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Application of mathematical statistics to evaluate the efficiency of using modern machines

Evgeny Shapiro*

Kuban State Agrarian University named after I.T. Trubilin, Kalinin 13, Krasnodar, 350044, Russia

Abstract. This article describes the engineering task of wear research, when a part is turned off after a known overhaul service life and its wear is determined. It is examined how the asymmetry coefficient is determined, the modal wear value corresponding to the largest ordinate of the normal wear distribution, etc. The figures presented in the paper illustrate the right-hand and left-hand asymmetry observed during accelerated wear, as well as the typical curve of the wear distribution of machine parts. Scientific-based judgments are presented on whether machine parts have been subjected to accelerated wear. This scientific article is prepared for agricultural specialists, researchers, teachers, postgraduates, undergraduates and students of agricultural universities in the field of training "Agroengineering".

Introduction

In scientific publications on the issue related to the evaluation of the efficiency of the use of modern machines, most often the evaluation of the efficiency of the use of modern technology is carried out on the condition that a separate part of the machine in question was turned off after its wear to the limit state, and on this basis its service life was determined. In this article, the inverse problem is solved – a part of a modern machine is turned off after a known overhaul service life and then its wear is determined [1, 2, 3].

Materials and methods

The methods used in this article consist in the systematic use of mathematical statistics, as well as in the probabilistic assessment of the efficiency of using modern machines. It mainly uses computational and analytical, experimental and other methods of mathematical statistics to realize the purpose and objectives of the study.

At the same time, in accordance with the objectives of this study, a comprehensive method of field tests is considered to assess the modal wear of the valve stem of the YAMZ-238 tractor engine.

This complex technique includes a number of special techniques, including [4, 5, 6]:

– carrying out mass micrometrization of valves of the YAMZ-238 tractor engine;

*Corresponding author: evgenij.shapiro@mail.ru

– a methodology for compiling a special table of initial data necessary for calculating the modal wear value of the valves of an automotive engine;

– evaluation of the effectiveness of the use of modern machines and mechanisms.

Results and discussion

Since the maximum permissible wear is usually regulated by the relevant technical conditions, the comparison of this regulated wear with the wear obtained from statistical data allows us to assess the quality of use of the studied part in the conditions under consideration.

It seems to us that the normal established conditions of use of the part should lead to the distribution of its wear according to the Gauss law.

The actual conditions with their variety will lead to all kinds of deviations. Based on these deviations, it is possible to make a general, but important, judgment for engineering practice about whether these parts were used normally or abnormally.

Obviously, if the right-hand asymmetry is obtained in the presence of data on the wear values (Fig. 1), then the parts were subjected to accelerated wear.

If the asymmetry turns out to be left-sided (Fig. 2), then the parts wore out slowly.

It is not possible to draw any other more detailed conclusions from the statistical materials obtained in this way due to the variety of factors that can lead to the same deviations of the observed distribution curves.

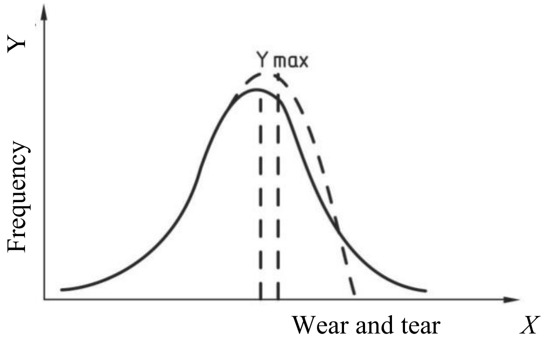

Fig. 1. Right-sided asymmetry (dotted curve) observed during accelerated wear

In order not to resort to the construction of distribution curves, we can judge the nature of the asymmetry and its magnitude by the following dependence [7, 8, 9]:

$$\alpha = \frac{\bar{x} - m_0}{\sigma}, \quad (1)$$

where: α – the coefficient of asymmetry;

m_0 – the mode is the abscissa corresponding to the largest ordinate Y_{max}.

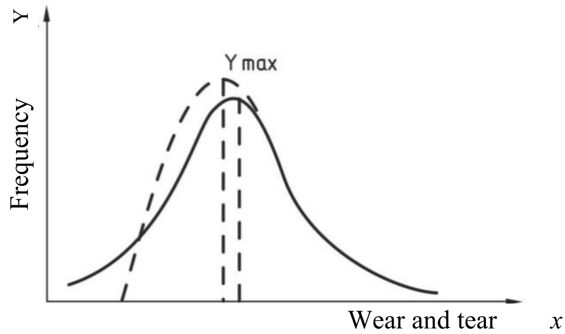

Fig. 2. Left-sided asymmetry (dotted curve) observed during slow wear

With the left asymmetry, i.e. when placing the largest ordinate to the left of the ordinate corresponding to the arithmetic mean x, a will obviously have a positive value, with the right asymmetry it will have a negative value. Modal values can be calculated using the following approximate dependence, valid for single-vertex and not sharply asymmetric distributions [10, 11, 12]:

$$m_0 = \bar{x} + 3(m_e - \bar{x}), \tag{2}$$

where: m_0 – the mode is the abscissa corresponding to the largest ordinate Y_{max};

m_e – median is the value of the value x, the ordinate of which divides in half the area enclosed between the abscissa and the distribution curve; the practical definition of the median is shown in the following example.

Let's now give a brief description of the wear of parts. The fact that multiple factors can lead to the same deviations of real distribution curves significantly limits the possibility of using statistical materials for any practical conclusions.

For example, only the following considerations can be made about the possibility of using these materials to judge the ultimate wear. If the maximum permissible wear is known (established by computational, analytical, experimental and other methods), then statistical materials allow us to say whether these maximum wear are maintained in practice or not.

If the maximum permissible wear is unknown and engineering practice is not guided by any technical conditions on this issue, then the statistical data regarding these wear reflect known practical experience, which, however, needs theoretical justification.

A certain practical value for the purposes of studying wear is provided by statistical materials collected during mass measurements of machine parts received by the repair company.

This easily assembled and very affordable material allows you to answer important questions in practical terms: what is the wear of individual parts and what is the ratio of their wear resistance (if it is known that the examined parts were not replaced during their operation).

Processing of such materials for this purpose is carried out as follows. If the collected data on the wear of a particular part gives a normal distribution, then given that in this case the arithmetic mean of the dimensions of the studied worn part is the abscissa of the grouping center, we can write for the shaft [13, 14]:

$$i_в = d_н - d_и = d_н - \bar{x}. \tag{3}$$

In turn, for the hole we will have the following expression [13, 14]:

$$i_o = D_u - D_н = \bar{X} - D_н, \quad (4)$$

where: d_H and D_H – initial largest shaft size and smallest hole size;

d_u and D_u – dimensions of the worn shaft and hole;

x and $\bar{X}$ – arithmetic averages of the sizes of the worn shaft and hole.

Most often, in such cases, the distribution curves have such deviations from normal ones, in which the arithmetic mean of the values of the dimensions of x does not coincide with the modal value of the abscissa of the curve m_0, that is, it does not coincide with the value that corresponds to the largest number of cases of this distribution.

The typical shape of the wear distribution curves observed in this case is shown in Fig. 3.

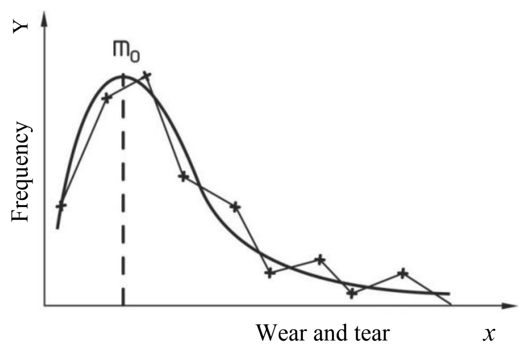

Fig. 3. Typical wear distribution curve of machine parts

For such wear curves of machine parts, dependencies (3) and (4) should have the following form [15]:

– for the shaft:

$$i_в = d_н - d_u = d_н - m_0. \quad (5)$$

– for the hole:

$$i_o = D_u - D_н = M_0 - D_н, \quad (6)$$

where: m_0 and M_0 – modal values of the dimensions of the worn shaft and hole.

Since usually the inter-repair service life of the machines received for repair is not known to the repair company, it is not possible to make any judgment on the practical acceptability of this period on the basis of the statistical data under consideration.

Often, in this regard, it is difficult to say anything definite about the compliance of the wear of the measured parts with the maximum wear set for them. It is difficult to judge from these data and the quality of the use of parts, if their wear cannot be attributed to an obviously emergency.

This explains the reason that in practice, despite the availability of such statistical material, relatively few people use it.

The typical shape of the izios distribution curve, shown in the scientific article [1], makes us admit that among the variety of random factors affecting the wear of machine parts, there is a prevailing one, according to I. Masienko – the dominant one, which leads to the same distortion of the normal distribution curve.

Let's consider this question in a little more detail. The wear of parts studied in this case is revealed under conditions when the service life of the machine (why the latter, as a rule, is not known to the repair company), and its technical condition.

If the replacement of any part was carried out immediately after reaching the limit of wear, the distribution curve of such a worn part would turn into a vertical straight line. Thus, the smaller the wear scattering field, the more definite the practice solves the issue of the rejection of this part.

This certainty is usually due, on the one hand, to the availability of the part for replacement, regardless of the condition of the entire machine, and, on the other, to the sufficient certainty of the culling feature. An example of such a detail is a segment of the cutting device of a mower, which is culled in practice according to the state and angle of inclination of the cutting blade.

The scientific article [1] shows the distribution curves obtained on the basis of mass measurement of worn segments of tractor mowers.

These curves confirm the validity of what has been said. The scattering field begins to increase if the part turns out to be not the leading one and the receipt for repair is not due to its condition, but to the condition of the leading parts, according to which a judgment is usually made about the condition of the machine as a whole (engine cylinders, crankshaft, piston group of parts, basic parts, etc.).

However, the wear of the leading parts is usually quite significant the scattering field. The latter is explained, as a rule, by the lack of certainty of the technical conditions for extreme wear, the difficult availability of parts for their control and, therefore, the difficulty of the control itself. As for the typical asymmetry of the distribution curve, namely the presence of a left asymmetry with a steep rise of the left branch of the curve and a gently stretched descent of the right branch, this asymmetry is the result of the action of the dominant

Such a dominant factor is the conscious influence of technical personnel on the time of putting the machine into repair in accordance with the requirements of technical conditions.

Indeed, let's assume that the engine is put into repair when the gap in the coupling of the crankshaft neck – bearings reaches (after using the service inserts) the maximum limit value and let's further assume that such a limit value of the gap is controlled by the oil pressure gauge.

Let's assume that in the technical conditions for repair, this maximum permissible minimum pressure is stipulated to be about 1 kg / cm^2.

It is very unlikely that the machine users sent the engine for repair before the required time. But as soon as the oil pressure drops to 1 kg / cm^2, the requirements of the technical conditions come into effect and the engines are sent to repair in masses.

If the oil pressure characterizes the condition of the crankshaft well, then the left branch of the wear distribution curve of this part will have a steep upward climb, which is usually observed.

If the technical conditions were strictly fulfilled by all technical personnel, the right branch of the curve would have a symmetrical descent.

This pattern is observed, as already mentioned, when culling, for example, mower segments. Here it is impossible to violate the technical conditions, because the segment worn to the limit ceases to cut grass.

It's a different matter with the crankshaft and bearings.

This coupling can work even in degraded conditions, however, being subjected to forced wear. Thus, the asymmetry of the distribution curve is an indicator of the degree to which machine users meet technical conditions and, in general, an indicator of technical discipline.

The higher the descent of the right branch of the curve and the further this branch extends to the right, the worse the situation is with technical discipline in terms of the timeliness of putting cars into repair and vice versa. If the stated position is clear for the leading parts, i.e. the parts that determine the condition of the machine, then with respect to other parts, the matter is somewhat complicated.

Considering, however, that the long-term experience of designers and technologists in equalizing the service life of the parts of the machines they create increases positive results every year, we can assume that the above considerations are also valid for other parts.

Due to the fact that one of the characteristics of the statistical series – the median – divides the area enclosed between the distribution curve and the abscissa in half, this characteristic can serve as a well-known indicator of the above-mentioned timeliness of putting cars into repair.

Usually, in the distributions under consideration, the median is placed between the mode and the arithmetic mean. Therefore, it can be assumed that the closer the median is to the fashion, the better the situation is with the maintenance of the examined machines and vice versa.

Let us now consider an example of determining the modal wear value of the valve stem of the YAMZ-238 tractor engine according to the data given in Table 1.

Table 1. Initial data for calculating the modal wear value of the valve stem of the YAMZ-238 tractor engine

Wear intervals	The middle of the wear intervals, x_i	n_i	x_i n_i
1	2	3	4
0 – 10	5	5	25
10 – 20	15	6	90
20 – 30	25	11	275
30 – 40	35	16	560
40 – 50	45	17	765
50 – 60	55	13	715
60 – 70	65	12	780
70 – 80	75	9	675
80 – 90	85	9	765
90 – 100	95	2	190
100 – 110	105	2	210
110 – 120	115	2	230
120 – 130	125	2	250
130 – 140	135	1	135
140 – 150	145	2	290
150 – 160	155	2	310
		11	6265

At the same time, it should be noted that the data of this table were obtained on the basis of materials of mass micrometering of parts by students of the Kuban State University, then processed by the author of this work using the method of mathematical statistics. The first two columns of this table show the wear in microns, calculated from the initial (normal) largest size of the rod. Let's calculate the arithmetic mean *x,* median $\overline{x}$ and fashion m_0.

Columns three and four of Table 1 allow you to calculate the average value of wear $\overline{x}$:

$$\bar{x} = \frac{1}{n}\sum_{i-1}^{i=k} x_i n_i = \frac{6205}{11} \approx 56 \text{ micron.} \quad (7)$$

To determine the median, we take into account that everything was measured $n = 111$ details, half of this number is 56 details.

Next, let's start summing up the frequencies of the first intervals (the first graph) until we get the nearest number less than 56. This number corresponds to the fifth row, i.e. the interval 40-50 mk and it is equal to 55.

Since the next interval 50 – 60 corresponds to $\sum n_i = 68 > 56$, then, obviously, the median value will be in this last interval (50 – 60 micron).

If we assume (as is usually done) that the frequencies within the interval change in proportion to the change in the argument, then based on the proportion (6):

$$(m_e - 50): 10 - (56 — 55): 13, \tag{8}$$

we obtain the following relation:

$$m_e = \frac{(56-55)10}{13} + 50 \approx 51 \text{ micron.} \tag{9}$$

We define the mode but approximate dependence (2):

$$m_0 = 56 + 3(51 - 56) = 41\text{micron.}$$

Let's calculate the coefficient of asymmetry α according to the formula (1):

$$\alpha = \frac{56-41}{\sigma} = \frac{15}{\sigma}.$$

Conclusion

Thus, we can conclude that since the values x, m_e и m_0 if they do not coincide, which is mandatory for a symmetric (for example, normal) distribution, then the series considered in the example is asymmetric.

The degree of discrepancy of the calculated three values is one of the indicators of the degree of asymmetry of this statistical series. Since the asymmetry coefficient then turns out to be a positive value, the distribution curve will have a left-sided asymmetry, i.e. the largest value of the ordinate will be located to the left of the ordinate corresponding to the arithmetic mean. This conclusion actually follows from a simple comparison of the calculated values $\overline{x}$ and m_0 since there is a relation:

$$m_0 \leq \overline{x}. \tag{10}$$

Thus, the answer to the question posed in the example should be the conclusion that the most common (modal) wear of the details of this statistical series will be such equality $i_в = m_0 = 41$ micron.

If it were known that all the parts of this series were measured after the same inter–repair service life and that by the end of this service life, wear is projected at which $m_0 - \overline{x}$, then the left-sided asymmetry of the distribution curve (for which $m_0 \leq \overline{x}$) it would make it possible to make a favorable conclusion about the use of these parts in operating conditions.

Indeed, since the bulk of the parts for the projected period were worn out less than expected (the fashion shifted to the left), it means that the conditions of use of these parts turned out to be better than the projected ones. However, since the service life of the measured parts is not known, it is impossible to make such a conclusion. Moreover, if it turned out that the parts were measured after a shortened period (compared to the projected one), then regardless of the nature of the asymmetry of the wear distribution curve, the opposite conclusion would have to be made.

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