Mathematical criteria for testing the logical control programs for technological equipment

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Abstract. The article covers examination of mathematical criteria that allow considering the process of testing the logical control systems at the stage of developing a control program as completed. Two mathematical approaches for detecting errors in software, i.e. the criterion for the intensity of error detection and the criterion for a given value of mean time to failure have been considered. An example of the calculation of mathematical criteria for a real task, i.e. testing the logical control program of the turret block of the electrical automation system of a machining center of oblique layout with CNC has been given. A variant of calculating the required test time to achieve the required value of time to failure has been given. It has been concluded that in order to increase the efficiency of testing, its acceleration and reduce the cost of testing, both for manual and automated testing methods, it is necessary to use methods and tools that allow eliminating the influence of the shortcomings of traditional approaches to testing.

1 Introduction

Analyzing and detecting errors in software is a subjective process. A wide range of specialists considers various options for checking the developed system for errors, depending on the goals set, tasks to be solved, project budget, timeframe, etc. [1- 5]. The more diverse the set of measures for testing the developed logical control system, the more comprehensively all its aspects and possible problems will be studied.

In order to increase the efficiency of testing, its acceleration and reduce the cost, it is necessary to use methods and tools that allow avoiding the influence of the shortcomings of traditional approaches to testing. This goal can be achieved by introducing single-valued mathematical criteria for deciding on the results of tests.

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2 Methods

2.1 Conceptual device and mathematical approaches to detecting errors in software

Among the available mathematical criteria that can be applied to the testing process, we will consider two that directly affect the evaluation of the testing process: the criterion for the intensity of error detection and the criterion for the given value of mean time to failure.

2.1.1 Intensity criterion of error detection

When working with the specified criterion, it is assumed that no more than one error is detected during one experiment, and each error is eliminated before the start of the next experiment. Then we can assume that with a favorable course of debugging and testing, the dependence curve is expressed by the equation:

$$N(K) = 1 - \frac{n}{K},$$

where n is the number of detected and eliminated errors; K is the number of experiments.

As can be seen from equation (1), the curve will asymptotically tend to unity. Moreover, the smaller the value of the coefficient n, the faster the function N(K) will tend to unity, and the larger the value of the variable K, the closer the value of the function N(K) to unity (Figure 1, curves 1, 2, 3) . Curve 4 indicates the unfavorable course of the process [3].

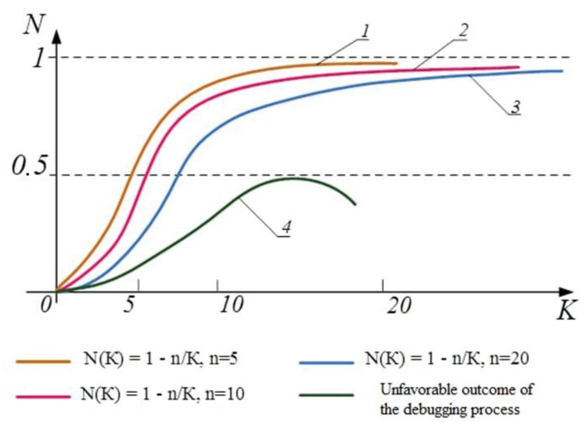

Fig. 1. Curve of the dependence of the termination of tests on the number of detected and eliminated errors.

Then, the following condition can be taken as a test termination criterion: N > 0.95, i.e., for example, the detection of no more than three errors in the last two hundred experiments [6]:

2.1.2 Criteria of the given value of mean time to failure

As part of the application of the criterion, which is also called the *J.D. Moose criterion*, two assumptions are made:

1. The total number of detected and eliminated defects in the program (a defect is understood as any reason for dissatisfaction with the properties of the program) is described by the function of the operating time τ:

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$$n = N_0\left[1 - exp\left(-\frac{C\cdot\tau}{M_0 T_0}\right)\right],$$

where N_0 is the initial number of defects in the program; M_0 is the total number of defects that may appear during the operation of the program; T_0 is the mean time to failure at the beginning of the tests. This is the mean time to failure of a program product. For program products, this usually means a period until the program is completely restarted or the operating system is completely rebooted. It is measured statistically, by testing multiple programs, or calculated by methods of reliability theory); C is the test compression coefficient [7].

Coefficient $C \neq 1$ when the absolute reactivity of the program during tests or statistical tests differs from the absolute reactivity during the running of program in real conditions. If, for example, in one hour of testing, a controlled process that occurs in real conditions for ten hours is simulated, then the compression ratio C is taken equal to 10 [8].

2. The rate of detection and elimination of defects, measured relative to the program running time, is proportional to the failure rate. The proportionality factor B=n/m is called the *defect reduction coefficient*.

The number of recorded failures *m* depends on the total program operation time as follows:

$$m = M_0\left[1 - exp\left(-\frac{C\cdot\tau}{M_0 T_0}\right)\right]$$

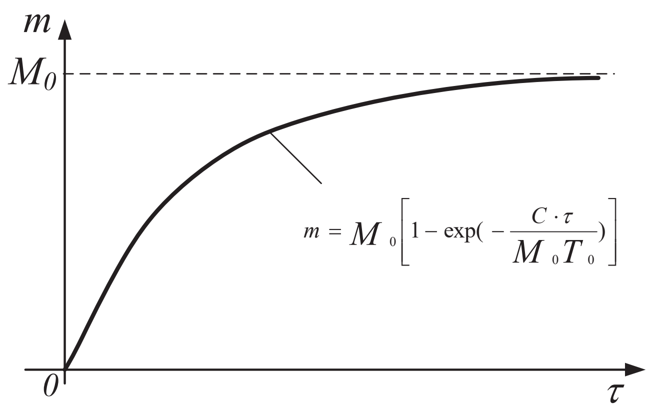

Fig. 2. Dependence of the number of failures on the operation time of the logic control system.

The value of the mean time to failure also depends on the total operating time:

$$T = T_0 \exp\left(\frac{C\cdot\tau}{M_0 T_0}\right)$$

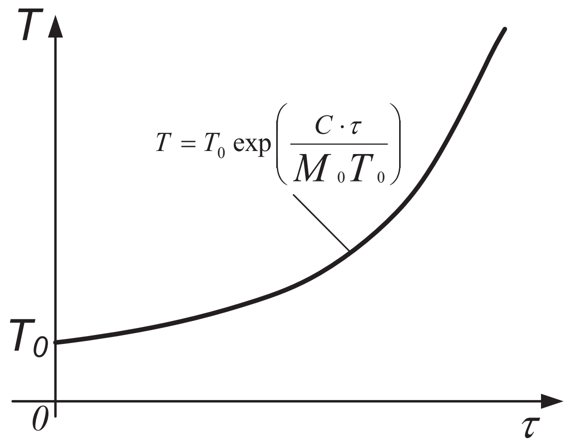

Fig. 3. Dependence of the current mean time to failure on the time of operation of the logical control system.

If the detected errors are eliminated during the test, then the current value of the mean time to failure will increase. Thereby, achievement of the required (specified) value of the mean time to failure T_τ can be taken as a test completion criterion. Then, by periodically determining the current value of the mean time to failure according to this formula, it is possible, when planning the further course of the test, to calculate the required time for further testing of the program according to the formula:

$$\Delta\tau = \frac{M_0 T_0}{C} ln\left(\frac{T_\tau}{T}\right)$$

3 Results

Practical aspects of calculating mathematical criteria for detecting errors in software. Let us consider the described theoretical provisions for practical calculations during tests. For this, we use the procedure of error detection in the logical control program of the turret block of the electrical automation system of a machining center of oblique layout with CNC SA535S10F4.

Description of the test object. The turret block, as a controlled element of the machine, has input variables given in Table 1.

Table 1. Input and output signals of the turret block.

Input signals	Output signals
Machine power on	Place the tool in the turret socket (Pocket)
Drum rotation clockwise	Drum rotation clockwise
Drum rotation counterclockwise	Drum rotation counterclockwise
Turret position at 0°	-
Turret position at 90°	-
Turret position at 180°	-
Spindle running	-
Turret socket is free (Pocket)	-

Since all these signals are discrete, in our example, a programmable logic controller (PLC) is used as a control device that implements the switching of the states of the turret. The logic control program for it is compiled in the FBD function block language.

The FBD language is a graphical language and is most convenient for programming the processes of passing signals through functional blocks. A program in the FBD language is a set of functional blocks that are connected by communication lines. It is to such a logical control program that it is proposed to apply the mathematical criteria described above along with the traditionally used approaches (functional, load testing, reliability testing, etc.)

Calculation and construction of the curve of intensity criterion of error detection. The intensity criterion of error detection is expressed by the formula (1) N(K) = 1-n/K, where n is the total number of detected and eliminated errors for the number of experiments K; K is the number of experiments. Let us conduct several experiments and fix the number of errors found in each of them. The research results are given in Table 2.

Table 2. Summary table on the number of tests carried out and the number of errors detected.

	n=17						n=12					
K	5	10	20	30	40	50	5	10	20	30	40	50
n/K	3.4	1.7	0.85	0.57	0.43	0.34	2.4	1.2	0.6	0.4	0.3	0.24
N(K)	-2.4	-0.7	0.15	0.43	0.57	0.66	-1.4	-0.2	0.4	0.6	0.7	0.76
	n=8						n=3					
K	5	10	20	30	40	50	5	10	20	30	40	50
n/K	1.6	0.8	0.4	0.27	0.2	0.16	0.6	0.3	0.15	0.1	0.075	0.06
N(K)	-0.6	0.2	0.6	0.73	0.8	0.84	0.4	0.7	0.85	0.9	0.925	0.94

The dependence graph of the obtained experimental data is shown in Figure 4.

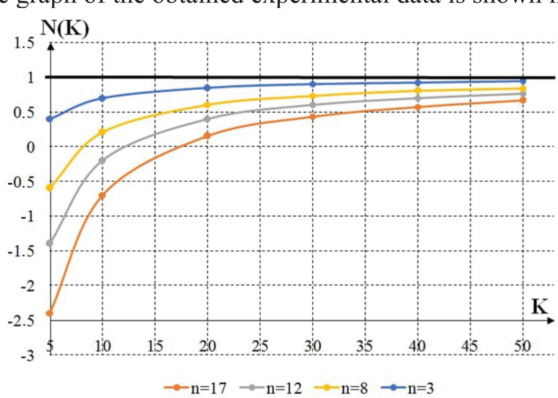

Fig. 4. Experimental curves of the intensity criterion of error detection for various values of the number of detected errors n.

As a test termination criterion, we take the following condition: N > 0.9.

From the graphs in Figure 4 it can be seen that with a decrease in the value of n, the curve asymptotically tends to 1 faster, respectively, the larger n, the more difficult it is to reach the threshold value taken equal to 0.9, and the more checks K will be required for this. In our case, at n=3 on the fiftieth test, the value of the intensity criterion, expressed by the value of the function N(K), becomes equal to 0.94 (see Table 2). 0.94>0.9, therefore, the performance test of the turret control system according to the intensity criterion can be considered successfully completed [9].

Calculation of the required test time to achieve the required value of mean time to failure. The value of the mean time is expressed by formula (4), and the required time for further testing of the program by formula (5).

In order to calculate the required time for checking the program to achieve the specified value of the completion criterion T_τ, we set the values of the arguments of formula (5), determined experimentally and given in Table 3.

Table 3. Values of constants for calculating mean time to failure.

$T_0 = 3$	- mean time to failure at the beginning of testing, h;
$C = 10$	- test compression coefficient;
$M_0 = 50$	- the total number of defects that may occur during the operation of the software;
$T_\tau = 1000$	- required (specified) value of mean time to failure, test completion criterion, h;
$T = 8.15$	- current value of the function T(τ), h; is determined by the formula based on the current moment of testing time τ = 15 h, see the graph in Figure 3.

Then

$$\Delta\tau = \frac{M_0 T_0}{C} ln\left(\frac{T_\tau}{T}\right) = \frac{50*3}{10} ln\frac{1000}{8.15} = 72\ h. \quad (6)$$

And the graph of the function T(τ), plotted on the control calculated points (Table 4), will look like it is shown in Figure 5.

Table 4. Control points for plotting the dependence graph of mean time to failure on operating time.

τ	0	5	10	15	20	25	30	35	40	45	50
T	3	5	7	10	16	24	37	55	84	128	194

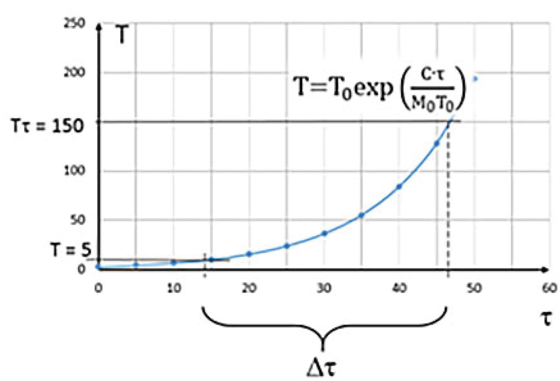

Fig. 5. Experimental curve of the dependence of the mean time to failure on the operation time of the logic control system.

The resulting calculated value of $\Delta\tau$=72 h is the time that it is necessary to continue testing the program to obtain the required total mean time to failure of the tested software product, equal to 1000 hours.

4 Discussion

In order to increase the efficiency of testing, its acceleration and reduce the cost of testing, both for manual and automated testing methods, it is necessary to use methods and tools that allow eliminating influence of the shortcomings of traditional approaches to testing. This goal can be achieved by applying specialized mathematical criteria.

5 Conclusions

The use of the intensity criterion of error detection is most applicable in the case of manual testing, since the result of the analysis within this criterion is the ordinal number of the testing iteration, after which the required accuracy degree of software product is achieved.

The application of the criterion of a given value of mean time to failure in practice is most applicable for automated testing, since this criterion provides information on the amount of time during which it is necessary to continue work out the program in details through automatically launched test scenario in order to obtain a system with the required mean time to failure.

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