ON THE QUESTION OF CONSTRUCTING INVARIANT INFORMATION AND MEASURING DEVICES

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Abstract

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The construction of the devices described is based on one of the principles for implementing invariant systems—the principle of two-channel operation ([1,2]). A class of measuring systems is considered that can be represented by the following block diagram, Fig. 1. $K_{y1}(s, g, F_1)$, $K_{z1}(s, F_2)$, $K_{y2}(s, g, F_1)$, $K_{z2}(s, F_2)$ are the transfer functions of the corresponding elements indicated in the diagram, with parameters depending on the actions $g(t)$, $F_1(t)$, $F_2(t)$: $g(t)$ is the information to be measured (useful information); $F_1(t)$, $F_2(t)$ are disturbances, bounded in modulus, acting symmetrically on both channels of the system; $y(t)$ is the signal probing the state of the system; $z(t)$ is the output coordinate of the measuring system, containing information about the action $g(t)$, whose invariance with respect to the disturbances $F_1(t)$ and $F_2(t)$ must be ensured.

Absolute invariance of the output coordinate $z(t)$ with respect to the actions $F_1(t)$ and $F_2(t)$ takes place when the following conditions are satisfied:

$$K_{y1}(s, g, F_1)K_{z1}(s, F_2) \equiv K_{y2}(s, g, F_1)K_z(s, F_2) \quad \text{for the action } F_1; \qquad (1)$$

$$K_{z1}(s, F_2) \equiv K_{z2}(s, F_2) \quad \text{for the action } F_2. \qquad (2)$$

In the presence of nonlinear elements in the measuring system, the condition of absolute invariance is the identity of the characteristics of the corresponding pairs of nonlinear elements composing the system, K_{y1}, K_{y2} and K_{z1}, K_{z2}, which ensures the "dynamic symmetry" of the channels ([2]).

In real measuring devices, the elements of the block diagram in Fig. 1 correspond to two main functional links—a sensor (K_{y1}, K_{y2}) for transforming the measured quantity into an output coordinate convenient for measurement, and an amplifying-converting cascade (K_{z1}, K_{z2}) for amplifying and shaping the signals from the sensor.

In constructing two-channel invariant measuring devices, fulfillment of condition (2) presents no difficulty, since it is always possible to construct, with sufficient

Fig. 1. Block diagram of a two-channel invariant measuring device

Figure 1: Fig. 1. Block diagram of a two-channel invariant measuring device

Fig. 2. Block diagram of a discrete invariant level meter

Figure 2: Fig. 2. Block diagram of a discrete invariant level meter

accuracy, two analogous amplifying-converting cascades and to ensure symmetry of the action upon them of destabilizing factors (changes in temperature, supply voltages, etc.). As for condition (1), its exact realization leads to loss of information about the parameter being measured, since, with complete analogy of both channels and equal action of the measured parameter $g(t)$ on both channels, the system output is completely invariant to any changes in the useful signal. Therefore a necessary condition for constructing systems described by the block diagram of Fig. 1 is the presence of asymmetry either in the sensor channels K_{y1} and K_{y2}, or in the action of the measured parameter upon them. Usually the first condition is technically simpler to realize. Let us write the asymmetry condition of the sensor channels in the form

$$K_{y1}(s, g, F_1) = K_{y2}(s, g, F_1) + \Delta K_y(s, g, F_1). \quad (3)$$

The fulfillment of certain requirements imposed on the magnitude of the asymmetry $\Delta K_y(s, g, F_1)$ with respect to each of the actions $g(t)$ and $F_1(t)$ ensures invariance of the output coordinate $z(t)$ with respect to the action-

of the perturbation F_1 with accuracy up to ε, while preserving information about the measured parameter. The problem of synthesizing such devices in general reduces to determining the magnitude ΔKy, for which, for given perturbations F_1, invariance is ensured to any preassigned degree of accuracy ε. Depending on the magnitude of the channel asymmetry for amplitude-limited perturbing actions, one can construct practically absolutely invariant or quasi-invariant information and measuring systems. Here absolute invariance is understood as the independence of the coordinate $z(t)$ from the magnitude of the perturbing action, with accuracy up to the dead zone of the device.

Fig. 1. Block diagram of a two-channel invariant measuring device

Fig. 2. Block diagram of a discrete invariant level meter

The measurement accuracy of such systems remains constant both in the absence of interference and at its maximum values. In quasi-invariant measuring systems, a certain dependence is observed between the coordinate $z(t)$ and the perturbation $F_1(t)$, and the changes in $z(t)$ can always be limited by the value ε, chosen within the limits of the permissible measurement error.

The principles set forth can be used as the basis for constructing various kinds of continuous and discrete measuring and information systems, for example

Fig. 3. Output (frequency) characteristics of the sensors of a discrete level-measurement absolutely invariant level meter (a) and quasi-invariant level meter (b)

Figure 3: Fig. 3. Output (frequency) characteristics of the sensors of a discrete level-measurement absolutely invariant level meter (a) and quasi-invariant level meter (b)

for monitoring the level of media in vessels, mechanical linear and angular displacements, etc. An example of the implementation of an invariant two-channel measuring system is provided by discrete level meters (indicators) for liquid and bulk media, developed at the Institute of Automation and Telemechanics ([3,4]).

Fig. 3. Output (frequency) characteristics of the sensors of a discrete level-measurement absolutely invariant level meter (*a*) and quasi-invariant level meter (*b*)

Sensor 1 of the level meter in Fig. 2, both channels of which are made on sections of an inhomogeneous long line, is an oscillatory resonant system. Each channel of the sensor, depending on the position of the level of the medium being measured, is characterized by resonant frequency characteristics, the aggregate of which determines the frequency or output characteristic of the sensor. Figure 3 shows the output characteristics of two types of level sensors—absolutely invariant (*a*) and quasi-invariant (*b*). Sections with an increased gradient of frequency variation are caused by the introduction of inhomogeneities into the sensor channels in accordance with the specified number and coordinates of the specified points of level measurement. The inhomogeneities are inclusions in the line of elements of capacitive, inductive, or mixed character (depending on the kind

of the measured medium—dielectric or conducting). The type of sensor—invariant or quasi-invariant—with the other channel parameters being equal, is determined by the manner in which the inhomogeneities (sensitive elements) are arranged.

The selected discrete values of the level in the invariant (a) and quasi-invariant (b) sensor are determined at the instant when the resonant frequencies of both channels of the sensor coincide. The secondary instrument also has a two-channel structure. A frequency-modulated voltage from generator 2, with a deviation covering the frequency range of the sensor, serves as the interrogation signal $y(t)$. When the resonant frequencies of the sensor channels coincide with the frequency of the high-frequency generator, signals are separated at the loads of detectors 3; these signals reproduce the shape of the resonance curve of the corresponding sections of the inhomogeneous long line.

To eliminate amplitude errors and increase the accuracy of level fixation, short pulses of strictly determined level and duration, tied to the instant of resonance, are formed from the signals from the sensor channels (blocks 4). The formed pulses are fed to comparison block 5. At the instants when the resonant frequencies of both sections of the long lines, corresponding to the intersection points of the output characteristics, coincide, the signals from the shaping circuits coincide, and signals $z(t)$, characterizing the instants at which the liquid mirror passes the prescribed discrete levels, are taken from the output of the instrument.

When condition (2) is satisfied, the principal disturbances exerting a destabilizing effect on the output coordinate $z(t)$ of the measuring system under consideration are the disturbances F_1 acting on the sensor. These include, above all, changes in the electromagnetic parameters of the liquid and gaseous media—the dielectric and magnetic permeabilities $\varepsilon_{2,1}$ and $\mu_{2,1}$, temperature, and pressure. The indicated influences lead mainly to changes in the electrical parameters of the line sections of the sensor, which determine their resonant properties. Since both channels of the invariant sensor (Fig. 3a) are made analogously with respect to the arrangement of the inhomogeneities and are under identical conditions, the effect of the destabilizing factors F_1 will synchronously shift the output characteristics of the sensors without disturbing their mutual position and, consequently, without impairing the accuracy of level fixation (for amplitude-limited disturbances). The measurement error remains constant and does not exceed the magnitude of the dead zone.

With asymmetry of the channels of a quasi-invariant sensor (Fig. 3b), this causes a relative deformation of their frequency characteristics and a shift of the intersection points of the characteristics within the frequency steps, leading to an error in measuring the level ΔH, which depends on the magnitude of the disturbance.

The synthesis of an instrument based on determining the time position of the extreme value of the output signals from the sensor channels, from the standpoint of ensuring the required measurement accuracy, reduces to the formation not of the transfer functions K_{y1} and K_{y2} of the sensor channels, but of their output (frequency) characteristics, since for selective systems, which are sections of long lines, the instant of resonance and the extremum of the transfer function of the sensor channels coincide. The output characteristics of the sensor channels can be calculated on the basis of the expression

$$f_\xi = v \Bigg/ \left(2\pi \sqrt{ vC_{\text{in}} \left(\sum_{q=1}^{n+1} w_q h_q + vL \right) + v \sum_{q=1}^{n} w_q h_q \sum_{p=q}^{n} \varepsilon_p C_p + A } \right), \quad (4)$$

where

$$A = v^2 L \sum_{p=1}^{n} \varepsilon_p C_p + \sum_{q=1}^{n} w_q h_q \sum_{i=q+1}^{n+1} \frac{\varepsilon_i h_i}{w_i} + vL \sum_{q=1}^{n+1} \frac{\varepsilon_q h_q}{w_q},$$

when the following conditions are satisfied:

1) for $H = h_1 + ... + h_\xi + l_1 + ... + l_{\xi-1}$

$$\varepsilon_p = \varepsilon_2 \text{ for } p \le \xi - 1, \qquad \varepsilon_q \text{ and } \varepsilon_i = \varepsilon_2 \text{ for } q \text{ and } i \le \xi,$$

$$\varepsilon_p = 1 \text{ for } p > \xi, \qquad \varepsilon_q \text{ and } \varepsilon_i = 1 \text{ for } q \text{ and } i > \xi,$$

2) for $H = h_1 + ... + h_\xi + l_1 + ... + l_\xi$

$$\varepsilon_p = \varepsilon_2 \text{ for } p \le \xi, \qquad \varepsilon_q \text{ and } \varepsilon_i = \varepsilon_2 \text{ for } q \text{ and } i \le \xi,$$

$$\varepsilon_p = 1 \text{ for } p > \xi, \qquad \varepsilon_q \text{ and } \varepsilon_i = 1 \text{ for } q \text{ and } i > \xi,$$

where f_ξ is the resonant frequency of the sensor channel corresponding to the position of the liquid surface at the level of the ξ-th sensing element; L is the inductance of the short-circuiting device of the sensor channel; C_{in} is the input capacitance of the sensor; h_q and w_q are the distance between the sensing elements of the q-th section of the sensor channel and its wave impedance; C_p is the capacitance of the p-th sensing element (inhomogeneity); v is the speed of light; ε_2 is the dielectric permittivity of the measured medium; l_ξ is the height of the ξ-th sensing element.

The synthesis of the invariant and quasi-invariant discrete level sensors under consideration consists in such a choice of the parameters of the sensor channels that, for all measurement points, the following conditions are satisfied:

$$K \le \Delta f / \delta f \le K + a \qquad \text{(for invariant sensors)},$$

$$K \le \Delta f / \delta f \le K + \varepsilon \qquad \text{(for quasi-invariant sensors)}$$

for $|F_1| \le M$, where δf is the magnitude of the section of the characteristic with an increased gradient of frequency change; Δf is the frequency displacement between the point of intersection and the beginning of the section of increased gradient of one of the channels; K is a quantity determined by the initial position of the point of intersection of the frequency characteristics in the absence of disturbances; a is a quantity determined by the dead zone of the recording instrument; ε is the relative magnitude of the measurement error; M is the maximum value of the disturbing action.

Experimental studies of invariant and quasi-invariant level meters have shown that the use of two-channel operation makes it possible to ensure invariance of the output coordinate not only with respect to deviations of the electromagnetic properties of the measured medium from the nominal values, but also with respect to changes in the nominal values themselves over wide ranges, as well as with respect to instability of the supply voltage, ambient temperature, and parameters of the high-frequency generator.

In conclusion, it should be noted that the construction of invariant information (measuring) systems using the principle of two-channel operation makes it possible to obtain high measurement accuracy, reduce the requirements on the stability of the units of these systems, and eliminate the influence on accuracy indices of disturbing actions, including those under which single-channel information systems practically lose their operability.

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