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Structural method for increasing the accuracy of converting parameters of the complex resistance of traction power supply objects into a time-frequency signal

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Abstract. The article discusses the principles of operation of quasi-balanced bridge converters with closely inductive couplings between the arms, having an extended range and maximum sensitivity by creating a parametric auto-resonant mode by changing the supply frequency of the measuring bridge. To reduce the errors of the conversion elements, a conversion algorithm based on a mathematical model is proposed, and a schematic diagram of a capacitive sensor parameter into code using a microcontroller is given.

1 Introduction

The most common technical parameters of traction power supply objects are controlled by sensors operating based on the transformation of complex resistance parameters, converting physical non-electrical quantities: humidity, mechanical vibrations, thermal, hydraulic, concentration of liquid and gaseous media, analyzers of probability distribution functions, measuring installations of mathematical expectation, dispersometers, etc [1-4].

Instruments and devices for measuring complex resistance (CR) parameters on alternating current occupy a special place in modern measuring technology.

Advances in microelectronics, in particular microcontroller technology, have made it possible to build compact and cheap components, the dimensions of which make it possible to freely place them in primary measuring transducers, improve and improve their technical and economic indicators.

2 Materials and Methods

Electrical measurements of electrical and non-electrical parameters using primary measuring transducers of CR or conductivity parameters, based on the use of automatic balancing methods that provide high metrological characteristics, are the most accurate, flexible, and universal [2-3].

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At the same time, it should be noted that special attention is currently being paid to the digitalization of the conversion of output values of AC bridges, with the possibility of entering measurement results into microprocessor units, in particular, using microcontrollers [1, 2, 6, 10].

This article proposes a block diagram and algorithm for converting the main parameter of a capacitive sensor into a digital code based on a microcontroller, which is used in large numbers in modern industrial and household appliances. They are widely used in automation systems as mobile diagnostic devices.

Manufacturers of microcontrollers are companies such as Hitachi, Intel, Philips, and Invention Technologies.

It is known that capacitive sensors can be used in measuring the absorption coefficient of insulating materials of transformers, linear and angular displacement transducers of contact network installations using various bridge balanced transducers, including four-arm auto-compensation, in the circuits of which transformers with close inductive coupling and operational amplifiers with deep feedback in alternating current are used [2, 7].

The most common structure of a four-arm transformer quasi-balanced bridge (TQBB) is a structure whose upper branch consists of a two-element chain, and the lower branch of active or reactive elements (Fig. 1).

Let's consider the principle of operation of the measuring and converting part for the TQBB.

The capacitive sensor, represented by a parallel equivalent circuit C_{1x} and the exemplary capacitance C_2 are connected, respectively, to the windings L_1 and L_2, wound on a ferromagnetic core.

At constant values of inductances L_3 and $L_3^{'}$, connected back-to-back in parallel with the switching capacitance C_3 near the equilibrium position, it is uniquely determined by the value of the balanced capacitance C_2.

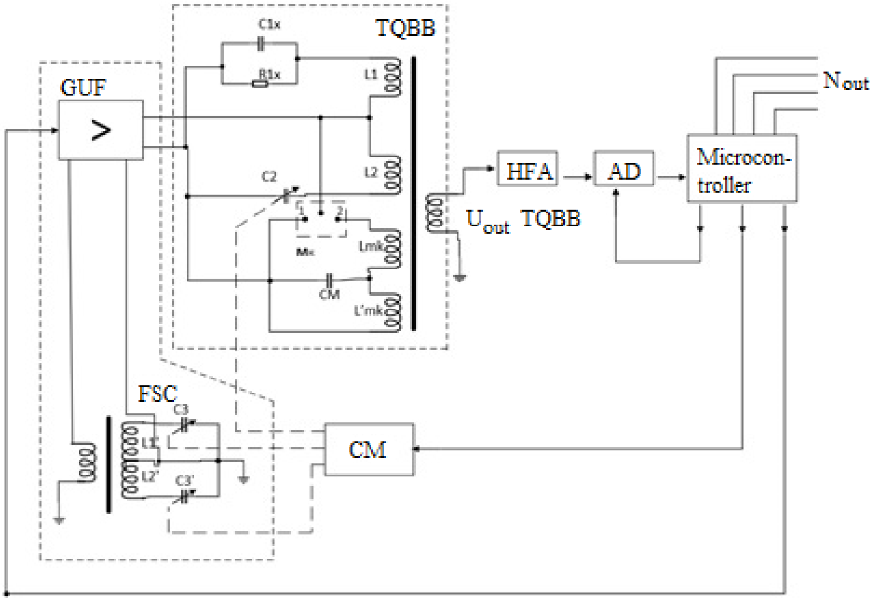

Fig.1. Measuring circuit of an extreme transformer quasi-balanced bridge converter to digital code.

GUF - generator of controlled frequency; FSC - Frequency-setting circuit; CM - capacitive magazine; TQBB - transformer quasi-balanced bridge; HFA - high frequency amplifier; AD - amplitude detector.

To simplify further calculations, we will assume that the active resistances of the windings L_1, L_2 and $L_3, L_3^{'}$ are equal to zero, and there are no parasitic capacitances. The coupling coefficient between the windings is equal to one, i.e. $M_{1,2} = \sqrt{L_1 L_2}$ and also $L_{mk} = L_{mk}^{'}$.

Output voltage TQBB at key position 1 of the modulator M_k (at $L_1 = L_2 = L_0$;

$$\dot{U}_{out1} = \dot{U}_n \frac{j\omega\left[Z_3\sqrt{L_0 L_4}\left(Z_2 - Z_1\right) + Z_1 Z_2\sqrt{L_3 L_4}\right]}{Z_1 Z_2 Z_3 + j\omega\left[Z_3 L_0\left(Z_1 + Z_2\right) + L_3 Z_1 Z_2\right]}, \tag{1}$$

and in position 2 –

$$\dot{U}_{out2} = \dot{U}_n \frac{j\omega\left[Z_3\sqrt{L_0 L_4}\left(Z_2 - Z_1\right) - Z_1 Z_2\sqrt{L_3 L_4}\right]}{Z_1 Z_2 Z_3 + j\omega\left[Z_3 L_0\left(Z_1 + Z_2\right) + L_3 Z_1 Z_2\right]}, \tag{2}$$

The maximum sensitivity at the equilibrium position for the modular mode will be determined by the expression [7]:

$$S_{C_2}^{0} = \left[\frac{\partial\left|\dot{W}\right|}{\partial p}U_{ij}\right]_{\left|\dot{W}\right|=1} = 2\omega^2 R_1^2 L_4\sqrt{L_0} \times$$
$$\times\sqrt{\frac{\omega^4 R_1^2 C_1\left(C_2\sqrt{L_4 L_0} - C_3\sqrt{L_3 L_1}\right)^2 + \omega^2 L_4 C_3}{\left(R_1 C_2 + \omega^2 R_1 C_2 L_0 + \omega^2 R_1 C_1 C_3 L_3\right)^2 + \frac{1}{\omega^2}\left[\omega^2 L_0\left(C_1 + C_2\right) + \omega^2 L_3 C_3 - 1\right]^2}}. \tag{3}$$

3 Results

Analysis of expression (3) shows that, provided:

$$\omega^2\left[L_0(C_1 + C_2) + L_2 C_3\right] + L_3 C_3 \tag{4}$$

It takes the maximum value. This condition can be maintained by changing the supply frequency of the TQBB according to the law:

$$\omega = \frac{1}{\sqrt{L_0(C_1 + C_2) + L_3 C_3}} \tag{5}$$

Condition (5) is an algorithm for the functioning of parametric communication (PC) due to the introduction of a changing frequency ω .

PC supporting conditions (5) are implemented by introducing an additional redundant channel by powering the TQBB using an *LC* generator with a stabilized output voltage. Moreover, the frequency-regulating parameters of the oscillatory circuit of the *LC* generator must be equal to L_0, within the control range $C_1 \approx C_2$. The TQBB converter described is an extreme control servo system that self-adjusts to maximum sensitivity.

The expression describes the module of the output voltage TQBB according to (3):

$$\left|\dot{U}_{out}\right| = \left|\dot{U}_n\right| \sqrt{\frac{\omega^4 R_1^2 C_1^2 \left(C_2\sqrt{L_4 L_0} - C_3\sqrt{L_3 L_4}\right)^2 + \omega^2\left[\sqrt{L_4 L_0}\left(C_1 + C_2\right) + \sqrt{L_4 L_3}\,C_3\right]^2}{\left[R_1 C_2 - \omega^2 R_1 C_1\left(-L_0 C_2 - L_3 C_3\right)\right]^2 + \omega^2\left[L_0\left(C_1 + C_2\right) + L_3 C_3 - \frac{1}{\omega^2}\right]^2}}. \tag{6}$$

The condition for the minimum of expression (6) i.e. the condition of quasi-equilibrium will be:

$$\frac{\partial\left|U_{out}\right|}{\partial C_0} = 0 \text{ ; and } \frac{\partial^2\left|U_{out}\right|}{\partial^2 C_0} > 0 . \tag{7}$$

Deviation from quasi-equilibrium i.e. from the minimum, is determined by a continuous trial change in the balanced parameter and an assessment of the magnitude and sign of these changes. This process is carried out using a modulation capacitance C_M through a switch M_k. The modulation frequency should significantly exceed the frequency of the quasi-equilibration process and at the same time be many times less than the TQBB supply frequency.

4 Discussion

Therefore, next we consider the transformation of the output voltage of the $\left|U_{out}\right|$, reflecting the informative parameters of the capacitive sensor C_1 into a digital code using a microcontroller [5].

However, the amplitude detector (AD) used in the circuit, from the output of which the signal is supplied to the balancing actuator element C_2 in the form of a capacitive magazine (CM) having a backlash, leads to the occurrence of an instrumental error [6].

In practical implementation, the output voltage $\left|U_{out}\right|$ is supplied to the input of an analog-to-digital converter (ADC) built into the microcontroller, which controls all processes of generating the output signal that balances the TQBB, according to the algorithm, according to the sequence of expressions (1)-(6).

Note that the process of balancing the TQBB is simultaneously ensured by its maximum sensitivity through structural parametric redundancy, i.e. obtaining additional structure [8-9, 11] by using the channel for changing the autoresonance of the measuring circuit.

5 Conclusion

A mathematical model is given that defines the process of generating the output voltage of a quasi-balanced measuring circuit, proportional to the informative parameter of a capacitive sensor connected through transformer windings with a closely inductive coupling, forming a four-arm quasi-balanced bridge that has high metrological properties. The quasi-balanced bridge is powered by a variable-frequency generator, the frequency-setting circuit of which is determined by an adaptive law that self-adjusts to maximum sensitivity over the entire conversion range during the balancing process.

The output voltage of the TQBB is fed through a high-frequency amplifier to an amplitude detector, from the output of which a low-frequency signal is supplied to an analog-digital converter that balances the bridge circuit using a ten-day capacitive store C_0. The digital value of the sensor capacitance is determined by using a capacitance store and a microcontroller.

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