ON THE QUESTION OF INTRODUCING CONNECTIONS FOR DISTURBING ACTIONS IN AUTOMATIC CONTROL SYSTEMS

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Abstract

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ON THE QUESTION OF INTRODUCING CONNECTIONS FOR DISTURBING ACTIONS IN AUTOMATIC CONTROL SYSTEMS

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Automatic control systems in which additional control is introduced by including connections for the principal disturbing actions, the so-called combined-control systems, are becoming increasingly widespread because they possess higher quality indices than systems constructed on the principle of deviation.

V. S. Kulebakin was the first to point out ([1]) the possibility of implementing systems invariant with respect to a disturbance in the case where there are connections for this disturbance, and he developed the general conditions and principles for solving the problems of the theory of combined automatic control systems ([2,3]). Subsequent works by A. G. Ivakhnenko, L. V. Tsukernik, V. L. Inosov, and others, who practically implemented the general conditions given by V. S. Kulebakin, N. N. Luzin, and P. I. Kuznetsov, showed that connections for disturbances and their derivatives can be used for a sharp reduction of the steady-state and transient errors. In calculating the parameters of such connections it is useful to have a method that would make it possible, without large expenditures of time, to estimate the effectiveness of these connections. One such method is considered in the present work.

If both control and disturbing actions are applied to an automatic control system, then the differential equation describing the behavior of the system' s output coordinate can be written in the general form:

$$X(D)x = F(D)f(t) + G(D)g(t), \tag{1}$$

where x is the output coordinate; $f(t)$ is the control action; $g(t)$ is the disturbing action; $X(D)$, $F(D)$, $G(D)$ are certain operator polynomials depending on the system parameters. Here and below $D = d/dt$.

It is obvious that the operator polynomial $G(D)$ will characterize the influence of the disturbing action $g(t)$ on the control process. If the law of variation of the function $g(t)$ is known to us, then, as V. S. Kulebakin showed ([3]), in order that $G(D)g(t) \equiv 0$, i.e., that the system be invariant with respect to the disturbing

Fig. 1

Figure 1: Fig. 1

action $g(t)$, it is necessary that the operator $G(D)$ contain as a factor $K(D)$, the image of the function $g(t)$, i.e.,

$$G(D)g(t) = A(D)K_g(D)g(t) \equiv 0, \tag{2}$$

since $K_g(D)g(t) \equiv 0$.

Thus, with a known law of variation of the disturbing action, it is in principle possible to select such a structure and such parameters of the system under which condition (2) will be satisfied.

If we are not able to determine or predict in advance the laws of variation of the disturbing actions, and have only the most general notions about the character of the disturbing actions and the operating conditions of the automatic control system, then the invariance principle can be applied, or the practical solution of the problem of reducing the influence of the disturbing action on the control process can be carried out as follows.

Suppose that the controlling action $f(t)$ remains unchanged; then the behavior of the output coordinate x will depend on the action $g(t)$, i.e.

$$X(D)x_g = G(D)g(t) + C, \tag{3}$$

where $C = F(D)f(t) = \text{const}$.

Fig. 1

Let us construct the Mikhailov curves for the differentiation operators of the left- and right-hand sides of equation (3), $X(j\omega)$ and $G(j\omega)$ (see Fig. 1), in one coordinate system; then, as we have shown earlier ([4]), directly from the drawing one can find the characteristics with respect to the disturbing action $g(t)$: the amplitude $A_g(\omega_i)$, the phase $\varphi_g(\omega_i)$, the real frequency response $P_g(\omega_i)$, and the imaginary frequency response $Q_g(\omega_i)$:

$$A_g(\omega_i) = \frac{R_g(\omega_i)}{r(\omega_i)},$$

$$\varphi_g(\omega_i) = \beta_g(\omega_i) - \alpha(\omega_i), \tag{4}$$

$$P_g(\omega_i) = \frac{\rho(\omega_i)}{r(\omega_i)}, \qquad Q_g(\omega_i) = \frac{\delta(\omega_i)}{r(\omega_i)}, \qquad 0 < \omega_i < \infty;$$

here $\rho(\omega_i) = R_g(\omega_i)\cos\varphi(\omega_i)$; $\delta(\omega_i) = R_g(\omega_i)\sin\varphi(\omega_i)$.

Obviously, if for ideal reproduction of the controlling action $f(t)$ it is necessary that

$$A_f(\omega_i) = \frac{R_f(\omega_i)}{r(\omega_i)} = \text{const}, \qquad \varphi_f(\omega_i) = \beta_f(\omega_i) - \alpha(\omega_i) = 0, \qquad 0 < \omega_i < \infty, \tag{5}$$

then, in order that the system not react to the disturbing action $g(t)$, it is necessary that

$$A_g(\omega_i) = \frac{R_g(\omega_i)}{r(\omega_i)} \to 0, \qquad 0 < \omega_i < \infty. \tag{6}$$

The phase characteristic $\varphi_g(\omega_i)$ is of importance only in certain specific cases.

Condition (6) can be fulfilled only if $R_g(\omega_i) \to 0$, $0 < \omega_i < \infty$, i.e. the curve $G(j\omega)$ must "contract" toward the origin of coordinates.

If we introduce into the system a link with respect to the disturbing action $g(t)$, described by a differential equation of the form

$$Z_g(D)\varepsilon = H_g(D)g(t), \tag{7}$$

and the output quantity ε is fed to the input of the system, then differential equation (1) is brought to the form

$$X(D)Z_g(D)x = F(D)Z_g(D)f(t) + G(D)Z_g(D)g(t) - H_g(D)g(t). \tag{8}$$

It should be noted that such an introduction of a disturbance connection does not introduce any changes into the process of reproducing the control action $f(t)$ and does not impair the stability of the system, since the operator polynomials appearing on the left- and right-hand sides of equation (1) are multiplied by one and the same operator polynomial $Z_g(D)$.

Denoting

$$X(L)Z_g(D) = X_k(D), \qquad F(D)Z_g(D) = F_k(D), \qquad G(D)Z_g(D) = G_k(D), \tag{9}$$

we write equation (8) in the form

$$X_k(D)x = F_k(L)f(t) + [G_k(D) - H_g(D)]g(t) = F_k(D)f(t) + Y_k(D)g(t). \tag{10}$$

Fig. 2

Figure 2: Fig. 2

Having plotted the Mikhailov curves $X_k(j\omega)$ and $Y_k(j\omega)$ in one coordinate system (see Fig. 2), and having found

$$A_{kg} = \frac{R_{gk}(\omega_i)}{r_k(\omega_i)}$$

and compared it with $A_g(\omega_i)$, it is easy to see what effect we have achieved by introducing the connection described by equation (7). Sometimes there is even no need to construct the frequency characteristics, since the relative position of the Mikhailov curves before introducing the connection with respect to the disturbing action and after introducing this connection indicates quite clearly whether we have obtained a significant effect or not.

Fig. 2

It is necessary to dwell on one more important question.

In order to deform the Mikhailov curve $Y_k(j\omega)$ over the entire frequency range $0 < \omega_i < \infty$, while making $R_{gk}(\omega_i) \to 0,\ 0 < \omega_i < \infty$, it is necessary that the order of the operator polynomial $H_g(D)$ be the same as that of $G_k(L)$, and this is practically difficult to realize.

In order not to complicate the structure of the connection with respect to the disturbing action, it is practically sufficient to deform the curve $Y_k(j\omega)$ in the region of essential frequencies, determining it, for example, by the same method as V. V. Solodovnikov uses in assessing the dynamic properties of automatic-control systems with the aid of real frequency characteristics. The real frequency characteristic $P_{gk}(\omega_i)$ is easily constructed from the curves $X_k(j\omega)$ and $Y_k(j\omega)$ by the method described by us[4].

Thus, when choosing the structure and parameters of the connections with respect to disturbing actions, one should strive to have the deformed Mikhailov curves $Y_k(j\omega)$ pass as close as possible to the origin in the region of essential frequencies. To make an automatic-control system insensitive to a disturbing action over the range of all frequencies $0 < \omega_i < \infty$ by means of comparatively simple connections having linear characteristics is practically impossible. However, this is often not necessary, since the higher harmonics of the disturbing-action signal are usually small in amplitude. In those cases where it is nevertheless necessary to widen the frequency region in which the required deformation of the curve $Y_k(j\omega)$ takes place, without introducing excessive complication into the structure of the connection with respect to the disturbing action, nonlinear elements should be used.

In the case where not one but several disturbing actions act on the automatic-control system, i.e., the differential equation describing the behavior of the system has the form

$$x(D)x = F(D)f(t) + G_1(D)g_1(t) + G_2(D)g_2(t) + ... + G_n(D)g_n(t), \qquad (11)$$

then, after plotting the Mikhailov curves $X(j\omega), G_1(j\omega), G_2(j\omega), \dots, G_n(j\omega)$ in one sense, one can, by constructing the Mikhailov curves $X(j\omega), G_1(j\omega), G_2(j\omega), \dots, G_n(j\omega)$ in one–

coordinate system, to evaluate the influence on the regulation process of each disturbing action, and to select the most significant of them in order to introduce connections that reduce their effectiveness.

Sometimes the introduction of a connection with respect to a disturbance becomes practically difficult to carry out because of the absence of the appropriate apparatus; in this case the role of a connection with respect to the disturbance can often be performed by a connection with respect to an action most closely related to the main disturbance (for example, with respect to the current in the armature circuit of an electric motor when the resisting torque on its shaft changes). By the proposed method one can assess how well such a connection meets the stated task of reducing the effectiveness of the action of the disturbance on the regulation process.

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Note: Figure translations are in progress. See original paper for figures.