Modeling maintenance of the machine-building complex

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Abstract. The problems associated with the modeling maintenance of the machine-building complex are considered. The forecasting technique for components based on one attribute in the framework of experiment is shown. The criterion is considered in terms of risk assessment for the consumer. The results of modeling of the main parameters characterizing the quality of electrolytic capacitors is demonstrated. After the tests are completed, the value of the predicted parameter will be determined for each of the implementations. The optimal value of the leakage current, which ensures the minimum probability of error, for tantalum electrolytic capacitors with a nominal capacitance is shown. The research results may be useful for specialists working in engineering complexes.

1. Introduction
When modeling the maintenance of a machine-building complex, different approaches can be used. They are based on the theory of systems analysis. Regression analysis methods are often used [1]. Then, based on the values of the parameters in a certain time period, it is possible to forecast their values in another time period.

There are also possibilities of classification and prognostic modeling. Based on the theory of pattern recognition, the initial state of each implementation of the components of the machine-building complex [2] is estimated by the values of some informative parameters - signs that are probabilistically associated with the predicted parameter, and based on this information, the state of the predicted parameter of each component in the future at the corresponding point in time is determined.

The purpose of this paper is to develop a forecasting technique and study its capabilities.

2. The forecasting technique for components based on one attribute in the framework of a training experiment
The data of the training experiment are used in the problem in order to select the threshold value of the sign $x_{KL}$.

Based on the selected criterion, the minimum probability of erroneous decisions will be provided for this value. The criterion is considered in terms of risk assessment for the consumer

$$Criteria = P(K_2 | реш K_1)$$ (1)
It is associated with the conditional probability that the implementation, which in practice will belong to the class $K_2$, will be defective, provided that it was decided to consider it serviceable when it belongs to the class $K_1$.

This approach is convenient to apply when considering systems related to assessing the quality of components of a machine-building complex [3, 4].

It is important that the most informative indicator of the process that will be observed in the components of the engineering complex be selected [5, 6].

It must be predicted. In addition, it is necessary to make a choice of a characteristic that will characterize the stability of a component of the engineering complex.

Predicted components are put to the test based on the appropriate methodology. After the tests are completed, the value of the predicted parameter will be determined for each of the implementations. When specifying the boundary value of the predicted parameter $y_{\text{bound}}$, classification is carried out according to two classes.

The classes will be such a $K_1$-class, showing implementations that meet the requirements, operational, and $K_2$-class, showing defective implementations. To determine the total number of solutions, we use the expression

$$n(solut\, K_1) + n(solut\, K_2) = n.$$  \hspace{1cm} (2)

Here $n(solut\, K_1), n(solut\, K_2)$ show the number of decisions that are made to include components in the classes $K_1$ and $K_2$.

Then the probability estimates are determined by the erroneous decisions and a priori probabilities. component use risk:

$$P(K_2|solut\, K_1) = \frac{n(K_2|solut\, K_1)}{n(solut\, K_1)},$$  \hspace{1cm} (3)

class manufacturer risk:

$$P(K_1|solut\, K_2) = \frac{n(K_1|solut\, K_2)}{n(solut\, K_2)}.$$  \hspace{1cm} (4)

For conditional probabilities of making erroneous decisions, we use the following expressions:

$$P(solut\, K_1|K_2) = \frac{n(solut\, K_1|K_2)}{n(K_2)};$$

$$P(solut\, K_2|K_1) = \frac{n(solut\, K_2|K_1)}{n(K_1)}.$$  \hspace{1cm} (5)

In order to determine the a priori probabilities of the component implementation belonging to the class $K_1$, we use the expression

$$P(K_1) = \frac{n(K_1)}{n}.$$  \hspace{1cm} (6)

This corresponds to the likelihood that the component will be operational for any implementation [7]. A priori probabilities of the component implementation belonging to the class $K_2$ are determined based on the expression

$$P(K_2) = \frac{n(K_2)}{n}.$$  \hspace{1cm} (7)

This corresponds to the probability that the component will be defective for any implementation [8].

The calculation of a priori decision-making probabilities to include the implementation of a component in the class $K_1$ is based on the expression

$$P(solut\, K_1) = \frac{n(solut\, K_1)}{n}.$$  \hspace{1cm} (8)

Calculation of a priori decision-making probabilities to include component implementation in class $K_2$ is based on the expression
If it is necessary to assess the losses from the fact that class $K_1$ will be renamed to class $K_2$ and class $K_2$ to class $K_1$, then the following probability estimates are applied:

$$P_{err} = \frac{n(solutK_1|K_2) + n(solutK_2|K_1)}{n};$$

(10)

the probability of making the right decisions (recognition efficiency)

$$P_{right} = 1 - P_{err}.$$  

(11)

In the above expression, $P(K_1|solutK_2)$ - is the conditional probability that the component implementation is actually healthy and belongs to the class $K_1$, but it was decided to consider it defective [9, 10].

Value $P(solutK_1|K_2)$ is the conditional probability of deciding whether to include the implementation of the component in the class $K_2$, provided that it actually belongs to the class $K_1$.

Value $n(solutK_1|K_2), n(solutK_2|K_1)$ - the number of erroneous decisions, consisting in the fact that the implementations of the components of the class $K_2$ will be assigned to the class $K_1$, equal to the number of implementations of the components, which are attributed to serviceable and in which the value of the sign is less than the threshold value $x_{KL}$, and their predicted parameter will exceed the boundary value $y_{bound}$.

Value $n(K_1|solutK_2), n(K_2|solutK_1)$ - the number of erroneous decisions in assigning instances of components of the class $K_1$ and class $K_2$, equal to the number of implementations of the components attributed to defective and for which the value of the attribute exceeds the threshold value $x_{KL}$, and their predicted parameter does not exceed the boundary value $y_{bound}$.

Values $n(K_1), nK_2$, are the number of component implementations that actually belong to the classes $K_1$ and $K_2$, respectively.

The threshold value of the attribute $x_{KL}$ should be chosen so that the probabilities of erroneous decisions do not exceed the specified tolerance.

If the losses from renaming the class $K_1$ to the class $K_2$ and the class $K_2$ to $K_1$ are the same, then the best value $x_{KL}$ will be such that the total number of erroneous decisions of both types is minimal ($P_{err} \to \min$).

The best value of $x_{KL}$ should be such that the minimum or acceptable value of consumer risk is achieved (3).

4. Results of modeling

One of the main parameters characterizing the quality of electrolytic capacitors is the leakage current, which depends on the oxide film and the working electrolyte.

The degree of instability of their structure during storage and operation is judged by the value of the leakage current after testing.

Therefore, as a sign of stability, the leakage current $I_0$ is taken, measured 10 minutes after the capacitor is turned on under the test voltage, and as a predicted parameter, the relative change in the leakage current in time $\alpha$, the boundary value of which is determined according to a priori information.

It was necessary to find the optimal value of the leakage current $I_0$, which ensures the minimum probability of error $P_{err}$ (10), for tantalum electrolytic capacitors with a nominal capacitance $C_{nom} = 2$ microfarads.

As a result of testing a batch of randomly selected capacitors ($n=98$) at a temperature of $t = 700 ^\circ C$ for a time $T = 2000 h$ under a pulsating voltage, a sample of the leakage current $I_0$ and coefficient $\alpha$ was obtained (Table 1).

According to the data in Table 2, we construct the correlation field (Fig. 1), where I is the region $K_1$ (operational capacitors); II – region ($K_2|solutK_1$); III - region $K_2$ (defective capacitors); IV - region ($K_1|solutK_2$).
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**Table 1.** Values of results that obtained during the experiment

| N | N_0, μA | α | N | N_0, μA | α | n | I_0, μA | α | n | I_0, μA | α |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0,04 | 0,7 | 26 | 0,14 | 2,75 | 5 | 0,18 | 3,30 | 7 | 60 | 0,22 |
| 2 | 0,04 | 0,6 | 127 | 0,10 | 2,52 | 5 | 0,11 | 3,4 | 7 | 77 | 0,24 |
| 3 | 0,06 | 0,6 | 128 | 0,16 | 1,9 | 5 | 0,12 | 3,4 | 7 | 78 | 0,24 |
| 4 | 0,07 | 0,9 | 29 | 0,17 | 1,8 | 5 | 0,15 | 3,3 | 7 | 79 | 0,23 |
| 5 | 0,075 | 1,75 | 30 | 0,17 | 1,75 | 5 | 0,17 | 3,4 | 8 | 80 | 0,23 |
| 6 | 0,076 | 1,4 | 31 | 0,185 | 2,1 | 5 | 0,17 | 3,4 | 8 | 81 | 0,26 |
| 7 | 0,08 | 1,25 | 32 | 0,16 | 2,4 | 5 | 0,18 | 3,4 | 8 | 82 | 0,26 |
| 8 | 0,06 | 2,9 | 33 | 0,19 | 1,9 | 5 | 0,21 | 3,4 | 8 | 83 | 0,17 |
| 9 | 0,075 | 2,75 | 34 | 0,22 | 1,9 | 5 | 0,18 | 3,7 | 8 | 84 | 0,3 |
| 10 | 0,075 | 3,15 | 35 | 0,22 | 2,2 | 6 | 0,16 | 3,8 | 8 | 85 | 0,32 |
| 11 | 0,09 | 3,1 | 36 | 0,21 | 2,4 | 6 | 0,21 | 3,8 | 8 | 86 | 0,37 |
| 12 | 0,09 | 2,4 | 37 | 0,21 | 2,7 | 6 | 0,18 | 3,9 | 8 | 87 | 0,34 |
| 13 | 0,11 | 1,6 | 38 | 0,21 | 2,9 | 6 | 0,16 | 3,9 | 8 | 88 | 0,32 |
| 14 | 0,1 | 2,0 | 39 | 0,21 | 3,1 | 6 | 0,22 | 3,4 | 9 | 89 | 0,31 |
| 15 | 0,11 | 2,6 | 40 | 0,23 | 2,3 | 6 | 0,22 | 3,8 | 9 | 90 | 0,34 |
| 16 | 0,11 | 2,8 | 41 | 0,23 | 2,6 | 6 | 0,17 | 3,6 | 9 | 91 | 0,34 |
| 17 | 0,12 | 3,1 | 42 | 0,23 | 2,4 | 6 | 0,16 | 3,7 | 9 | 92 | 0,31 |
| 18 | 0,12 | 2,4 | 43 | 0,23 | 3,1 | 6 | 0,18 | 3,9 | 9 | 93 | 0,31 |
| 19 | 0,13 | 2,4 | 44 | 0,26 | 2,75 | 6 | 0,16 | 4,0 | 9 | 94 | 0,34 |
| 20 | 0,013 | 2,2 | 45 | 0,27 | 2,7 | 7 | 0,21 | 4,2 | 9 | 95 | 0,26 |
| 21 | 0,13 | 1,7 | 46 | 0,26 | 3,1 | 7 | 0,23 | 2,3 | 96 | 0,28 |
| 22 | 0,14 | 1,4 | 47 | 0,3 | 2,8 | 7 | 0,23 | 2,6 | 97 | 0,31 |
| 23 | 0,14 | 1,8 | 48 | 0,31 | 3,1 | 7 | 0,23 | 2,7 | 98 | 0,33 |
| 24 | 0,14 | 2,3 | 49 | 0,14 | 3,25 | 7 | 0,23 | 3,1 | 99 | 0,31 |
| 25 | 0,13 | 2,5 | 50 | 0,16 | 3,25 | 7 | 0,23 | 3,4 | 99 | 0,31 |

**Table 2.** Data needed in order to make decisions

| № | I_plate, μA | n_1 | n_2 | P_err |
|---|---|---|---|---|
| 1 | 0,05 | 0 | 60 | 0,612 |
| 2 | 0,1 | 0 | 48 | 0,489 |
| 3 | 0,15 | 4 | 30 | 0,346 |
| 4 | 0,2 | 11 | 16 | 0,275 |
| 5 | 0,25 | 18 | 5 | 0,234 |
| 6 | 0,3 | 23 | 2 | 0,255 |
| 7 | 0,35 | 31 | 80 | 0,316 |

The probability of error that good products are considered defective and defective products are good is determined by the following expression (10).

According to the experiment, for n_1 = 4, n_2 = 30 and the probability of error for a given threshold value I_0 = 0,15 is P_err = 0,346.

To determine the optimal value of P_err, we construct the dependence P_err = f(I_plate) (Fig. 2), for which, for α = var, we find the values of P_err, (Table 2). From the analysis of the dependence of the probability of error on I_plate (Fig. 2), the values were determined: I_plate = 0,25; P_err = 0,234.

The dependence of the probability of error in decision-making on the sign of I_plate.
5

4. Conclusion
In the paper the characteristics of modeling maintenance of the machine-building complex are considered. The main results of the paper are as follows: the forecasting technique for components based on one attribute in the framework of a training experiment, the results of modeling of capacitors parameters. According to the results of mathematical modeling, the optimal value of probability of error is shown.

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