

MAGNETIC MEASURING SYSTEM (MMS), SPECIAL FEATURES OF THE DESIGN OF ITS TRANSDUCER AND ITS METROLOGY SUPPORT

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INTRODUCTION

At design the devices for measurement of magnetic characteristics of ferromagnetic materials and details, among this having the aim of magnetic nondestructive testing, the general part plays the selection of measuring method and of specific first-order transducer. Thanks the simplicity of realization and the stability of measurements wide use the methods which measure the magnetic flow of specimen, connected to the measuring coil, are found [1]. To this methods relate the method of ballistic galvanometer (devices type BY-3 and Y5045), different fluxmeters and devices with vibrating induction transducers.

Last time new high-productive methods on the base of continuous integration of the induced at the reverse magnetization signal and the implementing automatic measuring devices, which use the computers, are designed. Many systems, using these methods, among them computerized, are designed [2-6].

MAIN RESULTS

In the described device for measurement of magnetic characteristics УИМХ the slowly changing magnetic field is used with an opportunity of selection of optimum for the specimen under test velocity of reversal magnetization and the induction-continuous measurement of magnetic parameters of ferromagnetic materials is used. Such approach is characterized by high efficiency. The low frequency of the reversal magnetization field (up to 0,05 Hz) allows to decrease the influence of the eddy current and to measure the characteristics of ferromagnets near to static one. At the same time it allows the simple and effective automation of the measuring process of main magnetic characteristics of ferromagnets.

The system УИМХ is the measuring device working under the control of PC, that indicates, processes and brings out to display the measured parameters and the data files of the ferromagnetic specimen. The system consists of magnetizing unit, control unit, PC, printer and transducer.

The magnetizing unit consist of master oscillator, power amplifier and the reference resistor and generates through the winding of the transducer linear current of the saw-tooth form with maximum amplitude of 5,4 A and the frequency of 0,05-0,5 Hz for the magnetization of specimens.

The measuring unit includes integrator, channel of measuring the strength of the reversal magnetization field, channel of induction measuring, the unit of control and data processing. The channel of measuring the strength of the reversal magnetization field ensures the indication of the values of the reversal magnetization field under the control of magnetization controllers. The channel of magnetic induction measuring is constructed on the base of analogous integrator for the signal processing, received from the measuring windings of the transducer. The control and the error compensation of the transformation using PC are realized. The special feature of that device is the decrease of the measuring error thanks the taking into account of the self-bias of the channel of magnetic induction on the base of data, received before and after the measurements and thanks corrective actions. This allows at the reversal magnetization frequency of 0,05 Hz the minimize the drift of the measuring channel up to 0,4 %.

PC controls the processes of reversal magnetization and measuring through the universal port USB. The software of the microcontrollers of the magnetization unit and of the control unit and the main program ensure the process of measuring, data processing, saving and data output.

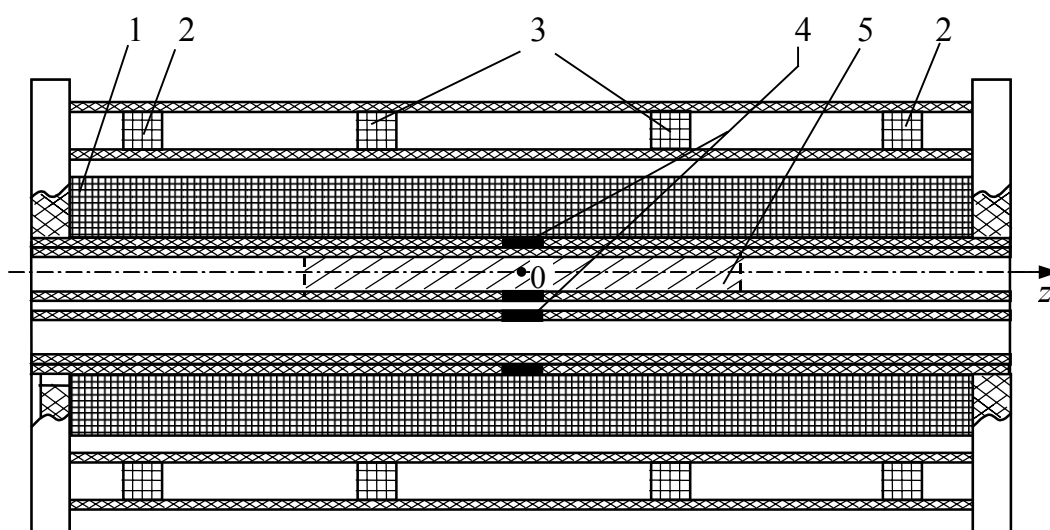
As the device is intended for the investigation of the magnetic characteristics of soft magnetic materials, than in accordance with the demands, the maximum value of the reversal magnetization field

strength is 40 kA/m, maximum value of the measured magnetic induction of the ferromagnetic specimen is about 2,5 T and minimum reversal magnetization frequency is 0,05 Hz.

The system magnetizes reversal the ferromagnet under test by the magnetic field of the through-type transducer (in the case of ring for this aim the field of the magnetizing winding is used) with the simultaneous indication of magnetic induction B , occurring in the specimen, and of the raising it field H . As a result the hysteresis loop and its main parameters (coercive force H_c , remanent induction B_r , maximum value of magnetic field H_m , maximum induction B_m , differential magnetic permeability μ_{H_c} at the field equal to the coercive force) are received.

To ensure the required value of maximum reversal magnetization field and its homogeneity along the specimen under test (in according to the standard ГОСТ 8.377-80 [7]) the transducer was designed [8], the design of what ensures the opportunity to correct the inaccuracy of production and to optimize its dimensions and weight.

The transducer of the system УИМХ includes the magnetizing system and the system of measuring windings. The magnetizing system (Figure 1) consists of many-turn solenoid 1, two identical windings 2, arranged above the solenoid 1 near its end-faces and connected with the solenoid in series-aiding, of two additional ring windings 3, arranged above the solenoid symmetrical relative its centre. Inside the magnetizing solenoid symmetrically are arranged two working zones, the central portion of each from they is encloses one from the two differentially connected measuring windings 4, each of them 10 mm long. In the one working zone 5 and accordingly the measuring winding the specimen is placed. At common length of the transducer of 384 mm each working zone has the length of 200 mm, the width of 20 mm and the height of 10 mm.

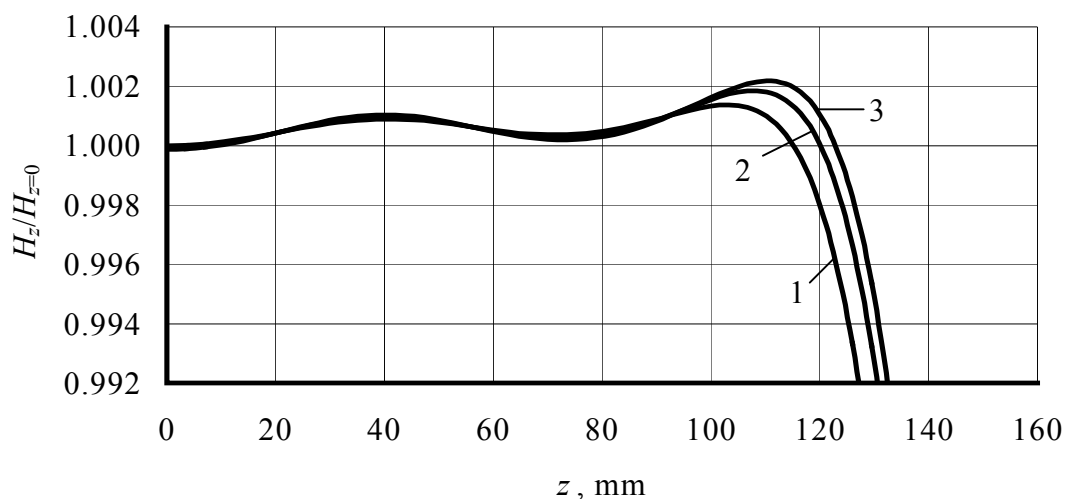


1 – solenoid, 2, 3 – compensation coils, 4 – measuring coils, 5 – working zone

Figure 1. Transducer of the system УИМХ

The required for the high measuring accuracy homogeneity of the magnetic field in the working zone is attained thanks the compensation of the magnetic field decrease along the axis of solenoid by the field of the ring windings. The decrease of the field of solenoid along its axis in the region of its end-faces is compensated by the field of the ring windings 2. The heterogeneity of the magnetic field of solenoid along the axis in its central portion is compensated by the ring windings 3. Such design ensures in the working zone 4 of the transducer the heterogeneity not more than 0,5 % in the distance of ± 120 mm from the centre, that all increases the range of dimensions of the tested specimens.

The results of calculation the component H_z of magnetic field relative its value $H_z = 0$ in the centre of solenoid in Figure 2 are done (the axis z is directed along the solenoid axis, the axis x and y are

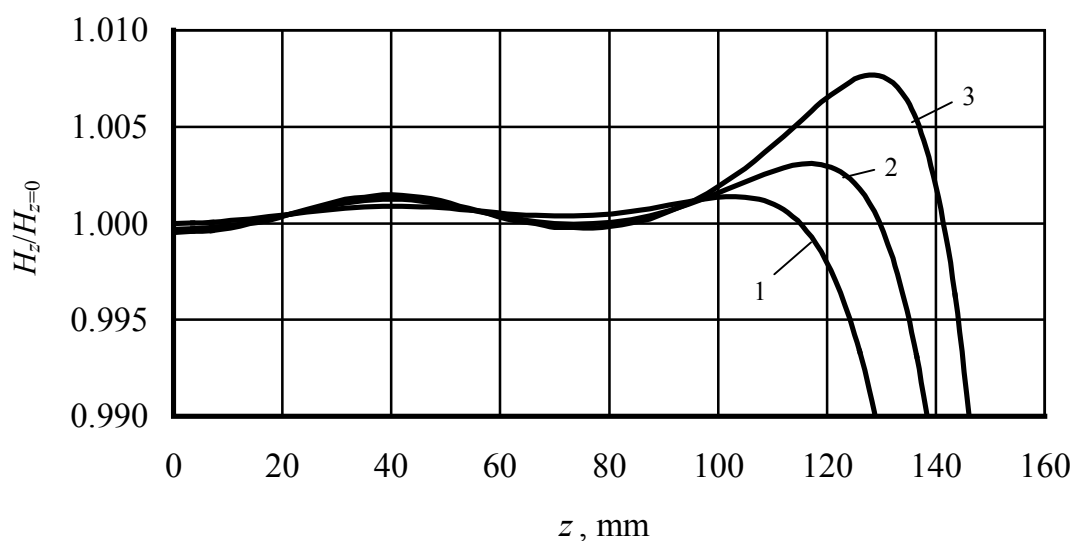


1 – ($x_0 = 0$ mm; $y_0 = 0$ mm); 2 – ($x_0 = 5$ mm; $y_0 = 10$ mm); 3 – ($x_0 = 10$ mm; $y_0 = 10$ mm)

Figure 2. The changes of the component H_z along the transducer from the centre at different displacements from its axis

perpendicular to it). It is seen, that the change of the component H_z don't exceed fractions of percent relative its value in the centre of transducer. The shift along the axis x and y in Figure 2 were selected in dependence on the specimens dimensions, the magnetic parameters of which must be measured using the specific transducer.

Some what higher error can have measurements, when the specimen is arranged close to the windings of transducer (Figure 3). This must be taken into account in practice. The most heterogeneity of the component H_z of magnetic field takes place near the end of solenoid, mainly near its end-face, where significant increases the value of other component of field (x and y).



1 – ($x_0 = 0$ mm; $y_0 = 0$ mm); 2 – ($x_0 = 20$ mm; $y_0 = 0$ mm); 3 – ($x_0 = 20$ mm; $y_0 = 16$ mm)

Figure 3. The changes of the component H_z along the transducer from the centre at different displacements from its axis

In Figure 4 the experimental distribution of the magnetic field strength H_z along the solenoid axis of the system УИМХ relative the field strength in its centre $H_z = 0$ is done. The heterogeneity of the magnetic field along the length of solenoid don't exceed the fraction of percent at the length of the specimen more than 200 mm, is near to the calculated and is in agreement with the requirements of the standard ГОСТ 8.377-80 [7] for the measurements in open magnetic circuit.

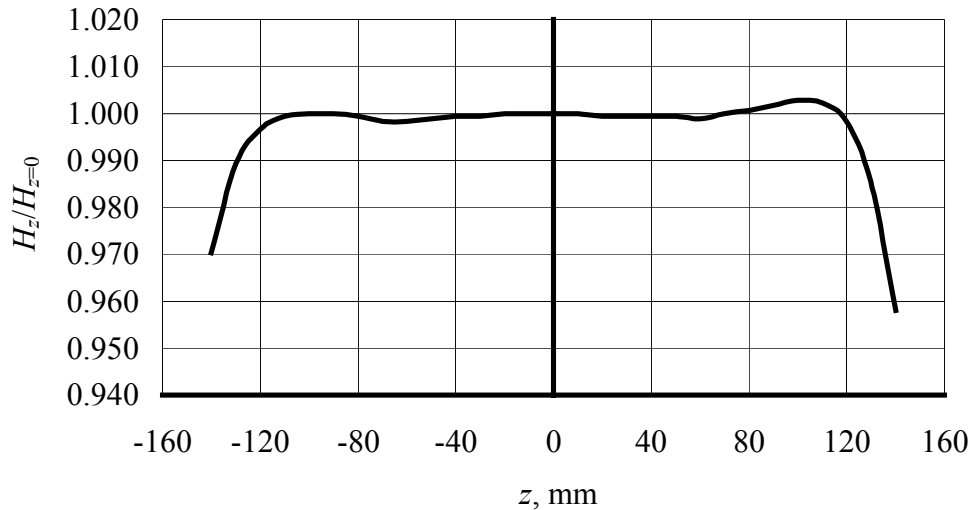


Figure 4. Distribution of the magnetic field strength along the axis of the magnetizing solenoid

The system УИМХ allows to carry out the measurements on the specimens in form of ring. For this in accordance with the standard [7] before the measurement on the ring the measuring and the magnetizing windings are applied. At testing of ring specimens use the set of special cables with connected to them board for connecting the magnetizing and the measuring windings.

If the form of the magnetizing field change corresponds to the equation $dI_{mag}/dt = \text{const}$, the change of the current has the saw-tooth form. The output signal of the measuring windings in the process of the reversal magnetization of the tested specimen goes to the control unit for integration and further processing.

For metrology support of the system is the methodic designed, including the testing of main parameters: errors of the channel, measuring the magnetic field strength, and of the channel, measuring the magnetic field induction. For this the special mode of system functioning is used.

magnetic field strength, on the value of magnetization reversal field consists in measuring using the high-precise nuclear-resonance fluxmeter of the field H , generated by the magnetizing system of the transducer, and in computation of the current I through the magnetizing system by way of measuring the strength on the reference transistor. Than on the equation

$$H = K_H \cdot I \quad (1)$$

The constant K_H of the magnetizing system is calculated. The value of K_H is recorded in the memory of system and that is used further for determination the numerical value of the magnetizing field. Using the constant K_H by way of determination the current I_m through the windings of the magnetizing system on the equation (1) the error check of the channel, measuring the magnetic field strength, and of upper limit of the strength H_m of the reversal magnetization field is carried out. The frequency of the reversal magnetization field is determined on the frequency of strength, reading on the reference transistor in the magnetizing circuit.

The certification of the channel, measuring the magnetic induction is carried out using the standard of mutual inductance by way of comparison the data, received at measuring the maximum induction

B_m , and the computed values of B'_m . At this one from the windings of the standard of mutual induction (input contacts) are connected in series with the magnetizing coil of the transducer in the break of its circuit with the magnetizing unit, the other winding of the mutual induction is connected to the input of the channel, measuring the magnetic field induction. As the system measures in fact the magnetic induction, but the magnetic flow (at connecting the standard of mutual induction it is equal to $L \cdot I$, where L is the value of the mutual induction of standard), than for determination of the value of magnetic induction, generating this flow in the working zone of the transducer, the value received must be divided by the cross-section area S and by number of turns W of the measuring winding. The values of S and W must be set in the PC memory. At measurement the conversion of the flow value in the according value of magnetic induction is carried out automatically. Because this reason the values of S and W must be introduced in the equation for calculation of induction B'_m :

$$B'_m = \frac{L}{WS} \frac{H_m}{K_H}, \quad (2)$$

Where L is the value of mutual induction of the standard, W is the number of turns of the measuring winding, S is the cross-section of measuring winding, H_m is the measured by the system value of maximum magnetic field. Measurements of B_m for further comparison with B'_m and for determination the measuring error are carried out at several specified frequencies and maximum values of reversal magnetizing field H_m .

Besides the express testing of completeness of the operation magnetization reversal – measuring, recording of the magnetization curve, magnetic hysteresis loops and parameters of the hysteresis loop, that all is executed in open magnetic circuit on the specimen having the length of 100-200 mm, the width not more than 20 mm and the thickness not more than 10 mm, or in the closed circuit on the specimen in the form of ring with the outer radius from 60 up to 100 mm, thickness of 1-3 mm and the relation of inner radius to outer radius not more than 1,3.

The check of the limits of magnetic induction measuring is not executed, that why they are attributed to the magnetic properties of the specimens under test for the steels, tested by УИМХ, they don't exceed 2,5 T.

DISCUSSION OF RESULTS

The system for automatic measuring of magnetic characteristics of ferromagnetic materials both in closed (specimens in the form of ring) and in open magnetic circuits in quasi-static mode is designed.

The system allows to read the initial magnetization curve, major and minor hysteresis loops and to determine their parameters. In the system the induction continuous method is realized having high operational efficiency of magnetic measuring of parameters of ferromagnets and the opportunity for selection the optimum velocity of magnetization reversal for each object under test.

The design of the transducer of the system УИМХ thanks the compensation of the magnetic field decrease along the solenoid axis by the field of ring windings ensures in the working zone of the transducer heterogeneity of the field less than 0,2 % in the distance of ± 100 mm from its centre, and that increases the range of the tested specimens at high measuring precision.

Metrologic check of the measuring channel of magnetic induction is executed by using the reference standard of mutual induction by way of comparison the data received at measuring the maximum induction value B_m with the calculated data of B'_m . The system is used for prediction of opportunity of magnetic nondestructive testing of materials and articles on the characteristics of magnetic hysteresis loop. The statistic values of coercive force can be derived by extrapolation from the velocity of magnetic field growth to zero or by way of selection the frequency of magnetization reversal less than 0,05 Hz. The system can be useful for investigations of the opportunities of multiple regression analysis and for tasks of multiparameter nondestructive testing. The system can determine the thickness of the case (hardened layer) of ferromagnetic articles, where as the testing pa-

rameters the relation of magnetization values, measured on the hysteresis loop in dependence of the relative thickness of the case, can serve.

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