RESISTANCE OF DIGITAL ELECTRONIC HARDWARE TO PULSES OF IONIZING RADIATION

N. I. Radaev

The probability characteristics of the resistance of digital hardware to pulses of ionizing radiation are analyzed. Factors responsible for the spread of this resistance are established and a method of its estimation is proposed.

The reliability of sampling testing of electronic hardware (EH) depends on the size and quality of information about the object of investigations and the mechanisms of its failures [1], in particular, because of exposure to pulses of ionizing radiation (IR) [2]. This is especially important in evaluating the agreement between the performance of newly developed EH and the specified demands from data obtained by testing experimental prototypes. Theoretical and experimental methods used for this purpose demand a priori information on the probability characteristics of the tested objects [3].

This paper presents a theoretical analysis and generalization of data on the spread of the radiation resistance of digital EH to pulses of IR that can be obtained before acceptance inspection and used in conformity analysis.

Let U be a random vector of output parameters that describes the serviceability of EH in the presence of IR of level x, and u – the vector of limiting (admissible) parameter values for which the EH is still serviceable. Then, \( \{X : U(x) = u_a\} \) is the random maximum load (or resistance to the effect of IR) for which the output parameters still lie within the specified tolerance. Its total probability characteristic is the resistance function \( R(x) = P(X \geq x) \). The total probability characteristic of the random vulnerability \( X' = X \) of EH (or the radiation levels at which the parameters exceed the admissible values) is the distribution function \( F(x) = 1 - R(x) = P(X < x) \).

Evaluation of the conformity of the equipment with the established specifications consists in testing the inequality \( R(x_s) \leq R_s \), where \( R(x_s) = P(X \geq x_s) \) is the probabilistic radiation resistance indicator, and \( x_s \) is the RI level established in the Standard Technical Documentation at which the EH must be serviceable with the established probability \( R_s \).

Let us write the maximum load as \( X = m_1 + \Delta \), where \( m_1 = M[X] \), and \( \Delta \) is the random spread. Planning of acceptance inspection requires a priori information on the spread \( \Delta \), i.e., on the form of the distribution \( F(x) \). On the adequacy of a priori information substantially depends the required size and efficiency of sampling tests [3]. However, acquisition of this information is associated with definite costs. At the same time, important information about the spread can be obtained by applying numerical and theoretical methods to experimental data on the spread of the resistance of models, parts, and the component types.

Let us analyze the information on spread obtainable before testing.

CLASSIFICATION OF INFORMATION ON RESISTANCE SPREAD

The information can be divided into the following groups:

- the class of distributions \( \Phi \), to which the unknown distribution function \( F(x) \) belongs, is known;
- the resistance variation coefficient \( v = \sigma/m_1 \), where \( \sigma = D[X]^{1/2} \) is the standard deviation of resistance, is known;
- the subclass of distributions \( \Phi' \in \Phi \) and \( v \) or \( \sigma \) are known;
- both the type and the form parameter of the \( F(x) \) distribution are known.


0543-1972/95/3811-1268 $12.50 ©1996 Plenum Publishing Corporation
Distribution Class. Let $x_t$ be the test load level, which in general differs from $x_s$. Since EH is not restorable during exposure, i.e., in the interval $[0, x_t]$, its failure rate is a nondecreasing function of the argument. Consequently, the distribution function $F(x)$ belongs to the class $\Phi$ of all distributions with, on the average, an ascending failure rate function (AFRF distribution) [1], and the resistance variation coefficient $v \leq 1$. To the class $\Phi$ belong, for example, the truncated normal distribution in the interval $[0, \infty)$, the lognormal distribution, the alpha distribution, the Weibull distribution with a form parameter $b \geq 1$, the DM distribution, and others.

Frequently, the only source of information on the probability characteristics of the EH resistance to the effects of IR is the variation coefficient $v$. Then, in the absence of a priori information on the distribution $F(x)$, the relation between the probabilistic indicator $R(x_s)$ and $v$ can be obtained with the aid of the well-known expressions [3] for guaranteed probability estimates (Chebyshev or Hermeyer inequalities).

Distribution Subclass. Practice shows [4] that if a product is not restorable and its failures are parametric, the mean time between failures (resources) of various devices and the resistance of EH components have unimodal distributions with positive asymmetry (in particular, Weibull, logarithmic normal, alpha, or DM distributions). Since the limiting distribution in this subclass is the normal distribution, the resistance coefficient of variation does not exceed 0.33.

If the parameters that govern the radiation resistance of components can be isolated and a parametric model of failures can be devised, strictly probabilistic models are less efficient than probabilistic-physical (diffuse) distributions whose type depends on the degradation process $U(x)$ (monotone) and the form parameter, on the results of measurements in cross sections with respect to $x$ [4, 5]. Thus, additional information on the failure mechanism makes it possible successively to narrow down the class of AFRF distributions to subclasses $\Phi' \in \Phi$ of unimodal, unimodal with positive asymmetry, and diffuse distributions.

The probability properties of radiation resistance are most fully characterized by the type and form parameter of the distribution $F(x)$. They can be established from the form of the random function $U(x)$ and the distribution of its parameters [5], as well as with the aid of full models of EH component parts, applying the methods of statistical trials and hypotheses testing [6]. Thus, the level of no-failure operation of digital EH exposed to IR pulses has, as a rule, a lognormal distribution.

SPREAD STRUCTURE

Analysis shows that the spread of EH radiation resistance, and in particular of electronic computers, is due to the effect of a combination of internal (random spread of parameters) and external (random spread of exposure conditions) factors. The resulting spread has a definite structure.