Enhancing performance of measurement of parametric sensors parameters

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Abstract. The way of improving performance of measurement of parametric sensors parameters is considered. The result is achieved by calculating the elements of phase-frequency characteristics of the measuring circuit during the transition process while excluding the influence of interfering components.

1. Introduction
In practice, during measurement regardless the method is not always possible to avoid commutation, and hence there will be transition processes due to the inertia of the electric circuits elements. During the transition process, the measured voltages and currents depend on all the elements of the scheme, including internal complex resistance of measuring devices, energy sources and lead wires. Therefore, measurements, i.e. a count of measured values is carried out during steady-state process.

Time of transition processes damping is different and determined by the parameters of specific measurement system. Almost always, this time is much longer than the reference frame time of the required parameters. This substantially reduces the performance of measurement.

2. Analysis of the problem and formulation of the problem.
There are ways to measure of the separate determination of the parameters of the bipolar electrical circuits on the instantaneous values of transition processes [1], [2]. This approach significantly reduces the measurement time. But it involves the use of multiple transducers the influence of which on the result is not considered, as well as the influence of the power supply and connecting wires.

There are ways that allow to identify uniquely the elements of the sensor according to its phase-frequency characteristic [3], [4]. However, they can be applied only at the steady-state output signals of the studied object. In addition the method does not take into account the effect of interfering elements: internal complex resistance of measuring devices, energy sources, connecting cables and contacts. This leads to a very large error. Therefore it is only used for identification and not for measurement

In [5] approach to the measurement of passive two-terminal at different frequencies is well founded. Its essence consists in the formation of array responses of multi-element two-terminal to sinusoidal measuring impact. They are obtained at different frequencies in the time domain \( x(t,s) \), by analog and digital conversion. Then, using computational tools make the transition to the frequency domain \( X(j\omega,s) \) or \( X(p,s) \). It is known, that

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\[ X(p, s) = \left[ c_n p^n + c_{n-1} p^{n-1} + \cdots + c_1 p + c_0 \right] \left[ c_{2n} p^n + c_{2n-1} p^{n-1} + \cdots + c_{n+1} p \right]^{-1}, \]

wherein \( n \) – the number of independent contours of two-terminal, \( s = (s_1, s_2, \ldots, s_n) \) – two-terminal parameters vector. Coefficients \( c_i \) are continuously differentiable functions of the parameters \( s_i \), \( i.e. c_i = u_i(s) \).

\( «+1» \) in the exponent corresponds to the resistance function \( Z(p, s) \), a \( «-1» \) – functions of the conduction \( Y(p, s) \) of two-terminal.

Components \( s_i \) - desired parameters are determined by solving a simple system of nonlinear equations \( c_i = u_i(s) \), derived from (1) using known mathematical operations.

Properties of this method are, first, the dependence of the measurement result of the parasitic parameters of the measuring circuit. Second, the ability to provide acceptable metrological characteristics only in the steady state so as these transformations do not take into account all the factors affecting the process.

In the device [6] the method for the four-element two-terminal measurement at two frequencies, analogous to [5]. Measurement is performed as well in the steady state. However, its property is that, due to changes in the topology of the measuring circuit and the use of linear fractional transformation during processing, the measurement result is independent of the parasitic parameters of the measuring circuit, as well as the frequency volume of the energy source.

This feature can be explained by a simplified example.

Let the measuring circuit is as it is shown at 'figure 1'.

![Figure 1. Method of compensation \( Y_{\text{ИСТ}} \) and \( Y_{\text{АЦП}} \).](image)

I – current source; \( Y_x \) – unknown conductivity; \( Y_0 \)– exemplary conductivity; ADC 1 и ADC 2 – analog-to-digital voltage transducers; \( K_1 \) – key, N11, N12, N21 and N22 - readings of the appropriate devices in the relevant tact.

Measurements are carried out in two tacts. In the first tact the key \( K_1 \) is in position 1, and in the second tacta – in position 2. In the first tact ADC 1 counts N11, and ADC 2 - N21. In the second tact ADC 1 counts N12, and ADC 2 - N22.

Calculation of \( Y_x \) is carried out by the formula:

\[ Y_x = Y_0 \frac{N_{11}}{N_{21}} \frac{N_{22}}{N_{12}} \]  

(2)

Analyzing this circuit is easy to see that the count does not depend on \( Y_{\text{ИСТ}} \) and both \( Y_{\text{АЦП}} \) and their complex transmission coefficients.
3. Solution
To increase the performance is proposed to use a measurement method described in [5], during the transition process. And it becomes possible as for the impulse as for frequency measuring impacts by using the measuring circuit topology changes and apply extra fractional-linear processing described above.

A new method, the essence of which is that it is necessary:
1. Generate response arrays of multielement two-terminal to sinusoidal measuring impacts at different frequencies in the time domain x (t, s), through analog-to-digital conversion during the transition process (true for the single impulse impacts also).
2. Change the measuring circuit topology during the first phase so that extra fractional-linear processing will exclude the impact of complex finite values of internal resistance of the devices, power source and leading wires.
3. Then, using the computing means we make a transition in the frequency domain X (jω, s), or X (p, s).
4. Calculate the required components s_i, solving simple systems of nonlinear equations c_i = u_i(s).

3.1. Example.
For example, consider a variant of strain-gage testing.
To increase the sensitivity and linearity the measurements are performed on an alternating current. However, with increasing frequency the effect of parasitic reactances of strain-gages increases. Strain-gage 'figure 2' is regarded as a complex resistance to intercontact capacitance Cx and inductance Ld ‘figure 2’. All measuring circuit should be considered, as it is shown in 'figure 3'.

![Figure 2](image1.png)
**Figure 2.** The equivalent circuit of the strain gauge

![Figure 3](image2.png)
**Figure 3.** Full bridge circuit of strain gages turning on

Energy capacity of inertial energy accumulators that are placed on the rotating parts is small. Therefore, the power of measuring circuits is carried out pulsed, and secondary processing devices in the pauses are transferred into a sleep mode. This leads to the appearance of transition processes, which greatly reduces speed. The time spent for waiting for the transition processes attenuation are much longer than the time of signal processing.

To eliminate the effects of complex resistance measurement signal source and recording devices (АЦП) use a technique based on the proposed method.
Measurement is carried out as follows:
In the scheme ‘figure 3’ in the transition process, for example at an pulse action time functions arrays are received $U_1(t)$ и $I_2(t)$. With the help of the discrete Fourier transform we transfer to images $U_1(j\omega)$ и $I_2(j\omega)$.

From [7] it is known, that transfer function $H(j\omega) = \frac{U_1(j\omega)}{I_2(j\omega)}$.

In [8] is shown, that transfer function of bridge circuit ‘figure 3’ is calculated as

$$H(j\omega) = \frac{\sqrt{Z_b} - \sqrt{Z_a}}{\sqrt{Z_b} + \sqrt{Z_a}}$$  \hspace{1cm} (3)$$

and $Z_a = Z_c \frac{1-H(j\omega)}{1+H(j\omega)}$, but $Z_b = \frac{Z_c^2}{Z_a}$, $Z_c$ – exemplary resistance equal to the characteristic impedance of the circuit образцовое $Z_c = \sqrt{Z_a Z_b}$, so, taking $Z_a$ and $Z_c$ known and exemplary, we find

$$Z_a - Z_b = Z_c \frac{1-H(j\omega)}{1+H(j\omega)} - Z_c^2 Z_a$$  \hspace{1cm} (4)$$

The resulting value (3) is used to determine the value of mechanical loads or displacements.

Application of the proposed methods will significantly reduce the measurement time by reducing the waiting for transition process damping.

4. Discussion of the results

In electrical engineering it is known that

$$\dot{U}_{ij} = n_i I_T_{ij} = \frac{n_i}{\Delta_j} \sum P_{ij} \Delta_{ij},$$  \hspace{1cm} (5)$$

wherein $\dot{U}_{ij}$ - output voltage i-th ADC in j-th measurement tact ; $n_i$ - voltage transfer ratio i-th ADC in any measurement tacts ; $I$ – source current; $T_{ij}$ - system function of the measuring circuit, which is determined by the ratio of the value measured i-th ADC in j-th measurement tact, to the magnitude of the current source ; $P_{ij}$ - the value of the transmission path through i-th ADC in j-th measurement tact; $\Delta_{ij}$ – algebraic complement of the corresponding transmission path; $\Delta_j$ - determinant of the measuring circuit in j-th measurement tact [7].

In the first tact the division of readings ADC 2 and ADC1 is carried out. For voltages which they count value $\Delta_j$ is the same, so when divided the determinants are reduced. Attitude $\Delta_k$ for different devices are different so they are determined by the product of the relationship n2 and n1 complex transfer coefficient of appropriate ADC to algebraic complement of the transmission path through it ($Y_0$ is determined). In the second tact the same relationship is received with the only difference that it is determined by the ratio n1 and n2 and the value of Yx. In the calculation of (2) the relationships of complex transmission coefficients are reduced. That is why the dependence of the result of measurement Yx from parasitic parameters is excluded.

To eliminate the influence of leading wire resistance the circuit in Figure 1 must be complicated. $Yx$ and $Y_0$ must now be three or four-poles elements. The number of switching elements [9] increases also.

5. Conclusion

Complexity associated with the use of digital processing retards the establishment of high-speed measurement instruments and systems. Development of technical means, the widespread use of computers and digital signal processing allow to overcome the difficulties associated with the measurement during the transition process. This will allow you to create simple, cheap, fast and sufficiently accurate measuring instruments.
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