INVESTIGATION OF A MEASURING SYSTEM WITH AUTOMATIC CALIBRATION

V. M. Ordyntsev

For automatic correction of measuring system's static errors it is advisable to use the so-called system with automatic calibration. Figure 1a shows a simplified schematic of the measuring system with automatic calibration.

The system comprises the switch S used for connecting to the succeeding elements the primary transducers with the output signals $s_i$, which it is required to measure, and the sources of the reference signals $s_{jk}$, whose values are known.

From the switch the signals $s_i$ and $s_{jk}$ are fed to the input of the system's analog converter (AC), which comprises a device for amplifying and converting the measured signals. The actual AC static characteristic can be nonlinear and unstable. The signals $s_i$ and $s_{jk}$ correspond at the AC output to the signals $K_i$ and $K_{jk}$. The signals $s_{jk}$ and $K_{jk}$ ($j = 1, 2, \ldots, m$) are used by the special computer SC for calculating the digital nonlinear simulator DNS coefficients $a_0, a_1, \ldots, a_n$ values for which the simulator is provided with an exactly inverse characteristic to that of the analog converter. Thus, when the next signal $s_i$ is connected by the switch, the signal $K_i$ is fed to the DNS and converted in it into the signal $s_{ip}$ which corresponds to the actual value of the measured signals $s_i$. The measurement results are recorded on the printer P.

Automatic calibration can be easily accomplished in a measuring system with a digital computer DC. At present digital computers are used in many measuring systems for processing measurement results. In this case the SC and DNS action algorithms are incorporated in the DC program which determines the inverse AC characteristic's equation used for evaluating $s_{ip}$ from $K_i$. Such a measuring system is shown in Fig. 1b [1].

A system with automatic calibration can be represented as two series-connected stages (Fig. 1c), with the first one having the static AC characteristic

$$K_i = f (s_i),$$

and a second the inverse AC characteristic

$$s_{pi} = f^{-1} (K_i).$$

If certain conditions which are examined below are met, the system's general characteristic will be linear and its conversion coefficient equal to unity, i.e.,

$$s_{pi} = f^{-1} [f (s_i)]$$

is converted to the form

$$s_{pi} = s_i.$$

The effect of such a system's operation is illustrated in Fig. 2. Here the system's nonlinear and nonstable static characteristic is shown at two instants $t_1$ and $t_2$ in the coordinated $K_i-s_i$.  

Translated from Izmeritel'naya Tekhnika, No. 4, pp. 25-27, April, 1974.
The system's inverse characteristics found by means of the reference signals are shown at the same instants in the coordinates \( \varepsilon_{pi} - K_i \).

The measuring system's resulting static characteristic and the inverse characteristic of the stage connected in series with the system are shown in the coordinates \( \varepsilon_{pi} - \varepsilon_i \). It will be seen from Fig. 2 that \( \varepsilon_{pi} = \varepsilon_i \) for both instants, i.e., despite the variations of the characteristic, the measurement result \( \varepsilon_{pi} \) remains the same.

In order to determine the particular feature of nonlinearities which limit the application of this method for correcting errors, let us examine a nominal characteristic \( K_i = f(s_i) \), which has the shape of a curve consisting of different segments (first quadrant of Fig. 3). The corresponding inverse characteristic \( \varepsilon_{pi} = f^{-1}(K_i) \) is shown in the second quadrant, and the system's resulting characteristic in the third quadrant.

It will be seen that monotonic nonlinear \((O-a)\), linear \((b-c \text{ and } d-e)\), and even vertical \((c-d)\) segments are permissible. However, the presence of horizontal segments \((a-b)\) and segments with extremums \((e-f)\) are not permissible, since such segments correspond to the complete characteristic to zones of indeterminacy (shaded).

In the course of calibration (when reference signals are fed) the measuring system's static characteristic continues to change, thus producing the residual error \( \delta_n \).

In order to evaluate the maximum value of this error let us make the following assumptions:

The characteristic's variation consists of a parallel displacement with the velocity \( v \) and a rotation with the slope-angle tangent variation speed \( \omega \). Let \( v \) and \( \omega \) be equal to small values of the corresponding velocities in the actual system;

The linearity of the static characteristic is preserved. Then its equation can be written in the form

\[
K_i = C_{00} + v (r - 1) \Delta t + [C_{10} + (r - 1) \omega \Delta t] \varepsilon_i,
\]

where \( C_{00} \) and \( C_{10} \) are the values of the coefficients for the zero and first powers of \( \varepsilon_i \) at the instant of the first signal's measurement \( \varepsilon_i = \varepsilon_{i1} \); \( \Delta t \) is the time interval between two consecutive measurements; \( r \) is the measurement's ordinal number \( [r = 1, 2, 3, \ldots, (m + q_m)] \); \( q_m \) is the number of primary transducers.

In measuring the reference signals \( \varepsilon_{jk} = 1/(m-1) \) for \( j = 1, 2, \ldots, m \) a series of results will be obtained:

\[
K_{1k} = C_{00},
\]

\[
K_{2k} = C_{00} + \varepsilon \Delta t + [C_{10} + \omega \Delta t] \frac{1}{m - 1},
\]

\[
K_{3k} = C_{00} + 2 \varepsilon \Delta t + [C_{10} + 2 \omega \Delta t] \frac{2}{m - 1},
\]

\[
K_{4k} = C_{00} + \ldots + (m - 1) \varepsilon \Delta t + [C_{10} + (m - 1) \omega \Delta t] \frac{m-1}{m-1}.
\]