Contactless galvano-magnetics transducers of monitoring and control systems in agricultural energy

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Abstract. The paper provides information on the state of the use of direct current energy in the electric power industry of agriculture and water resource, hydraulic engineering, industry and metallurgy, irrigation, and land reclamation. Identified the need for contactless non-destructive testing of large constant currents in high-power electrical installations in irrigation, land reclamation, and hydraulic engineering. The basic requirements for contactless transducers and meters of large direct currents in circuits without breaking them are shown. Identified priority areas in the development of these transducers. The general principles of constructing contactless ferromagnetic transducers of large direct currents also the basic requirements for them and the results of the development of one of the options for the development of effective innovative galvano-magnetic contactless transducers of large direct currents with an expanded range of monitoring and control systems for powerful pumping stations in water supply and land reclamation are presented. To increase the sensitivity of galvano-magnetic contactless transducers of large direct currents, Hall transducers have supplied with short-term rectangular current pulses from a special generator. When measuring the amplitude values of the rectified current, in this case of galvano-magnetic contactless transducers, the supply of pulses of the control current of the Hall transducers with the converted current in the bus synchronization is provided. This is achieved by supplying galvano-magnetic contactless transducers of large direct currents with a magnetically controlled contact located near the bus with the converted current and included in the circuit of the current electrodes of the Hall transducers.

A static characteristic of the developed galvano-magnetic contactless transducer of high currents obtained and its main technical characteristics and parameters are given. It is shown that the developed transducer, unlike the known ones, has increased accuracy and sensitivity, a technological design, and low weight and dimensions at low material consumption and cost. It can be widely used in electrical systems in land reclamation and irrigation, in water supply, industry, rail transport, science, technology, and for checking electric meters at the installation site.
1. Introduction
Purpose is the research contactless galvano-magnetics transducers of monitoring and control systems in agricultural energy. Object: galvanomagnetic non-contact ferromagnetic converter of large direct currents, which, in contrast to the known ones, has increased accuracy and sensitivity, technological design, and small weight and dimensions at low material consumption and cost, elements of its theory and basic characteristics.

Development of several new industries, science and technology, and in particular, development of the agricultural electric power industry, a powerful electric drive for water supply plants, in land reclamation, irrigation, the electrical industry, and several new industries, science, and technology are leading to ever-increasing production and consumption of high direct currents [1,2]. Currently, about 40% of the electricity generated in the Republic of Uzbekistan is consumed in the form of direct current energy. Therefore, the conversion and measurement of large direct currents (HDC) are one of the important problems of modern information - measuring equipment both in scientific and in applied directions. At the same time, the need to break the current circuit for the temporary inclusion of electrical measuring devices, the presence of large power losses on the shunts, the undesirability or impossibility of the circuit breakage under the conditions of the technological process, as well as safety requirements, led to the contactless conversion and measurement of direct current in the circuits without breaking them, t. e. without destroying the integrity of the conductive bus [3-7].

As a result of the analysis of the locations of contactless non-destructive contact control of the BFT, the basic requirements for the BP and BI are revealed. These include: high accuracy, reliability, sensitivity, low mass, dimensions, material consumption and cost, technological design, the absence of errors from the influence of external magnetic fields, a return bus with current from the center of the integrating circuit, ferromagnetic masses, residual magnetization and the presence of a variable component in controlled direct current, as well as the lack of galvanic connection between the measured direct current and the measuring circuit and the possibility in some cases of being fixed sensitivity control PD and BI in a wide range of large direct currents converted and flexibility of the integrating circuit, and the implementation of BP and BI as a portable or stationary [8 - 12].

It was found that the instability of the current control systems, the presence of additional resistance due to oxidation of the contacts lead to a decrease in the productivity of rolling machines, vacuum arc melting furnaces, chemical devices, and downtime, and large voltage drops on the shunts lead to unjustified loss of power [13 - 14].

Recently, the development of automated control and management systems for various technological and physical processes has been characterized by the widespread use of primary means of collecting and processing information [15 - 20], and constantly increasing requirements for elements and technical means of monitoring and control systems in the electric power industry and, in particular, in the power supply of electrical installations in hydraulic engineering, irrigation and industry, pumping stations in water supply and land reclamation, led to the development of energy-saving and measuring contactless ferromagnetic transducers of large DC currents (BFN) with split integrating circuit, which is the major part of BP and BI and enable without disturbing the structural integrity and the printed circuit device encircles the conductor with a current convertible and contactless control its value [21 - 24].

In practice, the studies showed an urgent need for land reclamation, in many enterprises and farms in the water supply zone of agriculture, in contactless non-destructive control of BPT in the number of tens to several thousand amperes and higher using both portable and stationary contactless non-destructive transducers (BP) and BPT measuring instruments (BI) of non-destructive testing with an error of 1 - 3%, applying in many cases multi-limit, as well as with a flexible integrating circuit BP and BI [14].

Despite a large number of individual developments in this area [25- 51], the instrumentation manufacturing industry both in the Republic of Uzbekistan and the CIS countries, as well as in the world has not yet produced commercially lightweight detachable wide-range technological, relatively
accurate and inexpensive lightweight detachable stationary and portable non-destructive non-contact transducers and high direct current meters [7,14]. This is due, on the one hand, to the lack of a sufficiently tested version of BP and BI and their appropriating theory, and, on the other hand, to the rigidity of the requirements for them.

It was established that none of the known and considered BP and BI satisfies the above requirements in full [2] with the exception of magneto-optical transformers and current converters. These magneto-optical measuring instruments have several advantages: the ability to install without breaking the circuit and use in high-voltage circuits, portability, resistance to transportation, and environmental factors. At the same time, they have relatively low sensitivity, a complex structure, and an ambiguous relationship between the converted current and the value of the angle of polarization. Besides, they have additional time and temperature errors and are of the high cost. This prevents their widespread use [52]. Therefore, non-contact control of large DC currents using optimal non-contact transducers and the creation of their theory is still an urgent task of automation and information-measuring equipment [14]. In practice, at present, for this purpose, the most widely used magnetic modulating contactless transducers and galvano-magnetic contactless ferromagnetic transducers (GBFP) high constant currents. However, the known transducers have several disadvantages, the main of which are: a narrow controlled current range, low accuracy and sensitivity, large dimensions, and weight [3-6,22,23,39,41]. Therefore, the elimination of these shortcomings in the developed GBFP and the development of their theory is the goal of this work. We have developed a number of GBFP [53].

2. Methods
Let us consider the features of the operation of galvano-magnetic contactless ferromagnetic transducers of large direct currents using the optimal design of GBFP, which is a practically generalized version of the developed galvano-magnetic contactless ferromagnetic transducers of high constant currents.

3. Results and Discussion
The GBFP has (Fig. 1 a) a detachable closed magnetic circuit made of separate ferromagnetic elements 1, 2 with longitudinal gaps, Hall transducers 3 and 5 located in the transverse gaps between the ferromagnetic elements 1 and ferromagnetic elements 2, and a recording device 9. Also, similar ferromagnetic elements are inserted into the transducer elements 1, forming additional longitudinal gaps with ferromagnetic elements 2, in which Hall transducers 4 and 6 are placed, comprising pairs of transducers with Hall transducers 3 and 5 pairs of transducers 3, 4 and 5, 6 of the Hall, located almost at one point of the magnetic circuit (Figure 1b).
As a result of the indicated arrangement of the pairs of Hall transducers and the counter closure of the Hall electrodes of the Hall transducers in these pairs, a large degree of compensation of the influence of external inhomogeneous magnetic fields on the transducer is provided, which increases its conversion accuracy. To increase the sensitivity of GBFP, Hall transducers were supplied with short-time rectangular current pulses from a special generator. When measuring the amplitude values of the rectified current in this case, the synchronous voltage supply of the control current pulses of the Hall transducers with the converted current in the bus is provided in the GBFP. This is achieved by supplying the GBFP with a magnetically controlled contact located near the bus with the converted current and included in the current electrode circuit of the Hall transducers. Fig. 2. shows the electrical circuitry of the output circuit of the GBFP with increased accuracy.

![Figure 2. High accuracy GBFP output circuit](image)

An expression was obtained for the magnetic flux passing through the extreme ferromagnetic elements 1 in the form

\[
\Phi = \frac{I}{2nZ_r K_\Delta} \cdot \{4 \sinh \beta + \beta \cdot [(K_m + K_b) \cdot (\cosh \beta - 1) - (K_m - K_b) \cdot (\cosh \beta_0 - \cosh \beta)(1 - x_0)]\} \quad (1)
\]

where:
- \( I \) is the controlled current;
- \( n \) is the number of ferromagnetic elements in one plane;
- \( Z_r \) is the magnetic resistance of the extreme ferromagnetic elements, equal to \( Z_r = r_{\mu mid} X_M \)

where in turn
- \( r_{\mu mid} \) is the linear magnetic resistance of a section of each extreme ferroelement length \( X_M \);
- \( X_M \) - maximum coordinate value \( x \):
  
  \[
  K_\Delta = \beta \cdot K_m \cdot (1 + K_m + 2K_b) \cdot (\cosh \beta - 1) + 2 \cdot (2 + K_m + K_b) \cdot \sin \beta
  \]

where \( \beta = \gamma X_M \)
where in turn \( \gamma = \sqrt{2I\mu_{mid}g} \) and \( g \) is the linear magnetic conductivity of the longitudinal air gap between the extreme and middle ferromagnetic elements:

\[
K_m = \frac{Z_m}{Z_r}, \quad K_b = \frac{Z_b}{Z_r},
\]

where in turn

- \( Z_m \) is the magnetic resistance of a section of one of the extreme ferromagnetic elements with a length equal to the length of the transverse clearance;
- \( Z_b \) is the magnetic resistance of the transverse gap between one pair of adjacent lower or upper ferromagnetic elements;

\[
K_{bm} = \frac{Z_b}{Z_m}
\]

\( x_0 \) is the coordinate of the considered section of ferromagnetic elements in relative units, equal to \( x_0 = \frac{x}{X_m} \).

Figure 3 shows the results of theoretical (continuous line) and experimental (dashed line) studies of the passage of magnetic flux through the extreme rods at a constant current \( I = 1000 \, A \) in GBFP having geometric dimensions and parameters:

\[
l_1 = l_3 = 4.71 \times 10^{-2} \, m; \quad l_2 = 2 \times 10^{-3} \, m; \quad X_M = 4.71 \times 10^{-2} \, m;
\]

\[
h_1 = h_3 = 2 \times 10^{-3} \, m; \quad h_2 = 4 \times 10^{-3} \, m; \quad \rho_m = 2600 \, \frac{m}{G\Omega}; \quad n = 2; \quad b = 6 \times 10^{-3} \, m.
\]

Ferrow elements are made of electrical steel of the ARMCO type. The discrepancies between theoretical and experimental results do not exceed 5 \%

Based on (1), a mathematical model of GBFP is obtained in the form:

\[
E = \frac{mK_xI_{\pi}}{2nZ_rK_{\Delta}} \cdot \left\{ 4\sinh \beta + \beta \cdot \left[ (K_m + K_b) \cdot (\cosh \beta - 1) - (K_m - K_b) \cdot (\cosh h_0 - \cosh \beta)(1 - x_0) \right] \right\} \quad (2)
\]

Here \( m \) is the number of Hall transducers;

- \( K_x \) is the proportionality coefficient of the Hall transducer, depending on the parameters of the semiconductor material, the ratio of the geometric dimensions of the transducer and its operation mode;
- \( I_{\pi} \) is the hall Transducers Supply Current;
\(S\) is the area occupied by the Hall Transducer;

The error in determining the electromotive force \(E\) by the expression (2) of the mathematical model of GBFP does not exceed 5%.

The obtained mathematical model of GBFP is used in the calculation of galvano-magnetic BPPs and can be widely used in the calculation of any BPP with longitudinally and transversely distributed electromagnetic parameters. The following is a technical description of one of the developed GBFP.

Technical characteristics of GBFP: the range of controlled direct and alternating currents – 0 – 20000 A; sensitivity – 0.1 mV/A; the value of the reduced error – 1.5%; insulation voltage – 2 kV; the diameter of the inner window of the detachable magnetic circuit – 210 mm; weight – 1.4 kg.

4. Conclusion

Effective universal galvano-magnetic contactless transducers of large direct currents have been developed for modern monitoring and control systems in agro-energy, characterized by an expanded controlled range of converted constant currents with small dimensions and weight, increased accuracy, simplicity, and manufacturability of the design with low material consumption and cost and the possibility of contactless control of constant and alternating currents with an error of 1.5%.

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