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Determination of the Probability of Tracking Trace in Following Systems

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ABSTRACT: In the article it is stated that using the measurement results "clogged" by noise of linear combinations of object state variables, their estimates can be obtained by applying a filter consisting of a "model" of the source system and a feedback signal proportional to the difference between the actual measurement and its estimate. In this case, the law of optimal control is the result of minimizing the ensemble averaged quadratic functional of the system's quality. Synthesized system has property that in the absence of other perturbations and noise of observations, the constant disturbance is always compensated in such a way that the error of regulation or tracking in the steady state is zero, which is achieved due to the integrating action of the proportional-integral-differential controller.

KEYWORDS:Tracking systems in complex noise - signal conditions, discriminative characteristics, deterministic function, probability of disruption of tracking, proportional-integral-differential controller.

I. INTRODUCTION

Before analyzing the functioning of multidimensional tracking systems in complex interference - signal conditions, the assessment of control quality, in terms of the tracking failure probability, which means breaking down the tracking process in at least one of the control loops, meaning the output of the tracking error ε_i beyond some limits, is of some interest γ_{1i} and γ_{2i}; the region of permissible values of the aperture d_i, after which the probability of returning to this region is zero.

II. STATEMENT OF A PROBLEM

Let us turn to a method based on the theory of emissions of random processes for determining the failure probability of tracking in multidimensional tracking systems, in which there are linear cross-linkless connections between separate control loops [1], [2]. The problem is solved for the case of linearity of the discriminatory characteristic within the aperture. In fig. 1 shows a block diagram of a separate channel of the tracking system, in which a linear inertial link with a transfer function $K_i(p)$ and an inertial link, which consists of a nonlinear element (discriminator) with a characteristic $F_i(\varepsilon_i)$ and a linear element with a transfer coefficient (distinguished) R_i. It is assumed that the system is in a steady state. The degree of connection between the *i*-th and *j*-th contours are characterized by coefficients R_{ij} and R_{ji}. The job signals are deterministic functions of time $z_i(t)$. Interference ξ_i are normal random processes with known spectral densities of $S_i(\omega)$ and zero averages.

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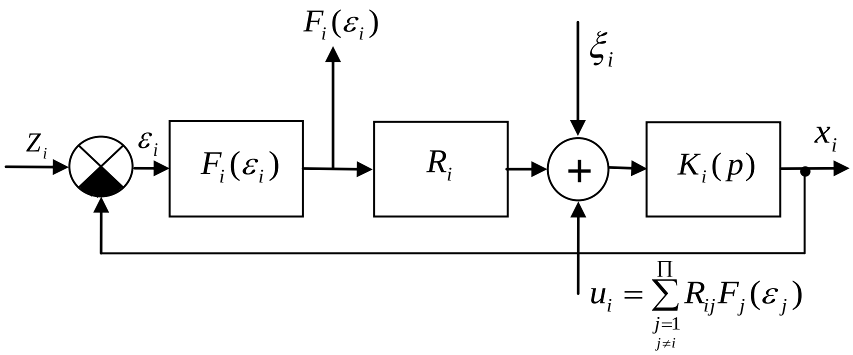

Fig. 1. Block diagram of the *i*-th channel of tracking system

In fig. 2 shows the characteristics of the *i*-th discriminator $F_i(\varepsilon_i)$ under the assumption that with $\gamma_{1i} \le \varepsilon_i \le \gamma_{2i}$ the characteristics of $F_i(\varepsilon_i)$ are linear, and outside the apertures - zero.

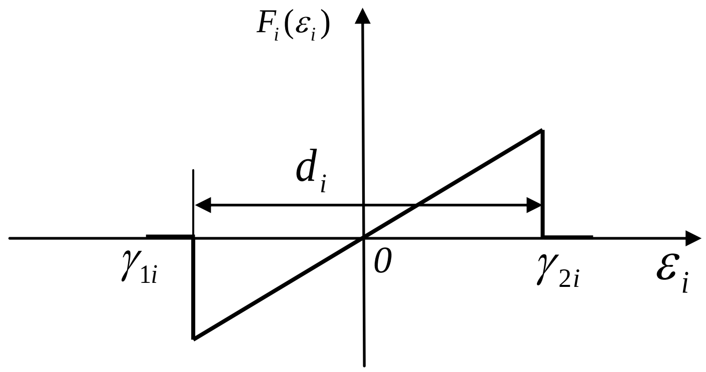

Fig. 2. Type of characteristics of the *i*-th discriminator $F_i(\varepsilon_i)$

We introduce the following notation for the error vector **E** in the system and the vector of the lower $\mathbf{G}_1$ and upper $\mathbf{G}_2$ boundaries of the region of allowable values for the components of the vector **E**:

$$\mathbf{E} = \begin{pmatrix} \varepsilon_1 \\ \vdots \\ \varepsilon_i \\ \vdots \\ \varepsilon_n \end{pmatrix}, G_1 = \begin{pmatrix} \gamma_{11} \\ \vdots \\ \gamma_{1i} \\ \vdots \\ \gamma_n \end{pmatrix}, G_2 = \begin{pmatrix} \gamma_{21} \\ \vdots \\ \gamma_{2i} \\ \vdots \\ \gamma_{2n} \end{pmatrix}.$$

Disruption tracking is considered as an overshoot of at least one of the components ε_i of the vector **E** for any of the corresponding components γ_{1i} and γ_{2i} of the vectors $\mathbf{G}_1$ and $\mathbf{G}_2$. With a low probability of emissions, methods of the theory of emissions of random processes can be used to determine the probability of failure of tracking in the system [3]. For one-dimensional systems, this problem is solved in [4].

Spreading the results of the theory of emissions to the multidimensional case, we can say that the probability of failure of tracking p_c in the system during time $t_н$ will be equal to:

$$p_c = 1 - e^{-Nt}н, \tag{1}$$

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where N is the frequency of emissions of the vector **E** for the levels $\mathbf{G}_1$ and $\mathbf{G}_2$.
To find N, we turn to a random number ***P*** equal to the number of outliers of vector **E** beyond the vectors $\mathbf{G_1}$ and $\mathbf{G_2}$ on the interval T:

$$\Pi = \sum_{i=1}^{n} p_{1i} + \sum_{i=1}^{n} p_{2i} . \tag{2}$$

Here: p_{1i} and p_{2i} are random numbers equal to the number of emissions ε_i for γ_{1i} and γ_{2i}, respectively, on the interval T.
At the same time the emission frequency N of the vector **E** behind the vector $\mathbf{G}_1$ and $\mathbf{G}_2$ on the interval *T* is equal to the mathematical expectation of the number *P*, referred to the value *T*:

$$N = \frac{M(\Pi)}{T} = \sum_{i=1}^{n} \frac{M\{p_{1i}\}}{T} + \sum_{i=1}^{n} \frac{M\{p_{2i}\}}{T} = \sum_{i=1}^{n} (\nu_{1i} + \nu_{2i}), \tag{3}$$

where ν_{1i} and ν_{2i} are the emission frequencies of processes ε_i for levels γ_{1i} and γ_{2i}.
To find the emission frequencies ν_{1i} and ν_{2i} of process ε_i beyond the levels γ_{1i} and γ_{2i}, it is necessary to have steady-state values of the dynamic error in the control loop $m_{\varepsilon i}$ and the spectral density of the fluctuation component of error $S_{\varepsilon i}(\omega)$ [5]:

$$\nu_{ri} = \frac{\left[\int_{-\infty}^{+\infty} \omega^2 S_{\varepsilon i}(\omega) d\omega\right]^{1/2}}{2\pi \left[\int_{-\infty}^{+\infty} S_{\varepsilon i}(\omega) d\omega\right]^{1/2}} \exp\left[\frac{-\pi \gamma_{\text{э}ri}^2}{\int_{-\infty}^{+\infty} S_{\varepsilon i}(\omega) d\omega}\right]. \tag{4}$$

where $\gamma_{\text{э}ri}$ - the boundaries of the aperture d_i, taking into account the presence of the established component of the dynamic error $m_{\varepsilon i}$; for the linear case, $\gamma_{\text{э}ri} = \gamma_{ri} - m_{\varepsilon i}; r = 1, 2$.
Relations for $m_{\varepsilon i}$ and $S_{\varepsilon i}(\omega)$ can be obtained by traditional methods of the theory of automatic control based on the equation for the error vector **E** [6]:

$$\mathbf{E}=(\mathbf{I}+\mathbf{Y})^{-1}\mathbf{Z}-(\mathbf{I}+\mathbf{Y})^{-1}\mathbf{K}\Xi, \tag{5}$$

Here: ***I*** *is the identity matrix* $n \times n$; ***Z*** *is the column vector of the master signals* $z_i(t)$; ***Ξ*** *- vector column, disturbing influences* $\xi_i(t)$; ***K*** *- diagonal matrix* $n \times n$, *the elements of the main diagonal which is* $k_{ii} = K_i(p)$; ***Y*** *is the matrix* $n \times n$, *whose elements are* $y_{ij} = Y_{ij}(p)$;

$$Y_{ij}(p) = \begin{cases} F_j' R_{ij} K_i(p) & \text{at} \quad i \neq j, \\ F_i' R_i K_i(p) & \text{at} \quad i = j, \end{cases} \tag{6}$$

F_i' - the slope of the characteristic $F_i(\varepsilon_i)$ at $\varepsilon_i = 0$.
Having determined $m_{\varepsilon i}$ *and* $S_{\varepsilon i}(\omega)$, *we find* ν_{ri} *from relation (4). Knowing* ν_{ri}, *we find N and then* P_c.
Let us turn to the case of a two-dimensional tracking system for which

$$F_i(\varepsilon_i) = \varepsilon_i \exp\left[-b\varepsilon_i^2/2\right], \quad z_i(t) = z_{1i} t,$$
$$S_i(\omega) = N_0, \; K_i(p) = K_i / \left[p(pT_i + 1)\right].$$

The probability of failure of tracking, found by the above method under the assumption that $R_1 = R_2 = R, \;\; K_1 = K_2 = K, \;\; T_1 = T_2 = T, \;\; z_{11} = z_{12} = z_1$ *(which provides* $F_1' \approx F_2' = F'$ *) and* $R_{12} = -R_{21} = -R'$, *is determined by the expression*

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$$P_c = 1 - \exp\left[-t_{\text{н}} \sum_{s=1}^{2} \sum_{k=1}^{2} v_{sk} \right]. \quad (7)$$

In fig. 3 shows the dependence of the probability of stall tracking P_c from α at $t_{\text{н}} = 5c$, $T = 0{,}05$, $RK = 20$, $z_1 = 2c^{-1}$, $R = 1$, $b = 6$, calculated by the formula (7) (curve 1).

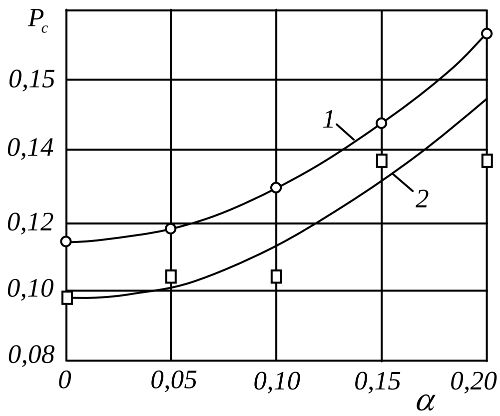

Fig. 3. Dependence P_c from α

The same figure also shows the dependence of P_c from P_c (curve 2), obtained by statistical testing by mathematical modeling of this system on a digital computer. Curves 1 and 2 are consistent. Approximate relationship between them

$$P_c^{(2)} = 0{,}86 P_c^{(1)}. \quad (8)$$

The considered method of determining the probability of stalling in multidimensional tracking systems is applicable also in the case when random processes ε_i have twice differentiable correlation functions.

III.CONCLUSION

Thus, a tracking system is constructed, with the property that in the absence of other disturbances and observation noise, the constant disturbance is always compensated so that the regulation or tracking error in the steady state was zero, which is achieved due to the integrating action of the proportional-integral-differential controller [7].

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