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Forecasting the Quasi-Deterministic Parameters' Drifts of Radioelectronics Apparatus on the Basis of Quantile Zones Techniques

Abstract. *This paper describes a method of forecasting the guaranteed operating time using the quantile zones. Also there are presented calculations of the guaranteed time operating error.*

Streszczenie. *Artykuł przedstawia metodę przewidywania bezawaryjnego czasu pracy urządzeń elektronicznych w oparciu o teorię kwantyli. Dodatkowo autorzy dokonują analizy błędów prezentowanej metody.* ***(Oszacowanie bezawaryjnego czasu pracy urządzeń radioelektronicznych na podstawie teorii kwantyli)***

Keywords: quasi-deterministic, quantile zones, parameters' drifts, reliability, guaranteed time, probability
Słowa kluczowe: niestabilność parametrów , niezawodność, bezawaryjny czas pracy

Introduction

The processes of parameters' drift in precision long-term service electronic apparatus are, in their physical essence, processes with clearly noticeable monotonic and fluctuating components. Taking into account the proportion between the components, one may classify those processes as belonging to the class of quasi-deterministic processes. Research has shown that in the case of certain equipment operating conditions and the appropriate impact of destabilizing factors, it is possible to develop identified models of parameters' drift in the form of quantile zones. On this basis, techniques of forecasting the reliability of the equipment have been developed; the techniques allow us to determine faultness probability and the guaranteed time interval of remaining the parameters within tolerance limits as well as to assess quantitatively the accuracy of forecasting. The results of investigating the dependencies of the forecasted reliability on deterministic and stochastic characteristics of the drifts have been presented.

Statement of the Problem

The processes of parameters' drift in radioelectronic long-term service apparatus are, to a great extent, characterized by two components: monotonic drifts and fluctuating drifts. The special feature of the monotonic drifts consists in their time irreversibility. These processes are the effect of gradual changes in materials due to ageing, oxidation, crystallization and decrystallization, resource depletion, continuous mechanical, thermal and radiation loads, amortization, and other factors. When establishing the relationship between the cause and effect for the given processes leading to an object's state change, those monotonic components can be considered determinate processes with stochastic initial values of parameters. The peculiarity of the second (fluctuating) drift component consists in its reversibility and non-stationary stochasticity caused by stochastic impact of many destabilizing factors of different nature, amplitude and frequency as well as different correlation dependencies between them. These processes are the effect of voltage instability, internal and external interference, short-term mechanical, electrical, and other influences. Within certain and often limited time intervals these drifts can be characterized by practically unchangeable values of initial and central moments, mainly, of normal distribution. Root mean-square parameters' deviations are much less than their tolerance values**.** Long-term usage of the apparatus makes the processes highly non-stationary in both narrow and wide implications.

Thus, the apparatus parameters' drifts with the given peculiarities of the components are the quasi-determinate processes whose forecasting is possible by using the technique of quantile zones.

In general, the quasi-determinate processes of parameter drift *x(t)* are described by the following adaptation function:

$$x(t)= x_{мон}(t)+ x_{фл}(t) \tag{1}$$

with appropriate monotonic and fluctuation components. For the known interval density *f[x(t_i)]*, where $t_i= t_к- t_e$ is the time interval, the probability of maintenance of working capacity in this interval is determined by the equation:

$$P(t_i) = P\{x(t_i) > \Delta_1\} = \int_{\Delta_1}^{\infty} f[x(t_i)]dx \tag{2}$$

$$P(t_i) = P\{x(t_1) < \Delta_2\} = \int_{-\infty}^{\Delta_2} f[x(t_i)]dx \tag{3}$$

where Δ_1, Δ_2 are tolerance limits.

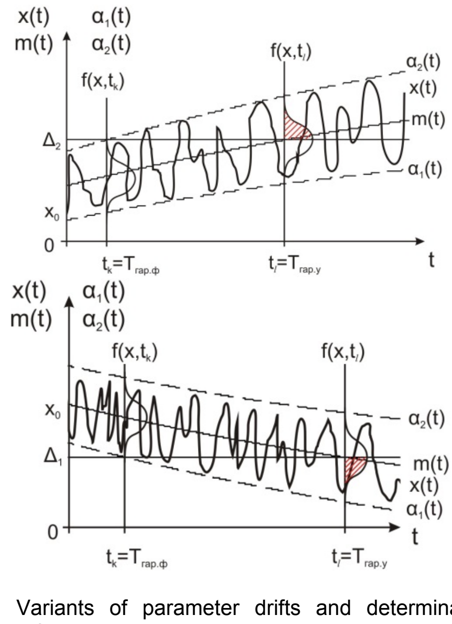

Fig. 1. Variants of parameter drifts and determination of guarantee faultless operation period

Fig. 1 shows the variants for determination of guarantee faultless operation period of a device when the parameter *x(t)* is one-side limited by the thresholds Δ_1 and Δ_2. The preliminary guarantee time $T_{гар.у}$ is defined when the fluctuation component $x_{фл}(t)$ is either absent or ignored. It is determined by the point of intersection of the monotonic component $x_{мон}(t)$ with the levels Δ_1 or Δ_2. The actual guarantee time of faultless operation is determined when the fluctuation component $x_{фл}(t)$ is taken into consideration. [1,2]

The error of guarantee faultless operation period $\Delta T_{гар}$ determination is estimated by the difference between $T_{гар.у}$ and $T_{гар.ф}$

(4) $$\Delta T_{гар} = T_{гар.у} - T_{гар.ф}$$

which, in general, is the following dependence:

(5) $$\Delta T_{гар} = f(\Delta,\ m_0,\ \sigma_0,\ k_1,\ k_2,\ P)$$

where m_0, σ_0 are the initial values of mathematical expectation and mean-square deviation of the parameter $x(t)$; κ_1, κ_2 are the adaptation coefficients.

(6) $$T_{гар.у} = arg/m(t)=\Delta_1/; \quad T_{гар.у} = arg/m(t)=\Delta_2/;$$

$$T_{гар.ф} = arg/\alpha_1(t)=\Delta_1/; \quad T_{гар.ф} = arg/\alpha_2(t)=\Delta_2/,$$

where $\alpha_{1,2}(t)=\psi[m(t),\ \sigma(t),\ u_p]$ are the quantile functions; $m(t)$, $\sigma(t)$, are the functions of mathematical expectation and mean-square deviation of the parameter; u_p is the standard distribution quantile determined by the confidence probability P.

As a result of research into parameters' drifts of electronic measuring apparatus as well as that for diverse purposes a mathematical model for the time-dependent mathematical expectation in quasi-determinate processes has been developed in the form of an exponentially increasing and decreasing function with the power adaptation coefficient k_1. The time-dependent mean-square deviation of a drift fluctuation component is adequately modeled by a linear function with the angle adaptation coefficient k_2. For a descending process, $T_{гар.у}$ and $T_{гар.ф}$ are determined by using the following dependencies:

(7) $$m(t)=m_0 exp(-k_1 t)= \Delta_1$$

(8) $$\sigma(t)= \sigma_0 + k_2 t$$

(9) $$\alpha_1(t)= m_0 exp(-k_1 t)-u_p(\sigma_0 + k_2 t)=\Delta_1$$

From the first equation we obtain

(10) $$T_{гар.у} = \ln\left(\frac{m_0}{\Delta_1}\right)^{\frac{1}{k_1}}$$

The second equation is transcendental with respect to t, thus one can use the series decomposition of the exponent exp($-\kappa_1$t) to determine $T_{гар.ф}$:

(11) $$\exp(-k_1 t) = 1\text{-}k_1 t + \frac{(k_1 t)^2}{2!} - \frac{(k_1 t)^3}{2!} + \cdots$$

This series is convergent. To model the quasi-determinate processes one can confine oneself to necessary number of the series terms in accordance with the required approximation accuracy.

For the linear case of a descending process, the equation (9) gets the following form:

(12) $$\alpha_1(t) \approx m_0(1-k_1 t)=u_p(\sigma_0 + k_2 t)=\Delta_1$$

from which we obtain

(13) $$T_{гар.ф} \approx \frac{m_0 - \Delta_1 - u_p \sigma_0}{m_0 k_1 + u_p k_2}$$

The error of guarantee faultless operation period determination for the descending process is determined by the given formula:

(14) $$\Delta T_{гар} \approx \ln\left(\frac{m_0}{\Delta_1}\right)^{\frac{1}{k_1}} - \frac{m_0 - \Delta_1 - u_p \sigma_0}{m_0 k_1 + u_p k_2}$$

For linear approximation of an ascending process:

(15) $$m(t)=m_0 [1-exp(-k_1 t)]= \Delta_1$$

(16) $$\sigma(t)= \sigma_0 + k_2 t$$

(17) $$\alpha 1(t)= m0k1t+up(\sigma 0+ k2t)=\Delta 2$$

The error $\Delta T_{гар}$ for the ascending process:

(18) $$\Delta T_{гар} \approx \ln\left(\frac{m_0}{m_0 - \Delta_2}\right)^{\frac{1}{k_1}} - \frac{\Delta_2 - u_p \sigma_0}{u_p k_2 + m_0 k_1}$$

In case of square approximation of ascending and descending exponents the following approximation formula is utilized:

(19) $$e^{-\kappa_1 t} \approx 1\text{-}k_1 t + \frac{(k_1 t)^2}{2!}$$

The error of guarantee faultless operation period determination for a descending process:

(20) $$\Delta T_{гар} \approx \ln\left(\frac{m_0}{\Delta_1}\right)^{\frac{1}{k_1}} - \frac{m_0 k_1 + u_p k_2}{m_0 k_1^2} - \frac{\sqrt{(m_0 k_1 + u_p k_2)^2 - 2 m_0 k_1^2 (m_0 + u_p \sigma_0 - \Delta_1)}}{m_0 k_1^2}$$

For an ascending process:

(21) $$\Delta T_{гар} \approx \ln\left(\frac{m_0}{m_0 - \Delta_2}\right)^{\frac{1}{k_1}} - \frac{m_0 k_1 - u_p k_2}{m_0 k_1^2} - \frac{\sqrt{(m_0 k_1 - u_p k_2)^2 - 2 m_0 k_1^2 (\Delta_2 + u_p \sigma_0)}}{m_0 k_1^2}$$

In case of cubic approximation of ascending and descending exponents the following approximation formula is utilized:

(22) $$e^{-k_1 t} \approx 1\text{-}k_1 t + \frac{(k_1 t)^2}{2!} - \frac{(k_1 t)^3}{3!}$$

Thus the error of guarantee faultless operation period determination for a descending process:

(23) $$\Delta T_{гар} \approx \ln\left(\frac{m_0}{\Delta_1}\right)^{\frac{1}{k_1}} - t_1$$

where t_1 is determined by means of the following expression:

(24) $$\alpha_1(t) = m_0\left[1 - k_1 t + \frac{(k_1 t)^2}{2!} - \frac{(k_1 t)^3}{3!}\right] - u_p \sigma_0 - u_p k_2 t$$

and is equal to the root of such equation:

(25) $$t_1 = root[\alpha_1(t) = \Delta_1]$$

For case of an ascending process:

(26) $$\Delta T_{гар} \approx \ln\left(\frac{m_0}{m_0 - \Delta_2}\right)^{\frac{1}{k_1}} - t_1$$

(27) $$t_1 = root[\alpha_2(t) = \Delta_2] \ ,$$

(28) $$\alpha_2(t) = m_0\left[k_1 t - \frac{(k_1 t)^2}{2!} + \frac{(k_1 t)^3}{3!}\right] + u_p \sigma_0 + u_p k_2 t$$

Experimental results

An exponential model of parameter drift process and its linear, square, and cubic approximations are shown in Fig. 2 for comparison.

One can see that, if one considers a short period of time, the approximation error is relatively small for the highest power of the approximating function and it is relatively large if one considers a long period of time. For our forecasting we have used a short period.

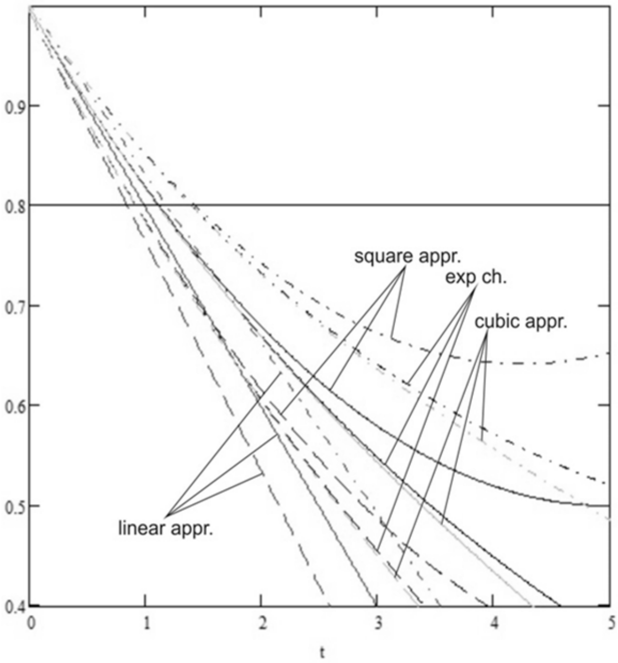

Fig. 2. Exponential model of a descending parameter drift process and its linear, square, and cubic approximations

Fig. 3 depicts the dependencies of guarantee faultless operation time error on the parameters of monotonic and fluctuating components of apparatus parameters' drifts for linear approximations.

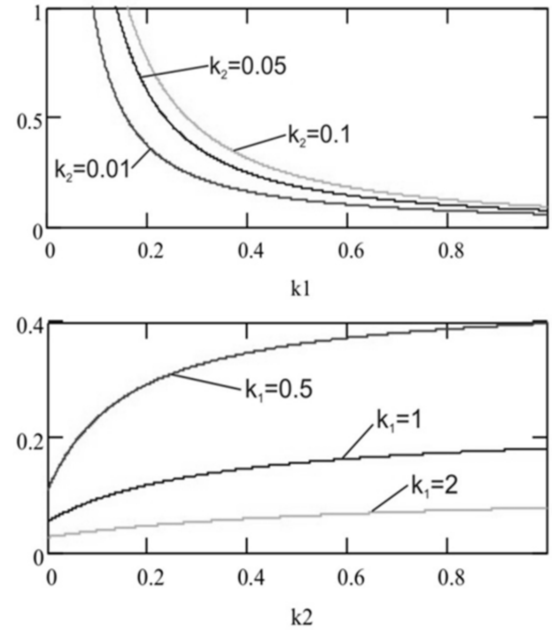

Fig.3. Dependencies of guarantee faultless operation time error (ΔT_{eap}) on the coefficients k_1 and k_2 in the case of linear approximation of descending parameters drift processes

Fig. 4 depicts the dependencies of guaranteed faultless operation time error on the parameters of monotonic and fluctuating components of apparatus parameters' drifts for cubic approximations.

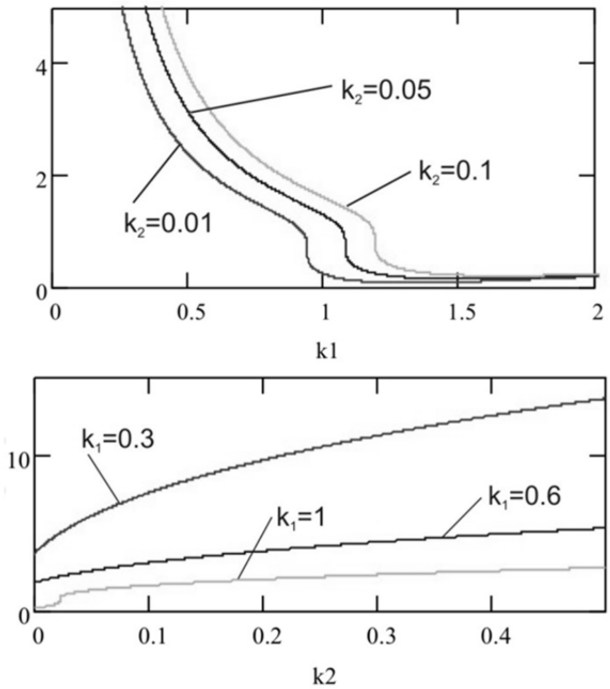

Fig.3. Dependencies of guarantee faultless operation time error (ΔT_{eap}) on the coefficients k_1 and k_2 in the case of cubic approximation of descending parameters drift processes

The obtained dependencies show a relation between the reliability of apparatus parameters, initial parameter values, and regularity of their change in the course of the apparatus operation [3].

Conclusions

The prediction of parameters' reliability of long-term service radioelectronic apparatus by using the methods of quantile zones makes it possible to take into consideration the real non-stationarity of fluctuating components of a parameter drift. Neglecting the fluctuating components or making unreasonable assumptions concerning their amplitude or stationarity can result in considerable forecast errors. The developed technique for quantitative assessment of guarantee faultless operation time of electronic equipment is designed for analyzing the equipment and choosing its rational variant.

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