INVESTIGATION OF MAGNETIC CIRCUITS OF A MAGNETOElastic CONVERTER WITH MAGNETIC FIELDS OF VARIOUS FREQUENCIES

Abstract. The article is devoted to the study of magnetic circuits of a magnetoelastic converter, the principle of operation of which is based on the magnetomodulation effect. A mathematical expression of the magnetization curve of the magnetic circuit of a magnetoelastic converter is obtained when magnetized by magnetic fields of various frequencies (direct and alternating) currents. The influence of the variable and constant components of magnetic induction on the nature of the magnetization curve is estimated. The obtained magnetization curves of a magnetic circuit with longitudinal modulation and their approximation formulas can be successfully used to calculate magnetomodulation magnetic circuits, where a constant magnetic field corresponding to the region of the magnetization curve above the Rayleigh one is modulated.

Keywords: magnetoelastic converter, magnetic circuit, magnetization curve, direct current, alternating current, mathematical model, experimental curves.

Introduction
Magnetic elements are widely used in computer science, measuring technology, computing and control systems. Research and development of new converters based on the use of magnetic properties of materials is an urgent direction in the creation of information systems [1, 2].

Materials and Methods
Currently, there are a number of works by domestic and foreign scientists devoted to the development of a mathematical model of the magnetization curve of a magnetic circuit of a magnetoelastic converter, taking into account the nonlinearity of magnetic characteristics. However, most of these works were carried out by the piecewise linear approximation method based on the linearization of magnetic characteristics, where nonlinearities are partially taken into account, which leads to an inaccurate calculation, as a result of which it is impossible to correctly choose optimal ratios between parameters to obtain the most effective values of the main characteristics of magnetic circuits of magnetoelastic converters. Therefore, it is necessary to develop mathematical models of the magnetization curve of the magnetic circuit of a magnetoelastic converter, which makes it possible to solve the problem in general, which is an
advantage over graphical and graphoanalytic calculation methods. To achieve this goal, it is necessary to describe the magnetic characteristics by analytical expressions [3].

Since the quality of the mathematical model being developed determines the accuracy of the calculation of magnetic circuits of a magnetoeelastic converter, taking into account the nonlinearity of magnetic characteristics, it is necessary to analyze existing analytical expressions.

Various converters are widely used in monitoring and control systems, the magnetic cores of which are magnetized simultaneously by constant and alternating magnetic fields. Such converters include magnetic circuits of a magnetoelastic converter. For the analytical calculation of magnetic circuits, it is required to develop a mathematical model of the magnetization curve of the magnetic circuit of a magnetoelastic converter with simultaneous magnetization by constant and alternating magnetic fields. The magnetization curves of magnetomodulatory magnetic circuits $B = f(H)$, in contrast to the magnetization curves of magnetic circuits with one magnetic field, are described by a function with two unknowns in the form of $B_n = f(H_m, B)$ or $B_\lambda = f(H_\lambda, B_\lambda)$, that is, the magnetization curve of direct current $B_n = f(H_n)$ is a function of the magnetizing magnitude $H_n$ or $B_n$, and the magnetization curve of alternating current $B_\lambda = (H_\lambda)$ is a function of the magnetizing $H_\lambda$ or $B_\lambda$.

Results and Discussion

Currently, about a hundred analytical expressions are known, determined by the methods of approximation of the magnetization curve $B = f(H)$ and the dependence of the specific magnetic resistance $\rho_\mu$ on magnetic induction $B - \rho_\mu = f(B)$, obtained by domestic and foreign authors [1-6]. From these expressions, it is necessary to choose the simplest ones and make it possible to solve the task to the end, while obtaining a non-cumbersome result of sufficient accuracy. The quality of the developed calculation method depends on the correct choice of the approximation formula.

In order to select a suitable approximation expression to obtain a more advanced method for calculating magnetic circuits of MEC-MM, taking into account the nonlinearity of magnetic characteristics, it is possible to analyze existing analytical expressions of magnetic characteristics and recommend new formulas for approximating the magnetization curve for magnetic modulating magnetic circuits of MEC-MM. However, it is necessary to determine the experimental dependence of the magnetization curve of magnetic circuits under the action of magnetic fields of different frequencies.

Experimental magnetization curves for a magnetic circuit with parallel directed constant and alternating magnetic fields are given in [4,5], where formulas for approximating the magnetization curve are given. However, these formulas are suitable for calculating magnetic circuits similar to chokes, magnetic amplifiers or magnetic stabilizers, their use in the analytical calculation of magnetomodulatory magnetic circuits leads to a large error. Consequently, analytical expressions describing the magnetization curve of magnetomodulatory magnetic circuits with longitudinal and transverse modulations should be obtained. To determine the analytical expressions, we construct an experimental magnetization curve in the form $B_n = f(H_n)$ of at different values of variable magnetic induction $B_n$ for both a magnetic circuit with longitudinal modulation and a magnetic circuit with transverse modulation [6].

To use these magnetization curves in the analytical calculation of magnetic circuits, it is necessary to express them by mathematical relations having the following form:
The experimental magnetization curve of magnetic circuits with modulation is determined by a sample made of electrical steel type E12 in the form of a hollow toroid (Fig. 1), consisting of two detachable parts. The curves defined by formula (1) \( B_a = \left( \frac{a_0}{a_0 - B_a} \right)^3 B_1^3 + \left( \frac{a_0}{a_0 - B_a} \right)^5 B_1^5 \), or

\[
H_a = a' B_1 - b' B_1^3 + c' B_1^5;
\]

where \( a_0, a, b, c \) - constant coefficients.

\( a_0 = (1.7+)T; a = 3.26 \text{ A/} \text{mT}; b = 3.68 \text{ A/} \text{mT}^3; c = 2.96 \text{ A/} \text{mT}^5; \)

\( B_a \) - the amplitude value of the magnetic induction of alternating current, and \( B_a = (0 \pm 1.2)T \) and \( B_a \);

\( B_1 \) - direct current magnetic induction in the presence of induction \( B_a \).

The curves defined by formula (1) \( B_a = 0.3; 0.6; 0.9; 1.2; T \); for longitudinal modulation with \( a_0 = 1.8T \) and for transverse modulation \( a_0 = 1.7T^{-1} \) with are given in [6].

The experimental magnetization curve of magnetic circuits with modulation \( B_a = f(H_a)B_a \) is determined by a sample made of electrical steel type E12 in the form of a hollow toroid (Fig. 1), consisting of two detachable parts.

One of them has an annular groove in which the windings are laid \( W_{M1}, W_{M2} \). The second part consists of a cylindrical ring closing the path of the transverse flow. Moreover, the contact surfaces of both parts of the ferromagnetic sample are carefully ground in order to reduce the resistance of the joint for the transverse field. The windings \( W_1 \) and \( W_2 \) are arranged evenly along the entire length of the toroidal core and cover the entire magnetic core.

To determine the dependence \( B_a = f(H_a)B_a \) at different values of magnetic induction \( B_{al} \), an alternating current \( I_M \) is supplied to the winding \( W_{M1} \) (Fig. 1), and the EMF of the \( E_{out} \) is removed from the winding \( W_2 \), according to which the value \( B_{al} \) is determined changes until it becomes equal to the specified value \( B_a \).

After that, a constant current \( I_a = 0 + I_{maks} \) is supplied to the winding \( W_1 \) until the magnetic material is saturated, and the EMF of the \( E_{out} \) is removed from the winding \( W_2 \), according to which, using known formulas, the values \( B_a \) are determined and the dependence is built \( B_a = f(H_a) \) at a given value \( B_{al} \). If this experiment is repeated for \( B_{al} = 0.3; 0.6; 1.2 \text{ T} \), then a family of magnetization curves \( B_a = f(H_a) \) will be obtained \( B_{al} \), which is shown in Fig. 2.
To determine the magnetization curve of a magnetomodulating magnetic circuit with transverse modulation.

Figure 2 - Family of magnetization curves $B$-$H$ at different values of longitudinal induction $B$ (curves 1+5-experimental 1+5-calculated at $a = 1.8$ T.)
From the family of magnetization curves shown in Fig. 2 and Fig. 3 it can be seen that the shape of the curves shown in Fig. 3 for all values of \( B_a \) is similar to the curves shown in Fig. 2. The analysis of these experimental curves showed that if the magnetic material of the samples is isotropic, and the samples have the same geometric dimensions, the same values of signals on both direct and alternating current, taking into account the influence of windings (especially in a magnetic circuit with longitudinal modulation), then the same magnetization curves of the magnetic circuit for the longitudinal and for the transverse modulation.

It is also shown there that the calculated curves differ from the experimental curves by no more than 5-6%, and in some part of the magnetization curve this difference is less than one percent.

The obtained magnetization curves of a magnetic circuit with a longitudinal one and their approximation formulas can be successfully used to calculate magnetomodulation magnetic circuits, where a constant magnetic field corresponding to the region of the magnetization curve above the Rayleigh one is modulated.

Magnetic circuits of a magnetoelastic converter with both transverse and longitudinal modulation, which allows converting to alternating EMF in the range \( E_x = 0 \div 100 [MV] \), and current \( I_x = 0 \div 100 [MA] \), correspond to a number of designs with \( B_{max} = 0.1 [T] \). After compensation \( B_{max} \) by compensating magnetic induction \( B_{sK} \), their difference tends \( \Delta B_s (\Delta B_s = B_{smax} = B_{sK}) \) to a minimum \( B_{smin} \), which corresponds to the sensitivity \( (B_{smin} = E) \) threshold of the amplifier. If we take the sensitivity threshold \( E^1 = 10 \cdot 10^{-6} \) of the amplifier in, then \( B_{smin} = 1 \cdot 10^{-4} [T] \).
Conclusion

It is established that the reduced value of induction $B_{\text{min}}$ is very small compared to variable magnetic induction $B_{\text{v}}$ and almost does not affect the nature of the magnetization curve of the magnetic circuit both with longitudinal and transverse modulation.

It is shown that with a small direct current signal, the dependences $\mu = f(wt)$ and $\mu_g = f(wt)$, respectively, are determined by the laws of change in magnetic induction $B_{\text{alt}}$ and $B_{\text{df}}$ or voltage $H_{\text{alt}}$, $H_{\text{df}}$, and almost do not depend on the magnitude of magnetic induction $B_{\text{v}}$ or direct current voltage $H_{\text{v}}$.

REFERENCES


Kamila Jurayeva, PhD (technical science), associate professor, of the Department “Power supply”, Tashkent state transport university, Tashkent, Uzbekistan, lade00@bk.ru