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Development of a Two-Parameter Inductive Sensor for use in Digital Program Control Systems for Machine Tools.

***Abstract**. This article presents the results of a study of a two-dimensional electromagnetic sensor designed to record various movements of an object. Experimental data obtained during the study indicate the possibility of reducing the overall dimensions of the housing and simplifying the design of the sensor. In the context of the mechanical engineering industry, various machine tools are widely used to carry out a variety of production processes, including the installation and shaping movements of tools and workpieces, as well as auxiliary operations such as chip removal, tool cooling, mechanism lubrication, etc. Improving the quality of recording various movements of an object can be achieved by introducing non-contact measuring sensors of the electromagnetic type.*

***Streszczenie.** W artykule przedstawiono wyniki badań dwuwymiarowego czujnika elektromagnetycznego przeznaczonego do rejestracji różnych ruchów obiektu. Dane eksperymentalne uzyskane w trakcie badań wskazują na możliwość zmniejszenia gabarytów obudowy i uproszczenia konstrukcji czujnika. W kontekście przemysłu budowy maszyn różne obrabiarki są szeroko stosowane do realizacji różnorodnych procesów produkcyjnych, w tym montażu i kształtowania ruchów narzędzi i detali, a także operacji pomocniczych, takich jak usuwanie wiórów, chłodzenie narzędzi, smarowanie mechanizmów itp. Poprawę jakości rejestracji różnych ruchów obiektu można osiągnąć poprzez wprowadzenie bezkontaktowych czujników pomiarowych typu elektromagnetycznego. (**Opracowanie dwuparametrowego czujnika indukcyjnego do zastosowania w cyfrowych systemach sterowania programami dla obrabiarek**)*

Keywords: two-parameter inductive sensor, linear displacement, angle rotation, winding, digital program control,.
Słowa kluczowe: dwuparametrowy czujnik indukcyjny, przemieszczenie liniowe, obrót kątowy, uzwojenie, cyfrowe sterowanie programowe,.

Introduction

A large number of converters are used in information, measuring and control systems of cutting, polishing and multi-operational machines, widely used in modern mechanical engineering [1]. In recent years, electrical transmissions of machine tools have been modernized, equipped with digital software control devices, the use of microprocessors, microelectronics, thyristors, bipolar transistors in transmission control systems, as well as the use of new converters and converters with greater accuracy, also required sensitive, economical and metrologically convenient control systems for them. For this purpose, it is considered relevant to reduce the number of sensors in the information, measuring and control systems of machines and to determine the possibility of transferring the function of the reduced sensors to the remaining sensors. In this regard, the creation, research and application of a two-dimensional electromagnetic type sensor for control systems of machine tools used in mechanical engineering is of great importance. In this regard, it is necessary to resolve the following issues:

- creation of a new two-dimensional electromagnetic type sensor for multi-operational chipping, cutting and stamping machines and its research;
- analytical determination of electromagnetic parameters of an electromagnetic two-dimensional sensor;
- determination of the operating characteristics of a two-dimensional sensor in unloaded and loaded modes;
- analytical determination of the metrological characteristics of a two-dimensional converter;
- experimental study of the created sensor and its introduction into production.In the field of mechanical engineering and the national economic industry, there is often a need to use two-dimensional electromagnetic sensors in information measuring systems and control systems for machine tools with numerical control [3,4]. Such machines require accurate measurements of various process parameters such as spindle torque, axial milling forces, tool deformation, temperature, vibration, etc. These measurements are carried out within the adaptive system of the machine.

In adaptive systems, as well as in numerical control systems, changes in the basic dimensions of parts are automatically taken into account [5-7]. Using appropriate sensors, for example, in the manufacture of curved long parts in which the deviation from straightness significantly exceeds the processing allowance. Multi-operational machines with numerical control are widely used in practice. Information measurement and control systems use a variety of sensors, including electromagnetic ones. In order to reduce the number of sensors in these systems, the authors of this work have developed a two-dimensional electromagnetic sensor made of solid structural steel.

Formulation of the problem

The magnetic two inductive sensor system is made from solid structural steel. Manufacturing the sensor's magnetic system from solid structural steel increases mechanical resistance to external shocks and shocks on the one hand, and on the other hand improves their performance characteristics. It is known that when the core material is made of hard steel, they exhibit a strong skin effect phenomenon. Based on the theoretical and experimental studies carried out, it has been established that by correctly choosing the geometric dimensions of the core, it is possible to bring their characteristics to a level that can satisfy the requirements of practice. It is also necessary to coordinate the created two-dimensional sensors with converters in systems for monitoring electromagnetic parameters. As a result of the scientific justification of the sensors, it was established that it is possible to obtain their necessary characteristics when the analytical expression of the output voltage of the sensor is known.

Since the magnetic system of the presented two-dimensional sensors of the electromagnetic type has a steel core, the magnetic circuit of the created sensors is considered non-linear. Depending on the principle of operation of such sensors, their magnetic system has a fixed or variable gap in the path of the magnetic flux. In the scheme for measuring the linear displacement of the sensor considered here, the air gap on the path of the magnetic flux is variable, and in its scheme for measuring the angular displacement, the air gap is constant.

The sensor is powered by an alternating current source, which creates an alternating magnetic flux in the magnetic system of the sensor. The magnitude of the generated magnetic flux depends on the change in the air distance in the linear displacement circuit of the sensor. But the angular displacement of the sensor is based on displacement, for example, between parallel resistances in a circuit with distributed parameters. The calculation of the changing magnetic field in the magnetic system of both measuring circuits is required. There are various methods for this purpose. Each method must fully reflect the creation of a mathematical model that takes into account the nonlinearity in the magnetic system of the sensor and the magnetic losses (current and hysteresis) arising from this nonlinearity. Electromagnetic sensors available and studied in the literature have different configurations. Therefore, the mathematical apparatus used for each of them should provide a mathematical model of the magnetic flux distribution.

Formulation of the problem. The created two-dimensional sensor with a continuous magnetic core makes it possible to simultaneously measure linear and angular movements of an object. It consists of a moving and stationary magnetic system. The electromagnetic system of the sensor's measuring circuit has a common excitation winding. When each measuring circuit operates in idle mode, there is no mutual influence between the measuring circuits. In this regard, the calculation of the electromagnetic systems of each measuring circuit is carried out as for independent one-dimensional sensors.

The solution of the problem

The moving part of the magnetic system of the linear movement measuring circuit is a flat cylindrical magnetic core, which is fixed on the axis of the sensor and, with its linear movement, more or less overlaps the end parts of the groove of the stationary magnetic core. The end parts of the groove are structurally made at opposite ends of the fixed magnetic circuit. Therefore, the magnetic system of the linear displacement measuring circuit x is equipped with two flat cylindrical magnetic cores, rigidly fixed to the sensor axis. In this case, the linear movement of the sensor axis causes more or less overlap of the windings and the voltage difference ΔU_{2x} is obtained at the output of these windings. The magnitude of this voltage is directly proportional to the linear displacement [1,2].

Measuring circuit for the angular movement of an object. The magnetic system of this circuit consists of a part of the excitation winding located on the longitudinal grooves of a fixed magnetic core and a winding system wound uniformly on thin-walled cylindrical magnetic cores mounted on the movable axis of the sensor and freely rotating around it. A system of windings uniformly wound on a thin-walled cylinder has uniform current leads connected through resistors to a common point. Each section along its length covers the longitudinal part of the field winding. Since the longitudinal part of the excitation winding is stationary, and the winding system rotates depending on the angle of rotation of the object, the change in voltage ΔU_{2y} varies depending on the angle of rotation of the object. The width of the down conductors is taken equal to the width of the longitudinal grooves and is made on the inside of the fixed magnetic core. There is an air gap between the thin-walled cylinder with the winding and the excitation winding, the size of which remains unchanged at any angle of rotation of the object. Therefore, the value of ΔU_{2y} depends on the rotation angle β [8-10].

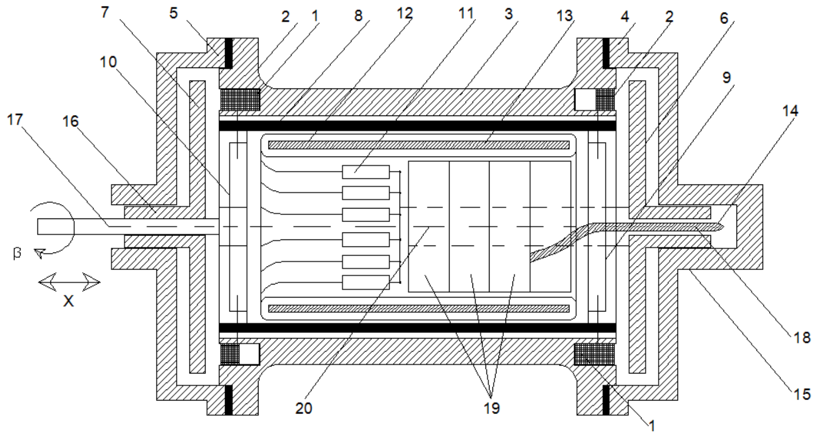

Fig.1. Sensor construction

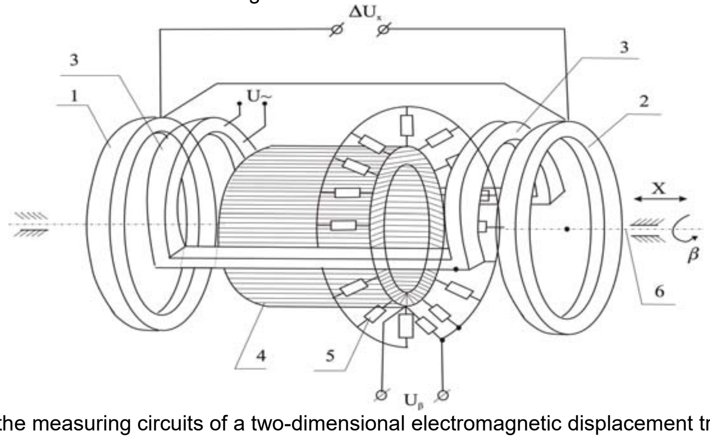

Fig. 2. Relative arrangement of the measuring circuits of a two-dimensional electromagnetic displacement transducer

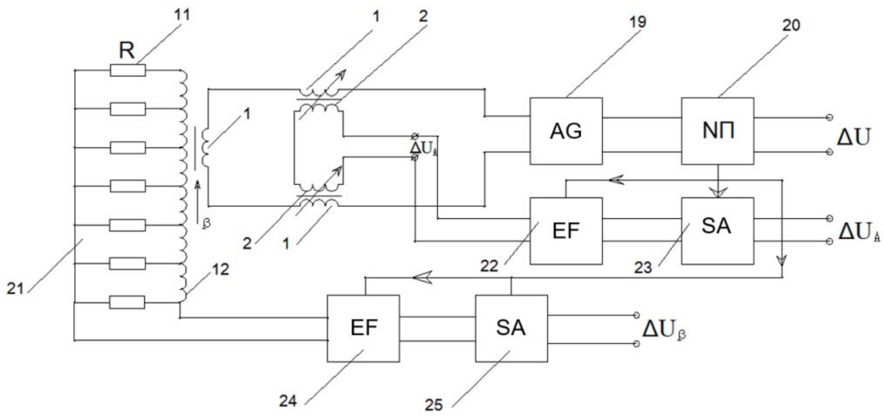

Fig.3 Electrical circuit diagram of the sensor

The developed two-dimensional electromagnetic type sensor is designed for continuous measurement of the linear movement of the machine tool and the rotation angle of its working parts. The design of the sensor is shown in Figure 1.

The sensor consists of the following elements: excitation winding 1, located on the end and longitudinal parts of the grooves; measuring windings 2 for the linear motion chain, located in the right and left end grooves of the housing 3; housing 3 equipped with covers 4 and 5; The end parts of the grooves are closed by movable disks 6 and 7, which are fixed to the axis 17-18. Discs 6 and 7 are mounted with their protrusions by sliding bearings 15 and 16**.**

The angular displacement measuring circuit is mounted inside a non-metallic cylinder 8. This cylinder is fixed on both sides to covers 9 and 10, having axes 17 and 18, the latter are fixed to the protrusion 15 and 16. In addition,

The cross-section of the grooves at the ends of the 3-cylindrical core, shown in Figure 1, is П -shaped and closed on both sides with cylindrical caps. On one side, the air gap between the covers and the body is δ_1, on the other hand - δ_2. Caps 15 and 16, shown in the figure, are rigidly fixed to each other by axis 17. Consequently, both covers move in parallel depending on the displacement *x*.

As we mentioned above, the thickness of the groove wall is taken equal to the hardening depth (1).

(1) $$d = \sqrt{\frac{2}{\omega\gamma\mu\mu_0}}$$

This thickness remains constant along the length of the nest. The circuit for measuring small displacement x of the transmitter is similar to that shown in Figure 1. Therefore, when studying a magnetic circuit, it is necessary to focus on one of them.

The electrical circuit diagram of the sensor is shown in Figure 3.

Figure 3 shows the designations of the elements in accordance with the design shown in Figure 1. Figure 3 shows excitation winding 1, measuring windings 2 for the linear movement circuit, measuring windings 12 for the angular movement circuit. The measuring winding 12 is sectioned and has uniform current leads through resistors R to a common point.

As can be seen from Figure 3, each measuring circuit of the sensor is equipped with emitter followers 22 and 24 and semiconductor amplifiers 23 and 25. The output ΔU_l is the output voltage of the linear movement circuit, and ΔU_β is the output voltage of the angular movement circuit. This sensor design allows you to measure linear displacement up to 25 mm, and angular displacement up to 180°.

connecting wires 14 pass through the hole of the cover 9 and axis 18 , connecting the measuring circuits of the sensor with external power sources and with measuring instruments and devices. Inside the thin-walled cylinder 8 there is a thin-walled cylinder 13 with a uniform sectioned winding 12, which has current leads through resistances - resistors 11. Inside the cylinder there are also elements of a semiconductor self-oscillator 19, powered by the excitation winding 20 of the sensor with high-frequency voltages.

The open shape of the windings is as shown in Figure 2. Here 1 and 2 are measuring rings used to measure displacement. The shape of these windings is a complete ring. They and the 3-semicircular part of the impact winding, parallel to these windings, are located in the end grooves. The longitudinal part of the shock winding is located in the longitudinal grooves of the cylinder. The longitudinal slots are located in the cylinder at a geometric angle of 180°.

The operating characteristics of the measuring circuits of a two-dimensional sensor are shown in Fig. 4.

The magnetic cores of the sensor are made of solid structural steel St. 65; the manufacture of magnetic cores from solid structural steel makes it possible to create a sensor with improved technical and economic indicators.

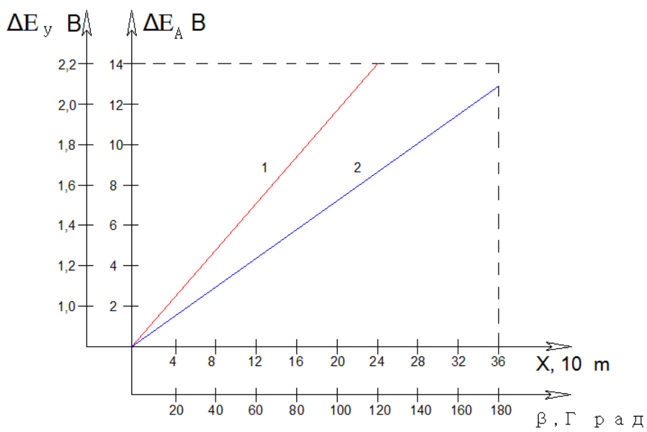

Fig.4. Dependences of the electromotive force of linear movement of the measurement chain ΔE_l on linear movement x(1) and the angle of rotation of the measurement chain ΔE_y on the angle of movement β(2)

During operation of the sensor, the amplitude of the output voltages is converted into a code, which is transmitted to the drive circuit and controls their operation. Since the error obtained in the process of converting voltages into codes has a significantly smaller value than the conversion error of the sensor itself, it has virtually no effect on the error of the measurement channel.

From this point of view, the development and use of two-dimensional inductive sensors in an electromagnetic-type control system for electric drives and digital program control of machine tools used in mechanical engineering are of great importance.

Conclusions

The experimental data obtained make it possible to reduce the overall dimensions of the housing and simplify the design of the sensor; you can make the housing from a non-metallic material and place an excitation winding with thin Π -shaped magnetic cores on its longitudinal and end grooves.

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