Issues of investigation of the dependence of static characteristics of magnetoelastic converters of mechanical quantities on the influence of external

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Abstract. The article presents the results of a study of the magnetic permeability and the magnetostriction coefficient of a magnetoelastic material on temperature, tensile forces, as well as the dependence of sensitivity to a large extent on the absence of joints in the design of a magnetoelastic transducer (MT). Analytical and graphical expressions of the dependences of the magnetic permeability and the magnetostriction coefficient on the tensile force are given. **Keywords**: magnetic permeability, magnetostriction coefficient, temperature, tensile forces, analytical and graphic expression, sensitivity, magnetoelastic transducer

1 Introduction

The current state of science and technology is characterized by the widespread use of converters, one of the components of which is a sensitive element (SE). It belongs to the most important parts of the block diagram of the converter and provides the conversion of a mechanical quantity into an active electrical quantity. Being an integral part of the converter, the SE must ensure the invariance of the measurement result to the parameters of the magnetic material and to the destabilizing factors affecting it. Another feature of the SE is that it must perform transformations only of those converter parameters whose functional relationship with the process under study will allow, after processing the output signals, to obtain a signal that depends only on the measured value. The sensing element, like all measuring instruments, has methodological and instrumental errors, and its methodological error is mainly due to the discrepancy between the informative parameter and the parameter of the parametric converter that is being converted, as well as the degree of error correction introduced as a result of measuring the magnetization curve of the magnetic material. Usually, in order to increase the sensitivity of the transducer, a magnetic material with a small instrumental but large methodological error was selected. In this case, the methodological error is due to the fact that its output signal is proportional to the difference in the complex

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resistances of the inductance coils of the converter, and the informative parameter is only the difference in inductance. The source of the occurrence of the instrumental error of the converter should be attributed to the dependence on the mechanical stresses arising in them (magnetoelastic effect) caused by the influence of mechanical forces on the ferromagnetic material. The desire to reduce the error of nonlinearity and dimensions, as well as to expand the temperature range, requires the study of the dependence of changes in both the magnetic permeability and the magnetostriction coefficient of the material on changes in ambient temperature.

Therefore, the identification and evaluation of the influence of destabilizing factors on the characteristics of magnetoelastic converters of mechanical quantities is relevant. Currently, there are various methods and means of solving this problem. However, their use for magnetoelastic converters of mechanical quantities does not allow us to evaluate the effects of destabilizing factors with high accuracy. Below we will consider the principle of operation and the influence of external influences on the properties of the SE converter.

The principle of operation of magnetoelastic transducers is based on a change in the magnetic permeability μ of ferromagnetic bodies depending on the mechanical stresses arising in them (magnetoelastic effect) caused by the action of mechanical forces P on ferromagnetic bodies, such as: stretching, compressing, bending, twisting. The change in magnetic permeability $\Delta\mu/\mu$ for various materials is $0.5-3\%$ with a change of σ by 1 MPa [1].

There are two main groups of magnetoelastic converters. Converters in which changes in the magnetic permeability of the sensing element are used in one direction; the magnetic flux in them is directed in most of the magnetic circuit along the line of action of the force, belong to the first group. In such converters, the inductance of the winding or the inductance between the windings changes under the action of the measured force. In the first case, a chain of transformations $\Delta\mu/\mu\ P\rightarrow\sigma\rightarrow\mu\rightarrow Z_m\rightarrow L\rightarrow Z$ is realized, in the second - $P\rightarrow\sigma\rightarrow\mu\rightarrow Z_m\rightarrow M\rightarrow E_2$.

Converters that use a change in magnetic permeability simultaneously in two mutually perpendicular directions belong to the second group. In such converters, the magnetic flux is directed at an angle of 45° to the line of action of the measured force. In the unloaded state of the converter, the power lines of the primary winding are arranged symmetrically and do not interlock with the secondary winding, therefore, the EMF of the secondary winding is zero. After applying an effort due to a change in the magnetic permeability of the material, the magnetic lines of force "stretch" in the direction of greater permeability, "contract" in the direction of lower permeability and, coupling with the secondary winding, induce an EMF in it proportional to the force applied to the converter. In this case, the phase of the output EMF varies depending on the sign of the load. Moreover, in the absence of a load, due to the initial magnetic anisotropy of the material, some EMF already appears.

When twisting ferromagnetic bodies, magnetoanisotropic properties are manifested when a current passes through a rod that is affected by a torque, in addition to a circular magnetic flux, a longitudinal magnetic flux arises in the rod, inducing an EMF proportional to the torque in the winding wound on the rod.

2 Statement of the problem

The characteristics of a magnetoelastic transducer are determined primarily by the magnetoelastic sensitivity S_μ of the material from which the magnetic circuit of the transducer is made. The value of $S_\mu=\Delta\mu/\mu\cdot\sigma$ depends on the type of material, the nature of its heat treatment, the nature of stresses (tension or compression), the mode of operation of the magnetic circuit (the mode of a given induction B or the mode of a given tension H), the value of induction B. Information about the magnetoelastic properties of ferromagnetic materials is still very limited. In addition, it is known that this process is most influenced by external destabilizing environmental factors, such as temperature (T), mechanical stresses P_x [2].

In this regard, there is a need to take into account these factors when conducting mathematical modeling of CBM mechanical quantities.

3 Solving the problem

The creation of mechanical (longitudinal P_n or torsional P_k) stresses in the ferromagnet medium leads to a violation of the initial domain structure, which consists in a change in the magnetic susceptibility χ, magnetic permeability μ, magnetostriction coefficient λ, and the electrical resistivity ρ_e of the material [3].

It is established that the change in the magnetic susceptibility χ of the ferromagnetic material of the magnetic core of the magnetoelastic converter (MEC) under the action of tensile stresses of the P_n occurs according to the following law:

$$\chi_{P_n} = \pm\left[\chi_0 + G_h(1+k_{P_n})^2\right] \tag{1}$$

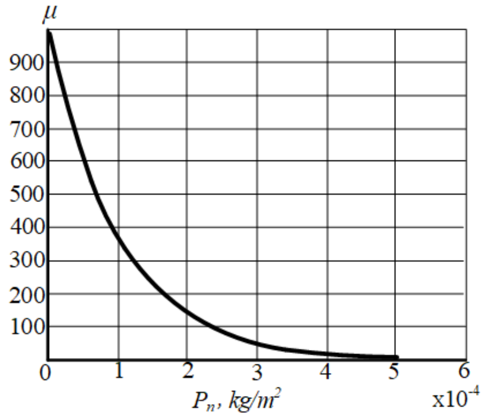
Were, χ_0 - initial magnetic susceptibility of the material, G_h - coefficient of energy losses per hysteresis, k_{P_n} - longitudinal stress coefficient.

As a result of a change in the magnetic susceptibility, χP_n (1) leads to a change in the magnetic permeability of μP_n and the magnetostriction coefficient λP_n in accordance with the following expressions:

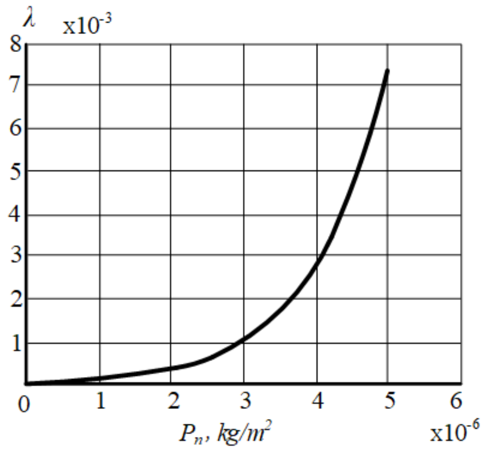
$$\mu P_n = \mu(1-k_{P_n}) \tag{2}$$

$$\lambda P_n = \pm\lambda(1+k_{P_n}) \tag{3}$$

Dependency graphs based on equations (2 - 3) for magnetic material.



a)



b)

Fig. 1. The effect of the tensile force P_n of the magnetic material, a) – influence on the magnetic permeability μ ; b) – influence on the magnetostriction coefficient λ .

It can be seen from the graphs that with an increase in the tensile stresses of P_n , the magnetic permeability μ decreases, and the magnetostriction coefficient λ increases.

Based on the consideration of permissible heating, the power supply voltage of the MES is selected and the mode corresponding to the maximum magneto-elastic sensitivity is provided in the magnetic circuit. For most materials, the maximum S_μ corresponds to approximately the same ranges B and H as the maximum μ . In magnetoelastic converters in the working part of the diagonal section, it is recommended to choose an induction of $B = 1.5Tl$.

In the design of the magnetic circuit of the converter, joints of individual parts are undesirable, since the magnetic resistance of the joints changes with the mechanical load of the magnetic circuit and this change can introduce a significant error. Therefore, despite technological difficulties, it is desirable to perform magnetic circuits of converters without joints according to [3, 9-10].

Another factor affecting the parameters of the MES is the ambient temperature (T) in the range from $T \geq 40^{\circ} C$, causing deviations from the specified output characteristics of the converter. The nature of these changes is primarily associated with thermal deformations of the crystal lattice of the magnetic core material of the MES, the redistribution of wave and electrical energy in the magnetic and electrical circuits of the primary and secondary converters of the magnetic system.

To describe thermal processes in the MES, we introduce an indicator of the temperature change of the parameter: $k_T = (1 - T / T_b)$, where T, T_b are the current and boundary values of temperature.

Thermodynamic theory is known for thermal processes in technical objects. However, its use for magnetoelastic ferromagnets causes difficulties in determining a number of thermodynamic coefficients. Therefore, using similar results of experimental studies [5, 7-8], we will obtain mathematical models of the main parameters of the CBM and conduct their study depending on temperature.

Its influence is taken into account through the coefficient of temperature change k_T determined in accordance with the expression [4]:

$$k_T = \left(1 - \frac{T}{T_C}\right)^{1/n} \tag{4}$$

Where T - is the current temperature value; T_C - is the temperature of the phase transition of the second kind (Curie point); $n = 2,3,4$ is an indicator of the influence of temperature on the material parameter.

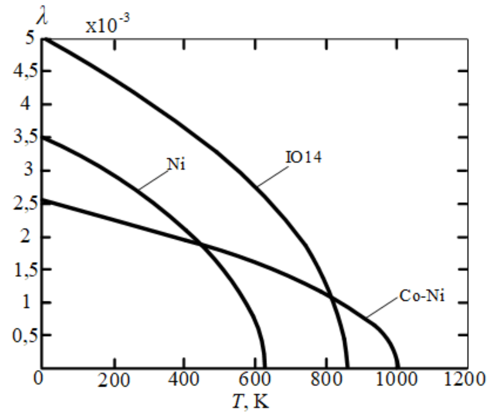
It is known that an increase in temperature T leads to a change in the magnetostriction coefficient λ_T according to [2, 6]:

$$\lambda_T = \pm \lambda \sqrt{\left(1 - \frac{T}{T_C}\right)} \tag{5}$$

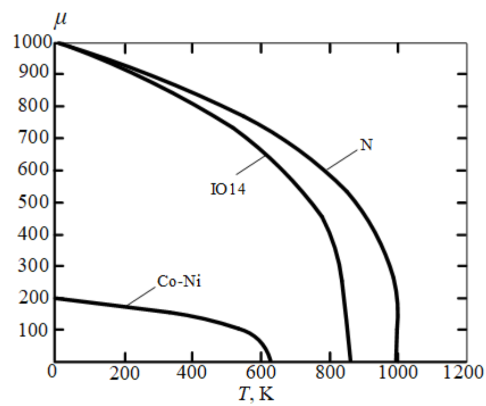
Consequently, the magnetic permeability μ_T of the MES material changes in accordance with the following expression [2]:

$$\mu_T = \mu \sqrt[3]{\left(1 - \frac{T}{T_C}\right)} \tag{6}$$

As a result of the analysis of equations (5) and (6) for various magnetoelastic materials of the MES, it is shown that a change in the ambient temperature causes a change in both the magnetic permeability μ, so is the magnetostriction coefficient λ of the material. The dependences of the magnetostriction coefficient and magnetic permeability are shown in Fig. 2.



a)



b)

Fig. 2. Temperature dependences T, a) – dependence of the magnetostriction coefficient λ ; b) - dependence of the magnetic permeability μ .

4 Conclusion

As a result of the study of the influence of destabilizing factors on the characteristics of magnetoelastic converters of mechanical quantities, it was found that the influence of temperature leads to a decrease in the values of magnetic and magnetostrictive parameters of the MES, while maintaining operability in the range not up to $T = 120...150^{\circ} C$, mechanical stresses $P_x = 0.5...1.5\, kg / mm^2$, on the contrary, lead to a significant increase in the amplitude of the output signal of the MES by changing the magnetostrictive parameters of the magnetic core material, and they can serve as a compensatory measure for changing the parameters of the converter caused by a change in the external temperature of the medium, improving its metrological and operational characteristics, and the implementation of magnetic circuits of converters without joints significantly improves the sensitivity of the MES.

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