliability (or correctness) of identification can be assessed using the decreasing error probability function [1].

\[
\theta = - \log_2 P_{er}
\]

In our case, identification processes have an explicit probabilistic nature, therefore, their analysis is based on the probabilistic methods (probability theory, mathematical expectation, information theory) [19,20].
3. Conclusions
The research conducted resulted in the development of statistical determination methods for the maximum content of wear products in engine oils.

To obtain the maximum content for the wear product in question, it is necessary to determine the distribution functions for faulty and non-faulty engines.

We also proposed a formula to determine the identification error.

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