Structures of absolutely invariant measuring systems and conditions for their physical realizability

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Abstract. The synthesis method for creating invariant measuring transducers and systems is presented. The method is based on the principle of double channeling, which was proposed by academician Petrov B.N. The advantage of this method is that it allows compensating disturbing influences. The system is influenced by disturbing factors through two symmetrical channels. The efficiency of this method is illustrated by dual-channel Nesterov measuring bridge. Moreover, the entire class of dual-channel measuring transducers was designed based on this method. This class of dual-channel measuring transducers includes measuring bridges and voltage dividers. Dual-channel systems have significant advantages over their standard equivalents.

1. Introduction

The main ideas of creating absolutely invariant under external disturbing influences systems as well as the conditions of their physical realizability found their application in the theory of automatic control and regulation [1-6]. However, then some time publications on the connection between the invariant theory and the measurement theory appeared [7-14]. Over the years, this direction was developed further. This fact confirms the relevance of the topic. Unfortunately, it is impossible to provide links to all works in this area.

The principle of double channeling was formulated by academician B N Petrov. It turned out to be effective for solving the problem of compensating for disturbing influences, which affect measuring instruments [6]. Analysis of the approaches, used in the process of building measuring transducers, based on the principle of double channeling, allows considering such systems as systems to which methods of synthesis and analysis from information-measurement systems theory can be applied. The first articles about dual-channeling measuring transducer showed the basis of double channeling. The discovery of the double channeling principle had brought an end to the contents of the physical unrealizability of invariant systems and predetermined the further development of invariant theory [15]. More than 20 patents, which appeared later, allowed creating the entire class of dual-channel measuring transducers. The main ideas of structural [12-13] and analytical [14] method, based on the principle of double channeling, were developed. These method-forming features are given below. These criteria are necessary and sufficient conditions for the physical feasibility of the method.
2. Method-forming features of the structural method for the synthesis of invariant transducers

In conformity with the main ideas of the structural method [13], it is necessary to introduce the following methodological features for its physical implementation.

1. There should be two (or more) channels that are symmetric in relation to influencing factors $\zeta_j$ and asymmetric in relation to the measuring quantity $x$ in the structure of the transducer:

$$
Y_1 = \Psi_1\left\{f_1(x), \zeta_j\right\}, \\
\vdots \\
Y_n = \Psi_n\left\{f_n(x), \zeta_j\right\},
$$

where $Y_1, \ldots, Y_n$ are the measurement functions of the measurement channels; $f_1(x), \ldots, f_n(x)$ are functions that ensure the asymmetry of the arrival of the informative quantity $x$ at the inputs of the corresponding measurement channels.

2. The system must implement an algorithm that is obtained by solving the equation system (1):

$$
x = F(Y_1, \ldots, Y_n).
$$

3. The system must satisfy the following requirement:

$$
\Delta F = \sum_{i=1}^{n} \sum_{j=1}^{g} \frac{\partial F}{\partial Y_i} \frac{\partial Y_i}{\partial \zeta_j} \Delta \zeta_j = 0,
$$

where $F$ is the resulting measurement function of the invariant transducer; $Y_i$ are the measurement functions of the corresponding measurement channel; $\zeta_j$ is a quantity out of $g$ quantities, influencing the $i$ measurement channel; $\Delta \zeta_j$ is the deviation of the quantity $\zeta_j$ from its true value.

The simplest variant of the system, based on this method, is implemented in a dual-channel structure when $n = 2$.

![Figure 1](image1.png)

**Figure 1.** The dual-channel structure of the invariant system.

The structure, shown in figure 1, demonstrates the “symmetry” of channels in relation to the influencing factors $\zeta$. Their “asymmetry” in relation to the measured quantity $x$ is obvious. As it is shown in numerous technical solutions [18], the use of two measurement channels, formed using the principle of symmetry, can compensate for the effect of any factors that cause instability. It is of great importance since traditional parametric transducers require precious power sources. Any power instability can affect measurement accuracy [19].

To illustrate the operation of the method, we consider a specific example of its implementation that falls under the structure, which is shown in figure 1.

3. The structure of a dual-channel non-equilibrium Nesterov measuring bridge

The non-equilibrium measurement bridge circuit, which is shown in figure 2, fully corresponds to the dual-channel structure in figure 1. Other examples could be given. However, this is one of the first technical solutions, for which a patent was obtained for a method of constructing an invariant measuring circuit [17]. It also provides a visual comparison with the classic unbalanced Wheatstone bridge.
The feature of this device is the following. The voltage, which is proportional to the current difference in the primary transducers 1 and 2, is taken from the measuring diagonal of the bridge, which consists of transducers 1 ... 4. The voltage, which is proportional to the sum of the currents in the primary transducers 1 and 2, is taken from transducer 5, which is connected in series with the power supply 6.

The sum of the named currents $i_1$ and $i_2$ is ensured by the equality of the parameters of the transducers 3, 4 and 5: $z_3 = z_4 = z_5 = z$. In accordance with the first Kirchhoff’s law, we have the voltage: $z \cdot i = z \cdot (i_1 + i_2)$ on converter 5, where $i$ is the current in the power diagonal. Measuring amplifiers 7 and 8 have a high input resistance. They provide isolation of conversion channels from the primary transducer circuit.

Thus, both channels of the bridge are symmetrical in relation to the power source 6 and asymmetrical in relation to informative increments of the parameters of the primary transducers 1 and 2. This corresponds to the first methodological feature in accordance with conditions (1) and (2), expressed in the measurement functions of channels:

$$U_1 = \frac{(E - z_3 i)[(z_1 + \Delta z)z_4 - (z_2 - \Delta z)z_3]}{[(z_1 + \Delta z) + z_3][(z_2 - \Delta z) + z_4]},$$

$$U_2 = \frac{(E - z_3 i)z_3[(z_1 + \Delta z) + (z_2 - \Delta z) + z_3 + z_4]}{[(z_1 + \Delta z) + z_3][(z_2 - \Delta z) + z_4]},$$

where $\frac{(E - z_3 i)}{[(z_1 + \Delta z) + z_3][(z_2 - \Delta z) + z_4]}$ is the symmetrical component of the measurement functions of the measuring channels; $[(z_1 + \Delta z)z_4 - (z_2 - \Delta z)z_3]$ and $z_3[(z_1 + \Delta z) + (z_2 - \Delta z) + z_3 + z_4]$ are asymmetric components of the measurement functions of the measuring channels; $E$ is the electromotive force of the power source 6; $(z_1 + \Delta z)$ and $(z_2 - \Delta z)$ are values of parameters of primary transducers 1 and 2, $z_1, z_2$ are initial values, $\Delta z$ is their informative increment; $z_3, z_4, z_5$ are the parameters of the transducers 3, 4 and 5.

The signals $U_1 = k_1 U_{1*}$ and $U_2 = k_2 U_{2*}$ from the outputs of the measuring amplifiers 7 and 8 are fed to the inputs of the division device 9. At the output of device 9, we get the result:

$$F = \frac{U_{1*}}{U_{2*}} = \frac{k_1}{k_2} \frac{[(z_1 + \Delta z)z_4 - (z_2 - \Delta z)z_3]}{z_3[(z_1 + \Delta z) + (z_2 - \Delta z) + z_3 + z_4]},$$

where $k_1$ and $k_2$ are voltage transmission factors of measuring amplifiers 7 and 8.

This way the second feature (3) of the structural method is implemented.

Fulfillment of the conditions: $k_1 = k_2$, $z_1 = z_2 = z_0$, $z_3 = z_4 = z_5 = z$ allows to obtain the following resultant bridge measurement function:

$$F = \frac{U_{1*}}{U_{2*}} = \frac{\Delta z}{(z_0 + z)}.$$
In accordance with criterion (4) for the measurement function (8) the implementation of the third feature is obtained:

\[ \Delta F = \frac{\partial F}{\partial U_1} \frac{\partial U_1}{\partial E} \Delta E + \frac{\partial F}{\partial U_2} \frac{\partial U_2}{\partial E} \Delta E \equiv 0. \quad (9) \]

Criterion (9) does not equal zero. This confirms the absolute invariance of the obtained structure in relation to the instability of the EMF of the power source. In addition, from criterion (8), it is seen that the measurement function of this measuring circuit is linear. This can be explained by the fact that the nonlinear component of the prototype measurement function was included as a symmetric component in the measurement function of the synthesized measuring channels and thus was compensated. An additional feature of the presented method is the ability to linearize the measurement functions of parametric measuring transducers. This is true for the entire class of parametric measuring transducers as a part of non-equilibrium measuring bridges and voltage dividers [18].

4. Conclusion

Thus, the principle of double channeling, which is realized in the structure of the measuring instrument, is effective. It allows creating new measuring transducers and systems. These systems have significant advantages over prototypes [19, 20]. Their accuracy of measurements is high when the system is not under normal conditions and their accuracy of measurements is acceptable when the nature of disturbing influences is unknown.

The distinctive feature of the considered method is that it allows compensating for disturbing influences, which affect both measuring channels. In the theoretical section of the article, this feature is formulated as “symmetry” of measuring channels in relation to influencing factors.

The importance of this method for theoretical and practical application is confirmed by the fact that the new class of measuring transducers was designed on its basis. This class created a new section of measuring technology.

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