Contactless wide-range ferromagnetic high-current converters for monitoring and control systems in the electric power industry

Anatoliy Plakhtiev*, *Gayratjon* Gaziev, *Odil* Doniyorov, and *Khayot* Muradov

"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Tashkent, Uzbekistan

Abstract. The paper shows that the impossibility of breaking the current circuit for the production necessity of temporarily switching on electrical measuring instruments, large power losses on shunts, and the need to obtain quick information about the quality of the functioning of technological processes have led to the widespread use of non-contact conversion and measurement of high direct currents in circuits without breaking them. Light detachable wide-range stationary and portable non-contact transducers and meters of high direct currents are not yet mass-produced. In this regard, it is expedient to develop and study non-contact converters and meters of high direct currents, which are distinguished by a wide range of converted currents, small dimensions and weight, increased accuracy, and sensitivity of electric power facilities. The questions of sensitivity of magneto-modulation non-contact transducers are considered. The expression for the optimal static characteristic of the developed magneto-modulation non-contact transducer is determined and analyzed. Its maximum deviation from the calculated value does not exceed 6%. The expressions for the current, average sensitivity, and sensitivity regarding the magnitude of the excitation of a magneto-modulation non-contact transducer are obtained and investigated. In this case, the maximum sensitivity of the transducer reaches a value of 0.425 with an optimal excitation value of 1.65. It is recommended to take the allowable limit of the input value of the converter to be less than one. Its input value must be taken equal to 0.7. The developed magneto-modulation non-contact transducer has an increased sensitivity due to longitudinal modulation. It can be widely applied in control and management systems in melioration and irrigation, water supply, industry, metallurgy, railway transport, science, technology, GIS technology, and, in particular, digital coverage and database visualization, and as well as for checking electric meters at the place of their installation for non-contact control of direct, as well as alternating currents.

* Corresponding author: a.plakhtiev@mail.ru

1 Introduction

Recently, the development of the electric power industry of agriculture, a powerful electric drive of power plants of large water supply stations, land reclamation, irrigation, hydraulic engineering, electrochemical industry, metallurgy, railway transport, and some new industries, science, and technology causes an ever-increasing production and consumption of large direct currents [1]. Currently, about 30% 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 (CLC) is one of the important problems of modern information and measurement technology [2]. At the same time, the need to break the current circuit for temporary switching on of electrical measuring devices [3], the presence of large power losses on shunts, the undesirability or impossibility of breaking the circuit under the conditions of the technological process [4], as well as safety requirements, led to the use of contactless converters [CC] and DC meters [BI] in circuits without breaking them, i.e., without destroying the integrity of the conductive bus [5].

Despite a large number of individual developments in this field [6, 12-28, 31], the instrument-making industry in both the Republic of Uzbekistan and the CIS countries has not yet produced lightweight detachable stationary and portable non-destructive contactless converters and meters of large direct currents [7]. This is explained, on the one hand, by the lack of a sufficiently tested version of CC and CM [8], and on the other hand, by the rigidity of the requirements imposed on them [9]. Therefore, analyzing and developing an approved version of CC and CM is the object and subject of research.

It is established that none of the known and considered CC and CM fully meet the stringent requirements. Therefore, the analysis and development of contactless converters and meters of large direct currents that meet stringent requirements is an urgent problem of automation and information and measuring technology [10] and the purpose of this work. In practice, magneto modulation contactless converters of large direct currents are currently the most widely used for this purpose. However, the known converters have a number of main disadvantages: a narrowly controlled current range, low accuracy and sensitivity, large dimensions, and weights [11]. Therefore, the development of contactless wide-range magneto-modulating ferromagnetic converters of high direct currents (CWC) of increased sensitivity for multidisciplinary monitoring and control systems can contribute to achieving this goal, which is the main task of the work.

2 Materials and Methods

We have developed several CWCs [6, 29,30]. Figure 1 partially shows one of the variants of the developed CWC with basic dimensions. This design was developed based on CC [32] and is a CWC with transversely and longitudinally distributed magnetic parameters. It is characterized by increased sensitivity and an extended range of converted currents. The CWC contains a detachable closed magnetic circuit 1 consisting of two identical halves 2 and 3, each of which in turn consists of separate ferromagnetic elements made in the form of trapezoids with the same gaps between them. In each ferromagnetic element, there are two through holes, through each of which a modulation winding is wound, consisting of sections 4 and 6. Sections 4 and 6 are connected in series and according to. A measuring winding 5 is wound at the modulation winding between the through holes. All measuring windings are connected to each other in series and close to the measuring device, and the modulation windings are also connected in series and connected to a stable AC source (not shown in Fig. 1). For a free girth of the bus 7 with a controlled current, the closed magnetic circuit 1 is made detachable. The serial connection of the modulation windings 4 and 6 with each other in the presence of alternating current in them and the location of the measuring

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windings 5 in the gaps between the through holes in the ferromagnetic elements made it possible to carry out longitudinal modulation of the magnetic resistance of the magnetic circuit in the path of the working flow F created by a controlled direct current, which made it possible to bring in the measuring windings 5 EMF, depending on the converted DC. The developed CWC can also control alternating currents. In this case, no alternating current should exist in sections 4 and 6 of the modulation winding.

Expansion of the upper limit of controlled direct current in the developed design of the CWC is carried out by increasing the length of the working magnetic flux along the steel of the magnetic circuit elements and including transverse and longitudinal air gaps in its path, i.e., performing a split magnetic circuit with transversely and longitudinally distributed magnetic parameters.

Use 170 x 250 mm paper size (W x H mm) and adjust the margins to those shown in Table 1. The final printed area will be 130 x 210 mm. Do not add any page numbers.

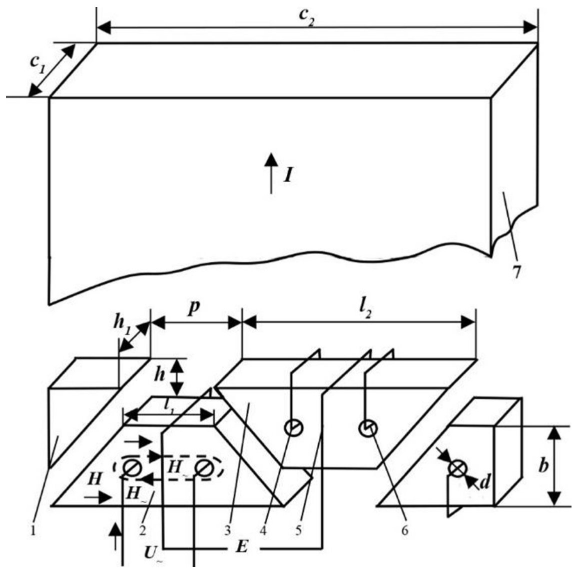

Fig.1. Part of contactless magnetomodulating wide-range converter for large direct currents

3 Analysis and Results

When measuring the CLC with a split magnetic circuit, the CWCS covers the bus 7. Due to the modulation ampere-turns, the split magnetic circuit is in a saturated state during each half-cycle of the supply voltage. In this case, the permeability of the magnetic core for the longitudinal field created by the controlled current decreases sharply. At the moment when the modulation current passes through the zero value, the permeability of the magnetic core increases to the initial value. Thus, with the stability of the ampere-turns of modulation in the measuring winding, an EMF of twice the frequency will be induced, depending on the controlled current, in the form of

$$E_m^* = \pi^{-1}\left(2arctgH_{xm} - arctg(H_{xm} - H_{mm}) - arctg(H_{xm} + H_{mm})\right). \quad (1)$$

Here E_m^* is the maximum output EMF in relative units; H_{xm} is the dimensionless value of the maximum limit of the measured value; H_{mm} is the dimensionless value of the excitation.

The obtained expression (1) is a static characteristic of the CWC, showing the dependence $E_m^*=f\,(H_{xm}, N_{mm})$. The use of an intermediate variable H_Hx m as a converted value is justified by the fact that the output EMF of the CWC is an unambiguous function $H_{of\ H}$x m for a given value *of* H_{mm}, and on the other hand$H_{,\ H}$ x m carries complete information about the value of the converted current I_{and} and the steel grade used in the magnetic circuit.

With the mutual movement of the halves 2 and 3 of the split magnetic circuit CWC, the size of the gaps between the trapezoids changes, leading to a change in the magnetic resistance of the magnetic circuit in the path of the working magnetic flux *F* created by a controlled direct current. This leads to a change in the limits of the controlled current, i.e., it allows us to make the CWC multi-limit.

To analyze the sensitivity of the CWC, we will use the expression of its static characteristic (1). The CWC has a sensitivity to the value of the excitation H_{mm} and the value of the converted current or its proportional emyvalue N_{xm}..

The sensitivity of the CWC in terms of the excitation value $S_B(H_{mm})$is determined from the expression

$$S_B(H_{SBHmm}) = \frac{E_m^{*H}}{H_{mm}} = \pi^{-1}H_{mm}^{-1}(2arctgH_{xm} - arctg(H_{xm} - H_{mm}) - arctg(H_{xm} + H_{mm})) \quad (2)$$

The calculated values of the CWC sensitivity in terms of the excitation value$S_B(H_{Sbh\ mm})$ obtained from (2) are shown in Fig. 2.

Analysis of the built characteristics shows that the maximum sensitivity reaches a value of 0.425 at

$$H_{mm} = 1.65. \quad (3)$$

This condition characterizes the optimal operating mode in terms of obtaining maximum sensitivity.

Expression (3) corresponds to the optimal excitation current determined by

$$I_{mOPT} = \frac{1.65 l_{cp}}{a_2 w_m}. \quad (4)$$

Now, from the family of static characteristics of the CWC, using (4), select one of its optimal static characteristics in the form

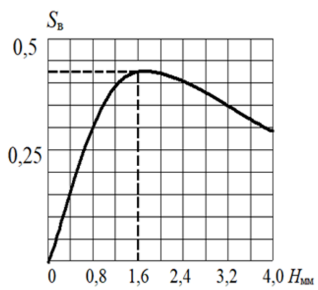

Fig. 2. CWC sensitivity

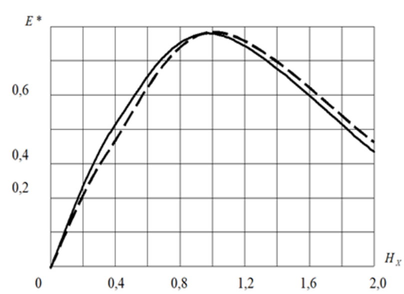

Fig. 3. Optimal static by the amount of characteristics modulation CWC

$$E^* = \pi^{-1}(2\ arctg\ H_x - arctg\ (H_x - 1.65) - arctg(H_x + 1.65)) \quad (5)$$

According to expression (5), the dependence $E^* = f(H_x)$ is calculated. The calculation results according to (5) are shown in Fig.3. The experimental optimal static characteristic (dashed line) for the following specific parameters of the CWC is also constructed there: $D_{out.} = 0.2$ m; $D_{in.} = 0.18$ m; $h_1 = 2.8 \cdot 10^{-3}$ m; $h = 1 \cdot 10^{-3}$ m; $\delta = 2 \cdot 10^{-3}$ m; $b = 15 \cdot 10^{-3}$ m; $X_m = 18 \cdot 10^{-3}$ m; $\beta = 0{,}19$; $n = 15$; $n_\Sigma = 30$; $K_{зп} = 300$. At the same time, the CWC sinter line is made of cold-rolled steel 3414 with a sheet thickness of 0.35mm in the set, for which $a_1 = 1.853$ T; $a_2 = 0.714 \cdot 10^{-2}$ m/A.

The maximum deviation of the experimental dependence $E^* = f(H_x)$ from the calculated one in the increasing part at $H_{mm} = 1.65$ does not exceed 6%.

The possibility of reducing the output EMF of the CWC to zero under the influence of a large measured value can be used to build contactless magnetic current switches.

In further studies, the increasing part of the static characteristic is used.

Dividing (5) by H_x, we obtain the average sensitivity expression in the following form

$$S_{cp} = E^* / H_x = \pi^{-1} H_x^{-1}(2\ arctg\ H_x - arctg\ (H_x - 1.65) - arctg(H_x + 1.65)) \quad (6)$$

The derivative of the output value (5) from the measured value H_x is the current sensitivity $S_{T.}$ The expression determines the current sensitivity

$$S_T = \frac{dE^*}{dH_x} = \pi^{-1}\left(\frac{2}{1+H_x^2} - \frac{1}{1+(H_x-1.65)^2} - \frac{1}{1+(H_x+1.65)^2}\right). \quad (7)$$

The results of the calculation according to (6) are shown in Fig. 4

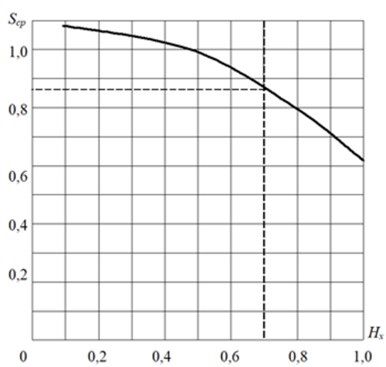

Fig. 4. Characteristics of the average

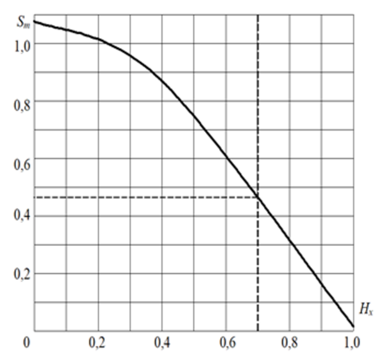

Fig.5. Characteristics of the current sensitivity of the CWC

Figure 5 shows the dependence $S_t = f\ (H_x)$ calculated from (7). The graph shows that the permissible limit of the input value of the converter must be taken less than one. Usually, its value is limited by H_x n = 0.7, corresponding to $S_t = 0.47$.

4 Conclusions

As a result of this work and the conducted research, the following results were obtained:
1. Universal creative multi–field wide – range magneto modulatory contactless converters of large direct currents with the possibility of measuring and alternating currents for modern monitoring and control systems in solar and laser

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technology, renewable energy sources, industry, agriculture, GIS technology, and, in particular, in digital coatings and database visualization, have been developed and also for checking electric meters at the installation site. They are distinguishedтby an extended controlled range of converted direct currents with small dimensions and weight, increased accuracy and sensitivity, simplicity and manufacturability of the design with low material consumption and cost, and the possibility of contactless control of direct and alternating currents with an error of 1.5 %.
2. The expression of the optimal static characteristic of the CWC is determined and analyzed. Its maximum deviation from the calculated value does not exceed 6%.
3. Expressions for the current and average sensitivity of the CWC, as well as the sensitivity of the CWC in terms of the excitation value, are obtained and studied. It is shown that the maximum sensitivity of the CWC in terms of the excitation value reaches 0.425 when the excitation is H_{vm} = 1.6. In this case, the permissible limit of the input value of the converter must be taken less than one.

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