National University of Life and Environmental Sciences of Ukraine

Department of Engineering Reliability

Methodical instructions for the laboratory work:

"Processing information about the reliability of machines"

Kyiv - 2017

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The methodical instructions contain information on the sequence of the laboratory work "Processing information on the reliability of machines" from the disciplines "Reliability of agricultural machines" structure of the study of discipline, which includes the following sections: basic terms and definitions; backtrack physics; mathematical theory of reliability; testing of machines for reliability; methods of ensuring the reliability of machines.

The methodical instructions also provide the form and procedure for the execution of laboratory work, control tasks.

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Educational edition

METHODICAL INSTRUCTIONS
before laboratory work:

"Processing information about the reliability of machines"
for students on disciplines "Reliability of agricultural machines" and "Reliability of machines and equipment"

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Knowledge and practical skills necessary for carrying out this laboratory work:

Getting to the laboratory work student must:

1. Know.

1.1. Mathematical methods for determination of reliability indexes [1,2,3].

1.2. Contents and procedure for laboratory work. (See instructions).

2. Be able to.

2.1. Perform calculations using micro calculators.

2.2. Conduct processing of information about the reliability of machines.

Tasks for the work:

1. According to the individual task (see tables A and B) it is necessary to determine the numerical indicators of durability of 50 new SMD-62 engines. Engines are repaired products. The main indicator of their reliability is the pre-repair resource (tdor.).

2. To repair the engine resources according to the results of observations to determine

with the help of methods of probability theory and mathematical statistics. (See the methodology for doing this work).

literature

1. Kashtanov V.A. Theory of Reliability of Complex Systems. Kashtanov, A.I. Medvedev. - 2 ed, revised. – M.: FIZMATLIT, 2010. - 608 p.

2. Grankin S.G. The goodness of agricultural machinery / SG Grankin, VS Malakhov, MI Chernovol, V.Yu. Cherkun - K., Harvest. - 1998 - 208 p.

3. Ermolov L.S. Fundamentals of reliability of agricultural machinery / Л.С. Ermolov, V.M. Kryazhkov, V.E. Cherkun - M., Kolos. -1982. - 247.

Table A Intervals of values before repair of engines

Variants	Numbers of Variants						
	1	2	3	4	5	6	7
1	1500-1800	1800-2100	2100-2400	2400-2700	2700-3000	3000-3300	3300-3600
2	1500-1900	1900-2300	2300-2700	2700-3100	3100-3500	3500-3900	3900-4300
3	1500-2000	2000-2500	2500-3000	3000-3500	3500-4000	4000-4500	4500-5000
4	1500-2100	2100-2700	2700-3300	3300-3900	3900-4500	4500-5100	5100-5700
5	1500-2200	2200-2900	2900-3600	3600-4300	4300-5000	5000-5700	5700-6400
6	2000-2300	2300-2600	2600-2900	2900-3200	3200-3500	3500-3800	3800-4100
7	2000-2400	2400-2800	2800-3200	3200-3600	3600-4000	4000-4400	4400-4800
8	2000-2500	2500-3000	3000-3500	3500-4000	4000-4500	4500-5000	5000-5500
9	2000-2600	2600-3200	3200-3800	3800-4400	4400-5000	5000-5600	5600-6200
10	2500-2800	2800-3100	3100-3400	3400-3700	3700-4000	4000-4300	4300-4600
11	2500-2900	2900-3300	3300-3700	3700-4100	4100-4500	4500-4900	4900-5300

* The version number corresponds to the number of the academic group of the course

Table B The value of the frequencies mi up to the repair resource of the SMD-62 engines in intervals

Variants	Numbers of Variants						
	1	2	3	4	5	6	7
1	1	5	13	22	6	2	1
2	2	4	5	21	15	2	1
3	2	4	15	19	6	3	1
4	1	3	20	16	5	3	2
5	2	3	13	22	6	3	1
6	1	4	14	17	7	5	2
7	2	3	8	17	13	6	1
8	1	4	11	16	9	5	2
9	1	6	8	17	14	3	1
10	2	5	17	14	7	3	2
11	1	6	5	13	20	4	1
12	2	8	5	11	19	4	1
13	1	3	16	22	5	2	1
14	2	4	3	23	16	1	1
15	2	3	17	21	4	2	1
16	1	3	19	19	5	2	1
17	2	3	23	7	3	1	1
18	2	4	20	16	4	3	1
19	1	3	27	13	3	2	1
20	2	2	4	16	23	2	1
21	2	6	5	13	22	1	1
23	1	6	3	13	24	2	1
24	2	9	20	14	2	2	1
25	2	10	19	10	6	2	1
26	1	2	9	27	9	1	1
27	1	6	24	13	3	2	1
28	1	4	7	16	15	5	2
29	2	3	8	17	13	6	1
30	1	3	10	19	14	2	1

* The version number corresponds to the student's serial number according to the academic group's journal.

Method of processing information on reliability indicators

Terms. Indicators of reliability (*PN*) of agricultural machines are categorized as random variables. In the real conditions of operation of the *PM* of specific machines and their elements have a significant dispersion. This is explained, on the one hand, by the instability of the quality of manufacturing, repair, maintenance of machinery, and, on the other hand, by the variety and variability of the conditions for their use.

In this regard, *PN* are characterized by their mean values obtained on the basis of tests or observations of a group of similar machines. Calculation of PM is conducted using methods of probability theory and mathematical statistics, which allow to determine:

1. The average value of *PN* - $\bar{t}_i$;

2. The theoretical law of distribution of IP for the whole set of similar machines.

3. Trustee limits of scattering of single and average values of *PN* ($\bar{t}_н$; $\bar{t}_в$).

4. Possible relative migration error. To this end, information on the reliability of agricultural machinery is processed in the following sequence.

As a result of the observation of a group of machines:

1. A consolidated table of information is made in the order of growth of the taxpayer.

2. A statistical series of initial information is created and determined the magnitude of the displacement of the beginning of the dispersion of *PN* ($t_{зм}$).

3. The average value and the mean square deviation of the *PN* ($\bar{t}$ and σ) .are determined.

4. Verifies information on drop-out points.

5. A histogram, a polygon, and a curve, accumulated in the probability of a *PN,* are being constructed.

6. The coefficient of variation of the *NP* (ν) is determined.

7. The theoretical distribution law *(TPD)* is selected, then its parameters are determined and the integral *F (t)* and the differential *f (t)* function are constructed.

8. The coincidence of the experimental and theoretical laws of the distribution of *IP* according to the criteria is checked.

9. Confidence limits *(DM)* of single and average *PM* and the greatest possible transfer error (δ) are determined.

We will consider the method of mathematical methods for determining the *PN* when solving a specific problem.

Problem. According to the results of observations, it is necessary to determine the repair life of engines. Observations were made on 70 engines manufactured at the Kharkov plant "Sickle and Hammer" in 2001. Engines were operated on (T-150K) tractors in agricultural enterprises of Kiyv region during 2015 ... 2017 year.

Solution to the problem

Conduct a compilation of a consolidated table of source information. Information about engine repairs in the order of their growth is presented in summary Table 1.

We build a statistical series of information. The statistical series of information is constructed in the case when the initial information (*N*) is repeated more than 25 values of *PN*. The number of integrals of the statistical series (*n*) is determined by the following formula:

$$n = \sqrt{(N.)} \qquad (1)$$

The resulting value is rounded up toward the nearest integer.

3. The value of one interval A is determined by the following formula:

$$\mathbf{A} = \frac{t_{max} - t_{min}}{n}, \qquad (2)$$

where t_{max} and t_{min} - respectively, the largest and smallest values of *MN*.

The value *A* is rounded up so that its value is convenient for further calculations.

Table 1 - Information about engine repairs

№ Engine	Pre-repair resource (moto-year).)	№ Engine	Pre-repair resource (moto-year)	№ Engine	Pre-repair resource (moto-year
1	1500	24	3700	47	4470
2	1870	25	3700	48	4490
3	2010	26	3810	49	4490
4	2210	27	3900	50	4570
5	2720	28	3900	51	4600
6	2900	29	3940	52	4710
7	3020	30	3970	53	4730
8	3060	31	4000	54	4620
9	3060	32	4000	55	4350
10	3180	33	4100	56	4910
11	3200	34	4130	57	4930
12	3210	35	4130	58	4990
13	3210	36	4180	59	4990
14	3260	37	4210	60	5100
15	3300	38	4230	61	5210
16	3300	39	4260	62	5350
17	3300	40	4290	63	5400
18	3420	41	4330	64	5670
19	3460	42	4350	65	5790
20	3480	43	4370	66	5840
21	3580	44	4380	67	5900
22	3600	45	4420	68	5950
23	3620	46	4470	69	5970
				70	7800

For information on engine repairs (Table 1) we obtain:

$$A = (7800-1500) / 9 = 700 \text{moto-year.}$$

The statistical series of information (Fig. 1) consists of 4 lines, which indicate: in the first line - the limits of each interval in units of the *MF*. The first interval is arranged so that the first point of the information roughly coincides with its beginning. For our example: t_1= 1500 moto-year., A = 700 moto-year. Then the boundaries of the first interval will be t_1+ A = 1500 + 700 = 2200 moto-year.

(1500 - 2200 moto-year.). Similarly, for the following intervals, 2200 + 700 = 2900 motor-hours, 2900 + 700 = 3500 moto-year. and so on (see Fig. 1).

In the second line - the number of cases (frequencies m_i) that fall into each interval. If the point of information falls on the border between the intervals, then in the previous and next intervals make 0,5 points. For our example, in the first interval, 3 points (m_i= 3), the second -2,5 points (m_i= 2,5), and so on (see Fig. 1) should be entered in the first interval.

In the third line - the probability of the position of the PN in each interval (frequency in units of a unit or in%).

The probabilistic probability is defined as the ratio of the number of occurrences occurring in each interval to the repetition of information

$$P = \frac{m_3}{N} \quad (3)$$

For example, the experimental probability in the third interval will be:

$$P = \frac{m_3}{N} = \frac{3}{70} = 0{,}16.$$

In the fourth line, we determine the accumulated (integral) probability (see Fig. 1).

Determine the displacement of the beginning of the dispersion of *PN*. In many agricultural machines, the start of the dispersion is shifted to their zero value. In the engineering calculations of the *MF* to determine the displacement use the following. recommendations: at N> 25 the displacement value is:

$$t_{зм} = t_{iн} - 0, \quad (4)$$

where t_{in} is the value of the beginning of the first interval, moto-year.

A is the value of one interval, moto-year.

For N <25 and the absence of statistical information t_m are determined by the following formula:

$$t_{зм} = t_1 - \Delta, \quad (5)$$

here Δ - the average value of the first 3-4 values of PN,

$$\Delta = \frac{(t_2 - t_1) + (t_3 - t_2)}{2} \quad (6)$$

where can we get:

$$t_{зм} = t_1 - \frac{(t_3 - t_2)}{2} \quad (7)$$

where t_1; t_2; t_3 - the value of 1, 2 and 3rd value of *PN* in the order of their growth.

For our example *N*> 25 we can write:

$t_{ms} = t_{in}$-0,5 A = 1500-0,5 • 700 = 1500 moto-year.

Determine the average value of *PN* and the mean square deviation of *PN* (i). For *N* <25, the average value of *PN* is determined by the following formula:

$$t_{зм} = t_{iн} - 0{,}5\,A = 1500 - 0{,}5 \cdot 700 = 1500\ \text{мото} - \text{год}. \quad (8)$$

For *N*> 25 and the presence of a statistical series, respectively, we can write:

$$\bar{t} = \frac{1}{N} \sum_{i=1}^{N} t_{i}.. \quad (9)$$

where *n* - number of intervals;

t_{ic} - the mean of the i-th interval.

For N <25, the mean square deviation is determined by the formula:

$$\sigma = \frac{\sum_{i=1}^{N} (t_{ic} - \bar{t})^2}{N-1} \quad (10)$$

In the presence of a statistical series of information (N> 25) we can write:

$$\sigma = \sqrt{\sum_{i=1}^{N} (t_{ic} - \bar{t})^2 P} \quad (11)$$

Using equations (9 and 11) we obtain:

average *PN*:

$\bar{t}$ = 1850 • 0.04 + 2550 • 0.04 + 3250 • 0.23 + 3950 • 0.26 + 4650 • 0.27 + 5350 • 0.07 + 6050 • 0 + 7450 • 0.02 = 4150 motorcycle year.

mean square deviation of *PN*:

$$\sigma = \sqrt{(1850 - 4150)^2 \cdot 0{,}04 + \cdots + (7450 - 4150)^2} = 1050\text{мото} - \text{год}.$$

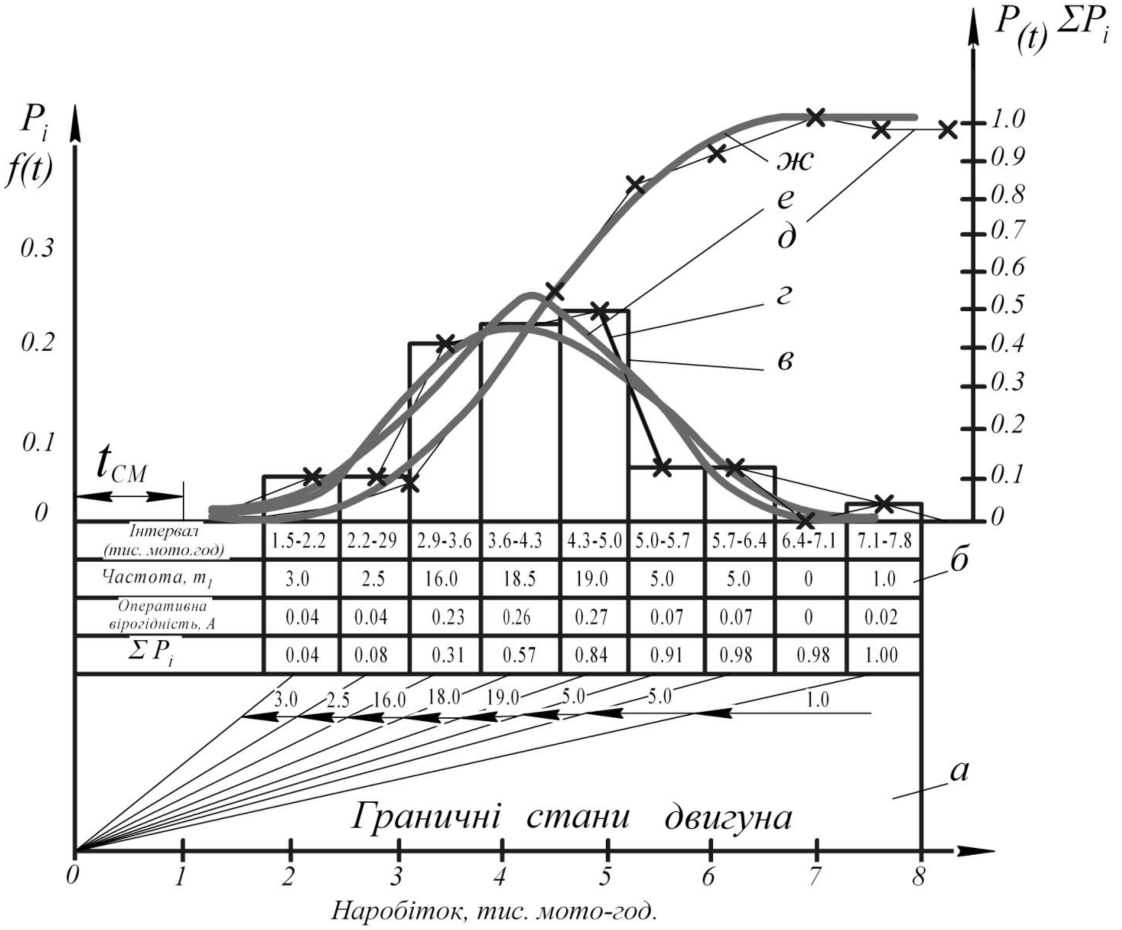

Fig. 1. Scheme of processing information on reliability indicators: a - distribution of primary information; b - a statistical series of information; in - histogram distribution; g - polygon; D - curve of accumulated probability probability; e is the differential function of the theoretical distribution law; h is the integral function of the theoretical distribution law.

Information is carried out according to the following rule. If the extreme points do not exceed these limits, they are recognized as valid. In the calculation for engines, the lower and upper limits of the probability of information will be equal:

4150 - 3 • 1050 = 1000 moto-year. (lower bound);

4150 + 3 • 1050 = 7300 moto-year. (lower bound).

The smallest engine maintenance capacity t1 = 1500 mto-h., Hence this point is reliable (1500 mto-h.> 1000 mto-hour) and should be taken into account in the calculations.

The largest upgrade engine life is t_{70} = 7800 moto-year. (7800 moto-year.> 7300 moto-year.). Consequently, this point goes beyond the upper boundary of certainty and should not be taken into account in subsequent calculations. More precisely, extreme, and any other adjacent points of information are checked by criterion (criterion Irwin). The actual values of the Irwin criterion are calculated using the following formula:

$$\lambda = \frac{1}{\sigma}(t_i - t_{i-1}). \qquad (12)$$

The obtained values of the criterion are compared with the theoretical values. Theoretical values of the Irwin criterion for different amounts of information are given in the annex table [1]. For our task we have:

- for the smallest point of information (t_1 = 1500 moto-hour.).

λ = (7800-1500) / 1050 = 0,35.

- for the largest point of information (= 7800 moto-hour).

λ = (7800-5970) / 1050 = 1,74.

Comparison of experimental and theoretical values (see Table 1) and the values of the criteria for N> 70 allows us to draw the following conclusions:

- the first point of information t_1 = 1500 moto-year. is true:

(λ_{opt} = 0,35 << λ_{theo} = 1,1).

- the last point of information t_{70} = 7800 moto-year. is unreliable

λ_{opt} = 1,74, and the λ_{the} = 1,1, that is, it turns out that from the subsequent calculations it should be eliminated.

In the case of the exclusion of points of information, a precise calculation of the statistical series is made.

For our task we obtain:

$$n = 9;\ A = \frac{5970-1500}{9} = 500\ мото - год.$$

$\bar{t}$ = 4050 moto-year., Σ σ = 935 moto-year.

The refined statistical distribution of the re-repair resource of SMD engines is presented in Table 2.

Table 2 - Refine the statistical distribution of the engine repair resources

Interval Moto-h.	m_i	P_i	$\sum P_i$
1500-2000	2	0,03	0,03
2000-2500	2	0,03	0,06
2500-3000	2	0,03	0,09
3000-3500	14	0,20	0,29
3500-4000	11	0,16	0,15
1000-1500	18	0,26	0,71
4500 -5000	10	0,14	0,85
5000-5500	4	0,06	0,91
5500-6000	6	0,09	1,0

According to Table 2, a histogram, a polygon and a curve of accumulated experimental probabilities are constructed.

The construction of a histogram, a polygon and a curve of the accumulated experimental probability of PN. On the axis of the abscissa on the scale of the value of PN, and along the axis of the ordinate - the frequency or probability of probability P_i; (in the histogram and polygon) and the accumulated probability of probability.

When choosing the scale of graphs, use the rule of the "golden section":

$$y = \frac{5}{8}x. \quad (13)$$

le x is the length of the largest ordinates;

y is the length of the abscissa.

The histogram and polygon are differential, and the curve of the accumulated probability is integral in terms of the distribution of experimental PM.

The area of each rectangle of the histogram or the corresponding area of the polygon determines the probability or number of machines (in units of a unit). Within this interval is the value of the reliability indicator.

The points of the polygon are formed by the intersection of the ordinate, equal to the probability of the interval and abscissa, equal to the middle of this interval. The points of the curve of the accumulated experimental are formed by the intersection of the ordinate, equal to the sum of the probabilities of the previous intervals and abscissa at the end of the interval. The number on the axis of the ordinate of the histogram or polygon shows the number of reliability indicators (in units of a unit), realized during a given interval of the statistical series.

Definition of the coefficient of variation. The coefficient of variation is a relative (non-dimensional) scattering characteristic of PN, convenient in choosing and evaluating the theoretical distribution law, than the mean square deviation σ.

The coefficient of variation is calculated by the following formula:

$$v = \sigma / \bar{t}. \quad (14)$$

Taking into account the bias t_{zm} we obtain:

$$v = \frac{\sigma}{\bar{t} - t_{зм}}. \quad (15)$$

For sampling of SMD engines we obtain:

$$t_{зм} = t_{ін} - 0{,}5\,A = 1500 - 0{,}5 \cdot 500 = 1250 \text{ мото} - \text{год.}.$$

v = 925 / (4050-1250) = 0.33.

The choice of the theoretical distribution law. In order to increase the accuracy of the calculation of the *MF*, the experimental information is aligned with the theoretical distribution law. In the case of agricultural machine and their elements, the law of normal distribution *(ZNR)* or the Weibull-Gnedenko (ZRV) distribution law can be used. One or another distribution law is chosen by the magnitude of the coefficient of variation ν. When ν> 0.30, ZNR is chosen, while for *ν*> 0,50 - *ZRV*. Within the limits of 0,3 - 0,5 choose the distribution law (*ZNR* or *ZRV*), which provides better correspondence with the distribution of research information. The accuracy of the match is determined by the criteria of agreement.

The functions of the theoretical distribution law are characterized by parameters. For *ZNR* their two are: $\bar{t}$ and *ν*, and for *ZRV* there are three: t_{mis}, parameters *a and b*).

For *ZNR* $\bar{t}$ - determined by the formulas 8, 9, and *ν* -10, 11). The parameters of ZRV are defined as follows:

1) In Table 4 of the applications [1] and the known coefficient of variation, we find the parameter b and the auxiliary coefficients C_b and K_b.

2) The parameter a is calculated by the formula:

$$a = \frac{\sigma}{C_b}. \tag{16}$$

$$a = \frac{\bar{t} - t_{\text{зм}}}{K_b} \tag{17}$$

In the absence of a table, when the value of the coefficient of variation is within the range of 0,30-0,72, a and b can be calculated from the simplified formulas:

$$b = \frac{1}{\nu^{1,06}}. \tag{18}$$

$$a = 1{,}11 \cdot (\bar{t} - t_{\text{зм}}) \tag{19}$$

According to the calculations, $t_{\text{дор.}}$= 4050 mto-h., σ = 925 moto-hour., that *ν* = 0,33. Using table 4 of applications [1] we find *b* = 3,34, *K* = 0,90 and *C* = 0,30.

Criteria agrees to the experimental and theoretical distributions of PN. The magnitude of the coefficient of variation *ν* = 0,33 does not make it possible to uniquely choose the theoretical distribution law (0,3 <*ν* <0,5). Therefore, the choice of the theoretical distribution law should be made according to the criteria of consent. In relation to the *MF* of agricultural machines, the degree of discrepancy between the experimental and theoretical probability is estimated using the Pearson criterion. This criterion is the sum of the squares of deviations of experimental and theoretical frequencies in each interval of statistical information series:

$$t_{зм} = \sum_{1}^{n_y} \frac{(m_i - m_{mi})^2}{m_{mi}} \quad (20)$$

where n_y is the number of intervals in the enlarged statistical series;

m_i is the experimental frequency in the i-th interval of the statistical series;

m_{th} is the theoretical frequency in the i-th interval.

$$m_{mi} = N[F(t_{in}) - F(t_{iк})] \quad (21)$$

where N - number of points of information;

$F(t_{ik})$, $F(t_{in})$- integral functions respectively at the end and beginning i - its interval of the value of *PN*.