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# Comprehensive Test Procedure for Digital Instruments and Devices of Automated Versatile Systems

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# Comprehensive Test Procedure for Digital Instruments and Devices of Automated Versatile Systems

**E M Khusnutdinova**[1]**, P P Pavlov**[2]**, V P Fandeyev**[2]**, R N Khizbullin**[2]**A N Khusnutdinov**[2] **and I V CHerepen'kin**[2]

[1]Kazan (Volga Region) Federal University 18 Kremlyovskaya Str., Kazan 420008, Russia
[2]Kazan State Power Engineering University51 Krasnoselskaya str., Kazan 420061, Russia

rr-088@mail.ru

**Abstract.** The authors present a comprehensive test procedure for digital devices, based on the calculation and control of two or more characteristics of a binary signal at a control point. The procedure is aimed at how to increase the reliability of performance monitoring and localization of the failure of digital devices as part of automated versatile systems.

Current automated systems consist of different components and systems (digital controls, monitoring, testing tools, etc.) The results of reliable monitoring and testing provide error-free decisions on safe operation and in-service resource saving. Performance monitoring and troubleshooting is done by hardware and software, selected depending on the principles of operation, design and fault classes of the components. Methods of hardware monitoring and troubleshooting of digital devices subject to logical failure (hereinafter referred to as the "failure") are usually based on comprehensive testing.

The comprehensive testing of the digital device by comparing a binary signal at a reference point with a valid binary signal ensures failure detection, but requires significant troubleshooting support. Limiting the cost of troubleshooting can be achieved, for example, by choosing the number of transitions, the number of units, the signal signature at the reference point of the digital device as controlled parameters [1]. At the same time, control of the number of transitions, the number of digits, and the signature is inferior to the method of signal comparison by the probability of failure detection. Some of the failures impossible to detect by the signature control can be detected by combining the signature control and the number of transitions or/and digits of binary signals of the digital device [1].

The signal at the reference point of the digital device subjected to testing is usually modeled by a multi-bit binary sequence of digits and zeros, which, in turn, is displayed by a binary polynomial or Boolean function [2, 3, 4]. These models make it possible to calculate the number of transitions, digits, and signal signature.

The number of different binary signal sequences is calculated by the formula

$$M=2^N=2^{2^n} , \qquad (1)$$

where $N$ is the number of bits of the binary sequence; $n$ is the number of binary input signals (inputs) of the digital device.

A healthy digital device has a single valid binary sequence. The remaining binary sequences correspond to failures of the digital device.

The probability of failing to detect the digital device failure by monitoring the number of transitions or digits with equally probable binary sequences is calculated by the formula

$$q = \frac{1}{M(M-1)} \sum_{k=0}^{N} C_N^k \left( C_N^k - 1 \right) \approx \frac{1}{\sqrt{\pi N}}, \qquad (2)$$

where $k$ is the number of transitions or digits in binary sequence; $C_N^k$ is the number of $N$ to $k$-combinations; $\pi \approx 3{,}14$.

The binary sequences of the healthy and failed digital device most often differ in only one bit (single failure). The probability of failing to detect the single failure by controlling the number of transitions is calculated by the formula

$$q_1 = \frac{N-1}{2N} \approx \frac{1}{2}. \qquad (3)$$

The single failure is detected by controlling the number of digits. Indeed, when changing 1 to 0 or 0 to 1 in one bit, the number of digits in a binary sequence always changes. Thus, controlling the number of digits has an advantage over controlling the number of transitions in terms of detecting single failures.

The binary sequence of the failed digital device may not differ from the binary sequence of the healthy digital device in the number of transitions, but may differ in the number of digits. The corresponding failures of the digital device are not detected by controlling the number of transitions, but are detected by controlling the number of digits [2, 5].

The probability of failing to detect the failure manifesting itself as an $N$-bit binary sequence containing $k$ transitions and $l$ digits is calculated using the theoretically substantiated formula

$$Q_{k,l}^N = \frac{C_N^k \left( C_N^k - 1 \right)}{M(M-1)} \sum_{l=1}^{N-1} \frac{M_{k,l}^N - 1}{C_N^k - 1}, \qquad (4)$$

where $M_{k,l}^N$ is the number of $N$-bit binary sequences containing $l$ digits among binary sequences containing $k$ transitions. The correctness of formula (4) is proved by the results of a simulation experiment with binary sequences.

The probability of failing to detect the failure when controlling the number of transitions and the number of digits is calculated by the formula

$$Q = \sum_{l=1}^{N-1} Q_{k,l}^N. \qquad (5)$$

With an increase in the number of binary bits from four to eight, the probability of failing to detect the failure by controlling the number of transitions and digits approaches the probability of failing to detect the failure by controlling the number of transitions only. Controlling the number of transitions and digits does not provide a significant reduction in the probability of failing to detect the failure.

The probability of failing to detect the digital device failure by the signature control method, is calculated by the formula

$$q_s = \frac{2^{N-m}-1}{2^N-1} \approx \frac{1}{2^m}, \tag{6}$$

where $m$ is the number of bits of the signature analyzer register, many times less than the probability of failing to detect the failure by controlling the number of transitions and digits.

A significant reduction in the probability of failing to detect the digital device failure is achieved by a combination of controlling the signature and the number of digits, since binary sequences of signals of both the healthy and the failed digital device may not differ in signature, but differ in the number of digits [6, 7, 8, 9].

The probability of failing to detect the failure, when combining the methods of controlling the signature and the number of digits of the signal, is calculated using theoretically valid formulas for the signature containing a digit in at least one of the bits (non-zero signature, $s \neq 0$), and the signature containing zeros in all bits (zero signature, $s = 0$).

$$q_{l,s^10} = \frac{1}{M-1}\left( \frac{N-1}{N/2} \sum_{c=1}^{l/2} C_{N/2}^{2c-1} C_{N/2}^{l-(2c-1)} - 1 \right), \tag{7}$$

$$q_{l,s=0} = \frac{1}{M-1}\left( C_N^l - \frac{N-1}{N/2} \sum_{c=1}^{l/2} C_{N/2}^{2c-1} C_{N/2}^{l-(2c-1)} - 1 \right), \tag{8}$$

where $M$, $N$ are calculated by the formula (1); $l$ is the number of digits in the binary sequence of the signal, $l/2$ is rounded to the nearest integer with an odd number; $C$ stands for the number of combinations; $c$ is the integer variable.

The approximate probability of failing to detect the digital device failure is calculated for both the non-zero and zero signature by the formula

$$q_{l,s} \approx \frac{1}{M-1}\left[ \frac{(N-1)!}{l!(N-l)!} - 1 \right] \tag{9}$$

Formulas (7) - (9) are obtained for the number of bits of the signature analyzer register equal to the number of binary input signals (inputs) of the digital device. Probabilities (7) - (9) take maximum values at $l = N/2$. The correctness of formulas is proved by the results of a simulation experiment with binary sequences [11, 12, 13, 14]. The maximum probability of failing to detect the failure by a combination of methods of controlling both the signature and the number of digits is significantly less than the probability of failing to detect the failure by signature control only.

The decision on the failure of the digital device is taken if the signal signature does not match the valid signature or the number of digits with the allowable number of digits. The valid signature and the allowable number of digits are calculated or determined experimentally.

The possibility of combining the control of both the signature control and the number of signal digits in order to detect the digital device failure, as justified in the paper, seems to be one of the possibilities of a compromise between conflicting requirements to limit troubleshooting costs and detect failures with high probability. A relatively small increase in the troubleshooting cost in terms of monitoring the number of signal digits results in a significant reduction in the probability of failing to detect the digital device failure due to the joint control of the signature and the number of digits. As a result, operational safety is increased and the system operation costs are reduced.

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