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Optimization of requirements for measuring instruments at metrological service of communication tools

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ABSTRACT

A method for determination of a minimal value for probability of correct estimation of measurement results (PCEMR), using conditional algorithms is developed. The novelty of the method is in the application of methods of technical diagnostics to the metrological service of communication systems. Namely, metrology and technical diagnostics are related through the fact, that the PCEMR, performed with a measuring instrument (MI) governs the value of the average time for determination of technical state of a communication tool (CT). Derived equations increase the accuracy of estimation of mathematical expectation of a deviation from the true value, which characterizes the technical state of a CT. To illustrate the capability of the method we check whether the digital multimeter Keithley 2000 as a MI is a correct choice for determination of the technical state of a controlling operational subsystem of a high-power transmitter.

1. Introduction

A communication tool (CT) during its functioning can be in different states (service/out-of-service; normal/limited, stable/with-perturbations, reliable/limited-reliability/non-reliable functioning, etc.). Identification of the technical state of a CT is performed basing on quantitative testing parameters, collected with measuring instruments (MIs) prior to the main measurements or during metrological service (MS).

The sequence of actions in a testing procedure is usually represented in a form of a conditional algorithm (CA). If the measured testing parameters deviate from their nominal values, one initiates the search for defects with regular MI, following standard programs which implement a chosen CA diagnosis.

Price of a MI depends on its metrological characteristics. For example, increase of the accuracy class of a universal voltmeter from 0.02 to 0.002 increases its price in 7.5 times [1]. To determine the sufficient value of the accuracy class, one uses so-called probabilistic characteristics of a MI, *i.e.* probability of correct estimation of the measurement result (PCEMR, further denoted by p), which for a MI, used during MS, should vary between 0.645 and 0.9997. PCEMR governs the probability (P) of correct determination of technical state of a CT as well as the mathematical expectation of average (ρ) and maximum (ρ_M) deviations in determination of the technical state of a CT from its true value [1,2]. The purpose of this paper is to develop a method for determination of a minimal sufficient value of p for the assessment (with given accuracy) of the technical state of a CT during its MS and maintenance, when searching for defects, using CAs of different types and forms.

2. Description of the method

Conditional algorithms, which are used for MS are distinguished by their type (binary, homogeneous, group) and form (perfect $F = 1$, minimal $F = 2$, arbitrary $F = 3$, maximal $F = 4$). Type of a CA is determined by the number m of possible results of the inspection (the so-called *selection module*), and by the number μ of simultaneously measured parameters. Group algorithms are used for multichannel MIs; two- or four-channel oscilloscopes, for example. When $m = 2$ (norm/not-norm), the CA is called a binary CA. For $m > 2$ (below norm, norm/higher-than-norm or less-than-norm/norm/more-than-norm, or at the absence of signal) the CA is called a homogeneous CA. Homogeneous CA are easily realized at $m = 3$, when the nominal value of the parameter is marked by a sector on the scale screen of MI. The higher is the value of m, the lower is the average number K of checks with the CA, needed to determine the element that fails to work in the CT from a set L of possible states, including the "in-service" state) [2,3].

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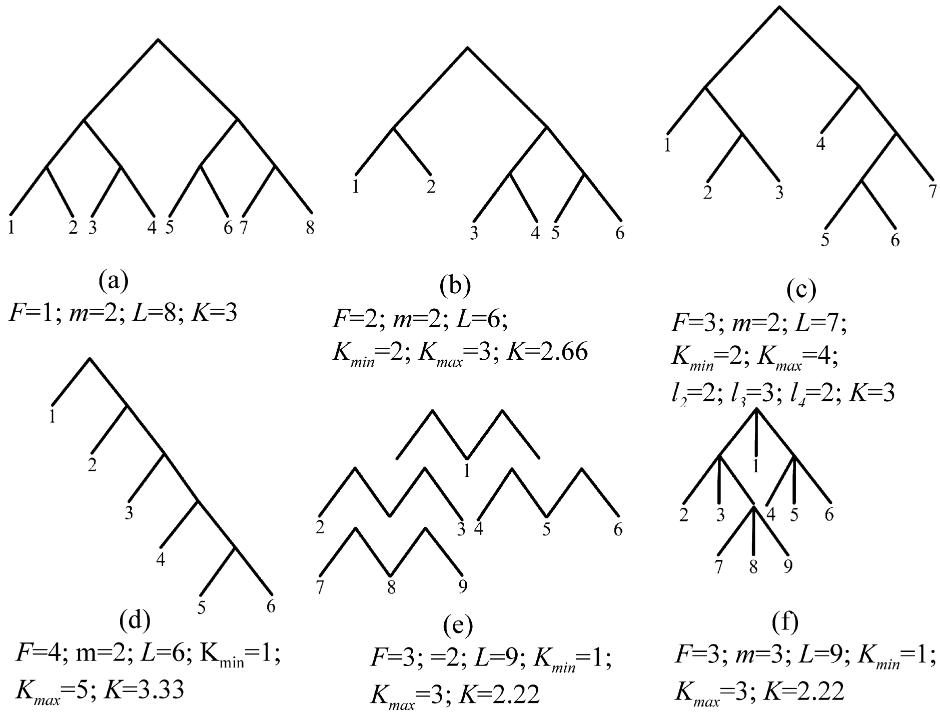

Fig. 1. Conditional algorithms of different types and forms.

Examples of types and forms of CAs are given in Fig. 1:

- binary ($m = 2$) perfect form ($K = \log_2 L$, Fig. 1a).
- binary minimal form (the difference between the maximal $K_{\max}$ and minimal $K_{\min}$ numbers of inspections is equal to 1, Fig. 1b).
- binary arbitrary form (the number of search results after the i checks $K = \frac{1}{L}\sum_{i=K_{\min}}^{K_{\max}} i{\cdot}l_i$, l_i, Fig. 1c).
- binary of maximal form ($K_{\min} = 1$, $K_{\max} = \frac{L-1}{m-1}$, $K(m=2) = \frac{(L-1)(L+2)}{2L}$, Fig. 1d).
- group (simultaneous checking of μ parameters) of arbitrary form ($K_{\min} < K < K_{\max}$, Fig. 1e).
- homogeneous ($m = 3$) of arbitrary form (Fig. 1f).

Application of the group CA implies somewhat worse probability of correct diagnosis, but significantly reduces the average number of inspections and duration of assessing of the technical state of a CT [3].

Binary algorithms are simple and easy in application and for this reason have been the most studied [3]. Table 1 presents functional dependences, which are used in available methodic of justification of the Ac value for a MI [1,4] for calculation of the mathematical expectation of average (ρ) and maximum (ρ_M) deviations in determination of the technical state of a CT in assumption of one mistake in assessing of the value of the parameter under inspection. It should be noticed that, at the standard, procedure when using a CA of any form, the required value p is overestimated and consequently the cost of selected MI appears to be overstated.

Overestimation of the$p$ value is due to the fact that for $m > 2$ one assumes an equally probable decision on any possible result of the verification, for example, in the absence of a signal one supposes to accept a decision "less than norm", which never happen in reality).

This problem was taken into account in [3], where corrected expressions for the CA of perfect form were proposed; in the case of error, a deviation in the estimation of the value of the parameter is assumed for only one decimal in each side with the probability $0.5(1{-}p)$:

$$\rho(m \geqslant 2) = 0.5\left(K + \frac{L-1}{m-1}\right)(1-p)p^{K-1}; \quad (1)$$

$$\rho(\mu \geqslant 1) = 0.5\left(K + \frac{L-1}{\mu}\right)(1-p)p^{\mu K-1}. \quad (2)$$

For practical calculations with a fairly high accuracy (error not more than 0.2%, when $K \leqslant 7$), one can use approximated expressions [3]:

$$\rho(m \geqslant 2) \approx 0.5\left(K + \frac{L-1}{m-1}\right)(1-p)(1-(1-p)(K-1));$$

$$\rho(\mu \geqslant 1) \approx 0.5\left(K + \frac{L-1}{\mu}\right)(1-p)(1-(1-p)(\mu K-1)).$$

In a general case for several inaccuracies in the assessment of the measurement results, the upper limit of the possible deviation of the assessment of the technical state of the CT is:

$$\rho_M = 0.5(L + K-1)(1-p^K),$$

where $(1{-}p^K)$ gives the probability of false assessment of the technical

Table 1
Quantitative evaluation of deviation of determination of the technical state of a CT using the CA of perfect form ($F = 1$) [3].

Type of algorithm	Average value of deviation, ρ	Maximum value of deviation, ρ_M	K	L	P
Binary $m = 2$	$0.5(L + K-1)(1-p)p^{K-1}$	$(L-1)(1-p)p^{K-1}$	$\log_2 L$	2^K	p^K
Homogeneous $2 \leqslant m = const$	$\frac{m-1}{m}\left(K + \frac{L-1}{m-1}\right)(1-p)p^{K-1}$	$\left(K + \frac{L-1}{m-1}\right)(1-p)p^{K-1}$	$\log_m L$	m^K	p^K
Group $m = \mu + 1$	$\frac{\mu}{\mu+1}\left(K + \frac{L-1}{\mu}\right)(1-p)p^{\mu K-1}$	$\left(K + \frac{L-1}{\mu}\right)(1-p)p^{\mu K-1}$	$\log_{\mu+1} L$	$(\mu+1)^K$	$p^{\mu K}$