Measurement Techniques, Vol. 37, No. 1, 1994

EFFECTS OF ERROR VARIATION IN MEANS OF MEASUREMENT ON RELIABILITY PARAMETERS IN ENGINEERING-SYSTEM MONITORING

V. N. Stroitelev, P. G. Shabanov, and T. V. Shaposhnikova

UDC 658.53/.59:681.2.088

A method is given for calculating the monitoring reliability parameters (MRP) for an engineering system with allowance for the drift in the measurement error of the means of measurement (MM). The approach is based on introducing a biased MM error distribution into the traditional formulas for the conditional probabilities of spurious and unobserved failure. The bias at the center of the distribution is determined by the systematic error at the given instant. An example is given to illustrate the performance in MRP calculation.

Efficient operation of complex equipment would be impossible without appropriate state monitoring by means of means of measurement (MM). One of the major aspects in metrological support to engineering systems is that of reliability parameter monitoring. The importance of that topic is indicated by the numerous papers constantly being published, which reflect many different aspects of monitoring reliability.

For example, in [1-5], general aspects are considered and approaches are given for calculating monitoring reliability parameters MRP for measurement systems. In [4, 5], there are discussions on choosing and using a system of MRP, while in [6, 7], methods are given for calculating the reliability parameters for multiparameter monitoring on complicated equipment, and [4, 8] deal with estimating the reliability in repeated monitoring of the parameter ranges.

A major aspect concerns the influence from various destabilizing factors, which can affect the state throughout the working life of the equipment. Some researchers [4, 5, 8] aging or factors associated with variable tolerance limits (due to random errors in comparators), but there remains the open question of how the MRP are affected by drift in the error of the MM used in state monitoring.

Here we present a way of calculating the MRP on the basis of the variability in the error of the MM due to natural aging.

As MRP we take the conditional probabilities of spurious failure α and unobserved failure β in monitoring a parameter, which are given by standard formulas [1-5]:

$$\alpha = \frac{\int_a^b f(x)\left[\int_{-\infty}^{a-x} f(z)dz + \int_{b-x}^{\infty} f(z)dz\right]dx}{\int_a^b f(x)dx}; \quad (1)$$

$$\beta = \frac{\int_{-\infty}^{a} f(x)dx \int_{a-x}^{b-x} f(z)dz + \int_b^{\infty} f(x) \int_{a-x}^{b-x} f(z)dzdx}{1-\int_a^b f(x)dx}, \quad (2)$$

in which f(x) is the probability density for the measured parameter, while f(z) is the error density for the means of measurement, and a and b are the lower and upper bounds to the tolerance range for a measured parameter.

Translated from Izmeritel'naya Tekhnika, No. 1, pp. 12-13, January, 1994.

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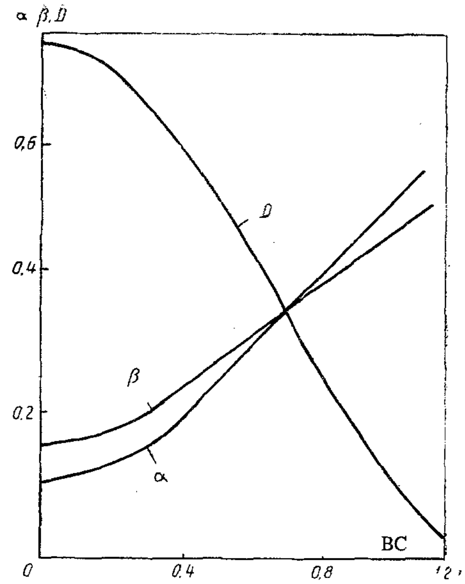

Fig. 1

The MRP in (1) and (2) is calculated on the assumption that the error distribution for the means of measurement (and that for the measured parameter) remains unaltered over time. One incorporates the effects from drift in the error of the MM on the monitoring reliability by replacing the centered f(z) distribution by a displaced f(z) having mathematical expectation equal to the systematic error of the MM $\Delta(t_0)$ at a given time t_0. Then the MRP will be corrected in accordance with the physical state of the MM used in the parameter monitoring. If a model exists for the error drift, one can use this technique to construct the corresponding model for the change in the MRP over time.

To illustrate this, we consider a linear model for the systematic error drift:

$$\Delta(t)=\Delta_0+At, \tag{3}$$

in which Δ_0 is the systematic error at t_0 (at the start of use), and A is a coefficient characterizing the rate of change in the systematic error.

That model quite adequately describes the error drift for various means of measurement such as electrical measuring instruments [9].

We track the MRP change with the following initial data. The measured parameter has a normal distribution with numerical characteristics $M_x = 0$; $S_x = 1$, while the error distribution is normal and has the characteristics $M_z = \Delta(t) = t$, $t \in [0; 1, 1]$; $S_z = 0.33$.

The values of the tolerance range for the measured parameter are $a = -3$ and $b = 3$.

The variation interval for the MM error is given on the basis that one has to examine the behavior up to the point where the error exceeds the permissible value (in our case, $\Delta_{per} = 1$), i.e., throughout the interval between tests.

Calculations with a personal computer enabled us to construct an MRP model for a given time interval. Figure 1 shows the time course of α, β, and $D = 1 - \alpha - \beta$. These show that the effects of drift in the systematic error on the MRP are large. For example, over a period equal to half of the interval between checks, the monitoring reliability is almost halved, while in $0.8T_{bc}$, it falls by almost a factor four. That MM can still be operated to provide MRP that are several times those actually occurring.

Such conclusions indicate that error drift during use is a decisive factor causing discrepancies between the actual MRP and the declared ones, and thus is responsible for low performance in the presence of apparently high reliability in parameter monitoring.

This method of constructing MRP models enables one to examine a wide range of error-variation processes. For example, one can introduce nonlinear error drift models into (1) and (2) (quadratic, exponential, logit, and so on), and one can also extend the class of models by varying the random component of the error, i.e., putting $S_z = S_z(t)$.

This approach enables one to consider the formal significance of the MRP more broadly, namely not simply as a deterministic time function $\alpha(t)$ or $\beta(t)$ but as numerical characteristics of random processes, whose stochastic behavior is due to the randomness of the instants t at which measurements are made on the apparatus.

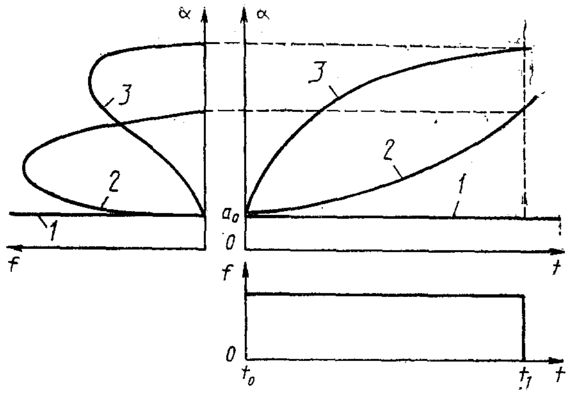

Fig. 2

To illustrate this, we take values of t uniformly distributed within the life cycle:

$$f(t)=1/(t_1-t_0),$$

in which t_0 and t_1 are the start and end of the equipment use.

The MRP variation is described by polynomials:

$$\alpha(t)=a_0+a_1t^k; \tag{4}$$

$$\beta(t)=b_0+b_1t^k. \tag{5}$$

Then α and β are random quantities whose distributions can be found from the theory of functions with random arguments [11].

One can determine the probability density for a random quantity such as α (and similarly for β) by defining the function inverse to (4):

$$t(\alpha)=[(\alpha-a_0)/a_1]^{1/k},$$

and then we get the absolute value of the derivative:

$$|t'(\alpha)|=\frac{1}{k}\,[(\alpha-a_0)/a_1]^{(1-k)/k}.$$

Then the distribution for α becomes

$$f(\alpha)=C((\alpha-a_0)/a_1)^{(1-k)/k}, \tag{6}$$

in which C is a constant defined by the normalization conditions.

The form of (6) will vary with k. Figure 2 shows possible forms of f(α) for three models for $\alpha = \alpha(t)$, where 1 — $\alpha = a_0$; 2 — $\alpha(t) = a_0 + t^2$; 3 — $\alpha(t) = a_0 + t^{1/2}$.

This shows that one needs a comprehensive analysis of the MM working conditions in order to draw up to MRP specifications.

This approach to calculating MRP on the basis of the error dynamics is not only a tool for analyzing changes in the MRP due to ageing but also an argument for the urgent necessity to incorporate error drift in defining and checking metrological specifications for various engineering systems.

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