Sensors & Transducers, Vol. 211, Issue 4, April 2017, pp. 38-42

Sensors & Transducers

Published by IFSA Publishing, S. L., 2017

http://www.sensorsportal.com

Phase Method of Invariant Measurement of Active-Inductive Measuring Two-Pole Parameters

Boris MAMIKONYAN

National Polytechnical University of Armenia, Gyumri Branch

2 Mher Mkrtchyan, 3103, Gyumri, Armenia

Tel.: +374312-46832, fax: +374312-43528

E-mail: b_mamikonyan@seua.am

Received: 25 March 2017 /Accepted: 25 April 2017 /Published: 30 April 2017

Abstract: There has been given the solution of the technical problem of separate measurement of parameters of inductance coils and inductive primary converters on alternating current without application of potential-current signals. As a measuring circuit the scheme of voltage divider with active-inductive two-pole is used, and as an output signal there has been used the angle of phase shift between two output voltages of the measuring circuit. For forming the output signal temporal separation of measurement channel is used. The advantages of phase method are mostly due to capacity of using microcontrollers. In the technical solutions under consideration the microcontroller regulates the measuring process and develops the measurement results.

Keywords: Inductance coil, Inductance, Active resistance, Measurement two-pole, Phase method.

1. Introduction

Inductance coils (IC) are widely used in electrical and electronic devices. They are the mandatory and main components of the relay, contactors, transformers, electrical machines; they are used as throttles for redistribution of alternating current along the circuits. While using IC with capacitors, high-quality vibration contours are generated, which are involved in filters and generators of high-frequency vibrations. In most electronic devices besides RC-circuits, RL-circuits are used for integrating or differentiating electrical signals.

Inductive sensors (IS) constitute a large group among devices with IC; these IS are used in various informational-measuring and regulating systems and are responsible for the most important functions. IS are the most available and fail-safe element of drive, machine, automatic line control systems and also measurement systems of physical units. IS are characterized with relatively simple structure, small sizes, high accuracy and sensibility, comparatively high output voltage value (up to several dozen watts), reduced sensibility to the environment changes and interference and low price. IC, being properly insulated, can successfully operate at around 500 °C [1, 2].

Measurement devices with IS of the plunger type with movable core, in which increment of the coil inductance (or unbalance of the inductance of two coils) is the informative parameter, have got dominant position among electronic devices for linear measurement in the range 0…10 mm due to a number of undeniable advantages over other types of mechanical devices and electrical converters. Numerous manufactory control devices and craft tools as well as laboratory verificatory devices and, among them devices for appraisal and verification of indicators and end measures of length, are equipped with these sensors [3, 4].

IS of eddy-current type, in which the informative parameter is the increment of the coil active resistance, are widely used in control systems of technological processes in food industry, in pulp and paper industry, in brewing, pharmaceutics, biotechnologies as contactless indicators of object position and for measuring electrical conductivity of liquids [5-7]. In these systems IS have significant advantages over mechanical and conductometric ones; i.e. lack of movable parts, lack of electrodes and, consequently, polarization; they provide exact measurement of the environment or solutions with high level of pollution and tendency to sedimentation, complete galvanic separation of the environment and measurement; high reliability and durability, resistance to temperature and pressure. Over 35 companies in the US are involved in the production of inductive sensors [8].

2. Design Considerations

Wide application of IC demands that simple, precise and fail-safe measurers of their parameters, compatible with up-to-date microcontrolling devices for proceeding the information and controlling the measurement process be developed.

The scheme of IC replacement is compiled with respect of the peculiarities of the coil with ferromagnetic core. If winding of the IC contains a great number of coils and there is a potential difference between particular coils and layers of coils, the IC will have some peculiar capacity, which will be switched on parallel to the inductance of the coil. When the current frequency is not very high (up to several hundred kHz), winding capacity can be neglected and the scheme of IC replacement can be presented as consistent connection of active resistance R_X and inductance L_X, which makes defining of the IC parameters considerably simpler [9]. For most IC, among them IS, inductance is a beneficial parameter, and active resistance is parasitic one. There are exceptions like eddy-current inductive sensors, induction electricity measurers and others, in which in the air gap of the magnetic circuit a non-magnetic conducting body is placed. In the latter due to the alternating magnetic field, created by the coil, eddy currents are induced, which cause active electric power loss and, consequently, increase of the coil active resistance. In the IS the primary converter (PC) and the measuring circuit (MC) are its constituent parts. Meanwhile MC is to provide invariance of the PC informative parameter measurement result to both destabilizing factors, acting upon PC (e.g. voltage and frequency of the feed generator) and to its non-informative parameters.

Due to the IC ferromagnetic core in which power loss depends on the magnetization reversal rate, active resistance R_X depends on the coil supply frequency; consequently, IC parameters should be measured by the alternating current of the frequency, on which application of IC is implied. Moreover, with respect of the nonlinearity of the magnetization curve of the magnetic core, measuring (testing) current should be equal to the operating current of the IC. In addition, since the scheme of IC replacement is in fact complex resistance, MC is to provide separate measurement of the parameters R_X and L_X.

3. Research Methods

For separate measurement of passive two-element two-pole parameters on alternating current a number of methods and schemes have been developed and they are thoroughly considered in [2, 9, 10]. All the direct methods and the ways of converting parameters of these circuits on the alternating current as an intermediate value have voltage or current. These signals are known to be exposed to the impact of interference and noise. In addition, when linked with the electronic components of the digital technology and computing means they require additional transformations, which make the measurement system complicated.

Comparatively new direction in the field of measurement of passive electrical two-pole parameters is application of the alternating current voltage dividers on the basis of the phase method and the method of measurement channel temporal separation. The development of this direction is due to the general application of microcontrollers in the measuring technology. We have used such technical solution for separate measurement of parameters of the IC replacement consistent scheme [11].

4. Electrical Circuit

The essence of the measurer is illustrated by the scheme of Fig. 1, where 1 is the measuring circuit, 2 - two-pole under consideration, 3 - the generator of sinusoidal signals, 4 - electronic switch, 5 - the programmable microcontroller, 6 - the digital reading device (DRD), 7 - the interface converter (UART-USB), 8 - the computer.

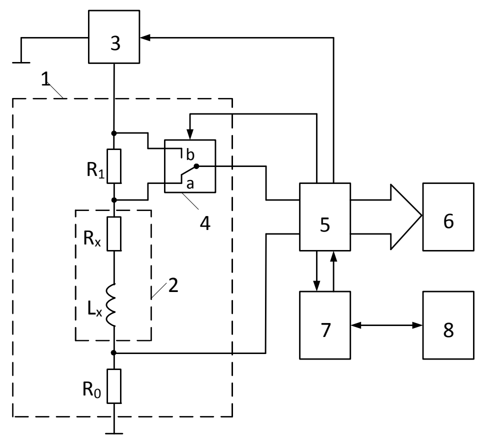

Fig. 1. Simplified principal scheme of the measurer of the inductance coil parameters.

In MC two sample resistors are series connected with the IC: reference resistor R_0 and additional resistor R_1. The MC, obtained in the result of these compounds, is connected to the generator of the sinusoidal signals as a voltage divider. MC has two output voltages with respect to a common point, which pass onto the microcontroller inlet; voltage u_S of the common contact of the switch and voltage u_0 of the reference resistor, and in this case the informative signal is the angle φ of phase shift between these voltages. In the process of measurement the microcontroller sets the required frequency ω of generator, regulates the switch position and measures the values φ_1 and φ_2 of the angle φ in the two switch positions. In the switch position *a*

$$ctg\varphi_1 = \frac{R_0 + R_X}{\omega L_X} \tag{1}$$

and in the switch position *b*

$$ctg\varphi_2 = \frac{R_0 + R_X + R_1}{\omega L_X} \tag{2}$$

When we subtract from the expression (2) the expression (1): $ctg\varphi_2 - ctg\varphi_1 = R_1/\omega L_X$, we get

$$L_X = \frac{R_1}{\omega\left(ctg\varphi_2 - ctg\varphi_1\right)} \tag{3}$$

Now we divide the expression (2) by the expression (1):

$$\frac{ctg\varphi_2}{ctg\varphi_1} = 1 + \frac{R_1}{R_0 + R_X}$$

and get

$$R_X = \frac{R_1}{\frac{ctg\varphi_2}{ctg\varphi_1} - 1} - R_0. \tag{4}$$

Formulas (3) and (4) provide separate definitions of the IC parameters on the alternating current. It is obvious that it is only required to measure the phase shift angle between two outlet voltages of the measuring circuit. The microcontroller measures the value of the angle φ, computes the parameters L_X and R_X according to the formulas (3) and (4) and introduces the measurement results on the digital display; as a display seven segment LED indicators are used. For increasing the reliability of the measurement results in every point the microcontroller performs 10 measurements and gives the average results of these measurements on the indicator.

When it is required, digitized signals of the angles φ_1 and φ_2 from the microcontroller can be sent on the computer through an interface converter (e. g. AVR 309) and processed and the measurement results can be displayed on the computer monitor.

Since in common case the measurement results R_X and L_X also depend on the frequency of the current, which feeds the measuring circuit, the problem of stabilization of this frequency or its control in the measurement process occurs. With respect of this circumstance as a power supply of the measuring circuit a programmable generator of sinusoidal signals AD9833 is used. For each measurement the microcontroller specifies the generator frequency and uses this frequency value while computing the IC parameters; due to it the change of the generator frequency can't have impact on the measurement accuracy. The generator voltage stability is not essential, for in formulas (3) and (4) the generator voltage does not appear.

Thus, the definition accuracy of the IC parameters only depends on the accuracy of measurement of the angle φ. In this device the measurement is performed by the discrete calculation method, therefore the measurement accuracy is considerably higher than when potential-current signals are used.

In these experiments as a measurement object IC with nominal values of parameters $L_X = 7.2$ *mH*, $R_X \approx 3$ *Ohm* have been used. A sample resistance box P4831 was connected successively with the IC; the change R_X was imitated by the change of the resistance in this box. The measuring current is selected equal to 1,0 *mA*, and frequency - 2 *kHz*. Multiple measurements, analysis of results and also theoretical estimate of metrological characteristics of the measurers, according to the scheme on Fig. 1 demonstrated that under production conditions the device can provide measurement of the IC parameters with the limit of permissible relative error, not exceeding 0.2 %.

It is obvious that in the device according to the scheme of Fig. 1 two-pole 2, which is under the investigation, can also be an ordinary inductive PC. It should be taken into account that PC coils of most modern IS have multilayer windings, a core of ferrite with high magnetic permeability, and that they are intended for feeding by alternating current with frequency 7-15 *kHz*. In case of differential inductive PC we used the MC according to the scheme of Fig. 2, where the sensitive parameters can both be inductance (classical inductive PC) and active resistance (inductive PC of eddy-current type) [12].

In this scheme for the angle of phase shift between voltages $\dot{U}_S$ and $\dot{U}_X$ in the initial and second positions of the switch there can be written respectively

$$tg\varphi_1 = \frac{\omega L_1}{R_1 + R_N}, \tag{5}$$

$$tg\varphi_2 = \frac{\omega L_2}{R_2 + R_N}. \quad (6)$$

If the inductance unbalance (ΔL) is an informative parameter, then $L_1 = L_0 + \Delta L$, $L_2 = L_0 - \Delta L$, $R_1 = R_2 = R_0$, where R_0 and L_0 are the initial values of these parameters, which are constant and known (they are indicated in the passport data of PC). For this case from (5) and (6) it follows:

$$tg\varphi_1 - tg\varphi_2 = \frac{\omega(L_1 - L_2)}{R_0 + R_N} = \frac{2\omega\Delta L}{R_0 + R_N},$$

$$tg\varphi_1 + tg\varphi_2 = \frac{\omega(L_1 + L_2)}{R_0 + R_N} = \frac{2\omega L_0}{R_0 + R_N},$$

from which we obtain the formula for defining the informative parameter of PC:

$$\Delta L = L_0 \cdot \frac{tg\varphi_1 - tg\varphi_2}{tg\varphi_1 + tg\varphi_2} = L_0 \cdot \frac{\sin(\varphi_1 - \varphi_2)}{\sin(\varphi_1 + \varphi_2)} \quad (7)$$

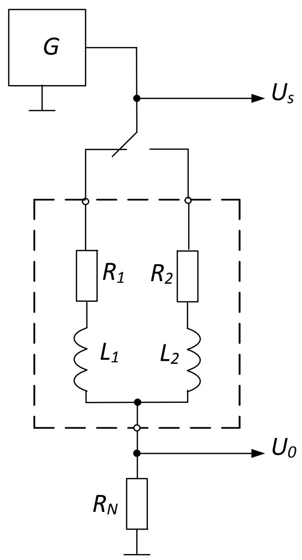

Fig. 2. The scheme of MC for measurement parameters of differential inductive PC.

But if the informative parameter is the unbalance of active resistance, then $R_1 = R_0 + \Delta R$, $R_2 = R_0 - \Delta R$, $L_1 = L_2 = L_0$. From (5) and (6) it is defined:

$$ctg\varphi_1 = \frac{R_1 + R_N}{\omega L_0} = \frac{R_0 + \Delta R + R_N}{\omega L_0},$$

$$ctg\varphi_2 = \frac{R_2 + R_N}{\omega L_0} = \frac{R_0 - \Delta R + R_N}{\omega L_0},$$

$$ctg\varphi_1 - ctg\varphi_2 = \frac{2\Delta R}{\omega L_0},$$

$$ctg\varphi_1 + ctg\varphi_2 = \frac{2(R_0 + R_N)}{\omega L_0},$$

$$\frac{ctg\varphi_1 - ctg\varphi_2}{ctg\varphi_1 + ctg\varphi_2} = \frac{\Delta R}{R_0 + R_N},$$

from which we obtain

$$\Delta R = (R_0 + R_N) \cdot \frac{\sin(\varphi_2 - \varphi_1)}{\sin(\varphi_2 + \varphi_1)} \quad (8)$$

5. Results

From formulas (7) and (8) it follows that MC, according to the scheme of Fig. 2, permits separate measurements of the differential inductive PC parameters by means of phase method. It is evident that in this case in formulas the generator frequency doesn't appear either, and it implies, that measurement accuracy can be provided, even if the curve shape of the feeding voltage is not purely sinusoidal.

6. Conclusion

Analysis of measurers according to the scheme of Figs. 1 and 2, demonstrates that the above-mentioned method of separate measurement of the IC parameters and parameters of inductive PC on alternating current, based on the application of the phase method combined with temporal separation of the measurement channel, is simple in its practical realization and has high accuracy. Its main merit is exception of potential-current signals, conversion and measurement of which are accompanied by unavoidable errors, which are caused by the impact of outer and inner interference and noises, voltages of displacement and shift of operating amplifiers, the non-stability of their amplification factors, the impact of cable communication parameters, etc.

References

[1]. Schepetov A. G., The theory, calculation and projecting of measuring devices, *Standartinform*, Moscow, 2008.

[2]. Fedotov A. V., The theory and calculation of the inductive displacement sensor for the automatic control systems, *OmGTU*, Omsk, 2011.

[3]. Sorochkin B. M., The automation of measuring and control of details' sizes, *Mashinostroyeniye*, Leningrad, 1990.

[4]. Sobolev M. P., Etingof M. I., Automatic size control on metal-cutting machines, *Oykumena*, Smolensk, 2005.

[5]. Klyuev A. S. and others, The projecting of the automated systems of the technological processes: Handbook, *Energoatomizdat*, Moscow, 1990.

[6]. Buylov G. P. , Doronin V. A. Serebryakov N. P., The automatic and automation of the productions process of the pulp-and-paper productions, *Ecology*, Moscow, 1995.

[7]. Smirnov V. I., The methods and means of functional diagnostics and control of the technological processes on the base of the electromagnetic sensors, *UlGTU*, Ulyanovsk, 2001.

[8]. Sensors expo // Sensors. September 1990: http://www.sensor.ru/articles/299/element_1235.html

[9]. Melentyev V. S., Kostenko E. V., Mironov D. A., The approximate methods of parameters separate determination of two-element and bipolar electric circuits, *Polzunskiy Vestnik.* Issue 3/1, 2011, pp. 47-50.

[10]. Martyashin A. I., Shakhov E. K., Shlyandin V. M., The converters of electric parameters for control and measurement systems, *Energy*, Moscow, 1976.

[11]. B. M. Mamikonyan, Kh. B. Mamikonyan, The way of measurement of parameters of the coil of inductance, Patent RA N2930.GO1R 27/00, 2015.

[12]. B. M. Mamikonyan, Kh. B. Mamikonyan, The way of measurement of informative parameter of the differential inductive transducer, Patent RA N2959.GO1R27/00, 2015.

Published by International Frequency Sensor Association (IFSA) Publishing, S. L., 2017 (http://www.sensorsportal.com).