Magnetic Method of Layered Structures Testing

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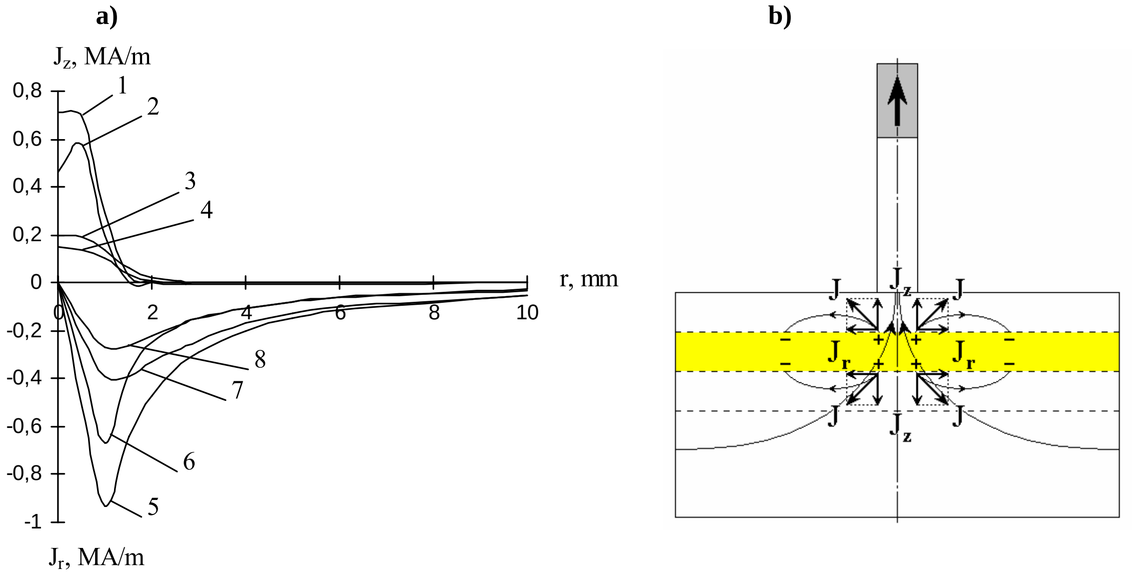
Abstract. On a computer model for a few types of magnetic field sources magnetization distribution of layer structures and secondary fields are made by these structures is investigated. Magnetic properties of layers are changed independently and determined by appropriate magnetization curves. Computations are made by finite element method for three equal thickness layers. It is shown, that magnetization curve change of any of the layers results in magnetization change of the remaining layers and appropriate secondary field redistribution. For determination of every layer properties is necessary to have three equations, i. e. to measure secondary field in three nonequivalent points. For the equations solving, method of calibration in coordinate system on axis of which measurement results in these points are marked is used. It is turned out, that calibration curve is a direct line. Having three signals from an object under investigation, one can determine any of the parameters of any layer if this parameter is unambiguously determined with the magnetization curve. Optimal parameters of a gauge on base of permanent magnets are determined.
The method, in contrast to existing magnetic methods, allows to detect distribution of magnetic and physical mechanical properties over a hardened layer depth.

Contents

There are various methods and technologies for surface hardening of materials [1]. All they result in essential change of properties of the superficial layer in depth. In turn, any structure properties of which change with depth may be considered as consisting of separate layers with different properties; that is, continuous distribution of material properties over the depth may be presented as partial-homogeneous distribution of ones. The number of layers and their thickness may be arbitrary. In this report, we consider only three layers of equal thickness together with a core area of material under them. As a material of investigations, we used the cemented steel 20XH3A with the contents of carbon C = 0.28 %.

Nondestructive testing of layered structures is possible if the procedure assumes obtaining a system of the equations, number of which is equal to number of values of measuring parameter. During the magnetic testing, such system can be obtained either by change of depth of information area or by measurement of an informative (secondary) field in non-equivalent points.

Let us consider character of mutual influence of two layers of equal thickness with identical properties. For this purpose, we used the method of finite elements (the package of applied programs FEMM) and performed calculations of magnetization using model of the elementary transducer with a cylindrical permanent magnet. The layer properties were determined by a normal magnetization curve obtained earlier for the sample from steel 20XH3A with the contents of carbon C = 0.28 % [2]. The results of computations are presented in **fig. 1a**.



1 and 5 are curves for the top layer (z = -0.25 mm), 2 and 6 – for both layers (z = -0.25 mm), 3 and 7 – for the bottom layer (z = -0.75 mm), 4 and 8 – for both layers (z = -0.75 mm); the arrow indicates the magnetization direction

Fig. 1. Radius distribution of the normal J_z and the tangential J_r components of magnetization in the middle of top and bottom layers for the sample from steel 20XH3A (**fig. 1a**); the diagram of magnetic interaction between the layers (**fig. 1b**).

How it follows from **fig. 1a** the interaction of the layers is the reason of significant redistribution of magnetization in each layer. The redistribution has asymmetrical character; that is, the bottom layer increases the normal component of magnetization of the top layer, and, on the contrary, the top layer decreases the normal component of magnetization of the bottom layer. The tangential component of magnetization decreases in both layers and the decrease is about 30 %.

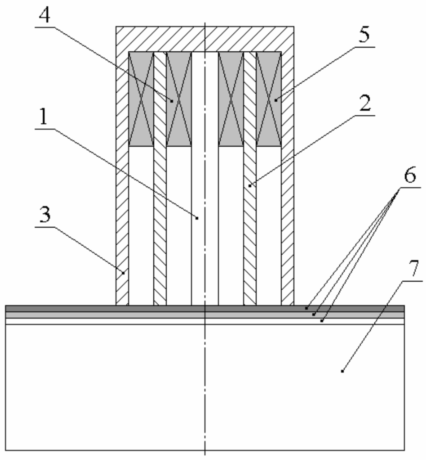
The reason of such changes is explained in **fig. 1b**, where a magnetizing field of a source in the layered sample and a field of the secondary layer together with vectors of magnetization and of its two components are shown. At the chosen direction of source magnetization, the field of the source in informative area will have the components of magnetic intensity $\vec{H}_z > 0$ and $\vec{H}_r < 0$; the magnetization components $\vec{J}_z$ and $\vec{J}_r$ will have the same direction. As $\vec{J}_r(r = 0) = 0$, there will appear magnetic charges $\sigma_r > 0$ in area adjacent to axis; really, $\sigma_r = -\mathrm{div}\vec{J}_r = -\dfrac{\vec{J}_r(\Delta r) - \vec{J}_r(0)}{\Delta r} > 0$. As follows from **fig. 1b**, the normal component $\vec{J}_z$ of the field of the magnetic charges causes the mentioned changes of magnetization of the adjacent layers.

If the sample is made from steel 20XH3A with C = 0.28 % and the second layer has the contents of carbon C = 0.60 %, magnetization of this layer will be less than in the case of the homogeneous sample with C = 0.28 % in all layers and in the core area. Therefore, in a non-homogeneous sample the tangential component of magnetization of the first and the third layers will increase (in comparison with the homogeneous sample) due to a smaller demagnetizing field of the second layer. It is clear that the normal component of magnetization in the central area of the sample (small r) will decrease in the first layer and will increase in the third layer. As to the second layer, the tangential component of magnetization will decrease and the normal component will increase in comparison with the homogeneous sample with C = 0.28 %. If on the contrary, the second layer of the sample has the contents of carbon C = 0.28 % while the rest material has C = 0.60 %, the difference in magnetization distribution will have opposite sign comparison with the homogeneous sample with C = 0.60 % in all layers and in the core.

It is established during calculations, that noted above character of magnetization change is correct for any sources (with the account of the distribution of their field) and at any combinations of properties of separate layers. It follows that the magnetization distribution in any layer carries information not only about properties of this layer, but also about properties of other layers.

Testing of distribution of properties over the depth is an inverse task; therefore, it is impossible to solve the task only analytically. In the nondestructive testing, the calibration method for solving these tasks is used. At the first stage, the method demands solving a direct task; in this case, it is determination of distribution of the secondary field for known combinations of properties of separate layers. The second stage represents comparison of the obtained results with the measured distribution of the field above a surface of a testing product. The latter stage allows finding out testing parameter's distribution over the depth of the product.

As follows from told above, it is necessary to obtain three equations for separate detection of values of the testing parameter in three layers by calculation (or measurement) of the secondary field on three distances from the sample's surface. The preliminary calculations have shown that the magnetic flow or one of magnetic induction's components can be used as an informative parameter of the magnetic field. In this case, nonequivalent points can be set up vertically on various distances from the surface. As an example, the results obtained for model of electromagnetic transducer may be presented. Scheme of the transducer together with scheme of the testing object is shown in **fig. 2**.



1 – rod-shaped magnetic conductor, 2 – internal screen, 3 – external screen, 4 – internal magnetizing coil, 5 – external magnetizing coil, 6 – layers, 7 – core

Fig. 2. Scheme of the electromagnetic transducer

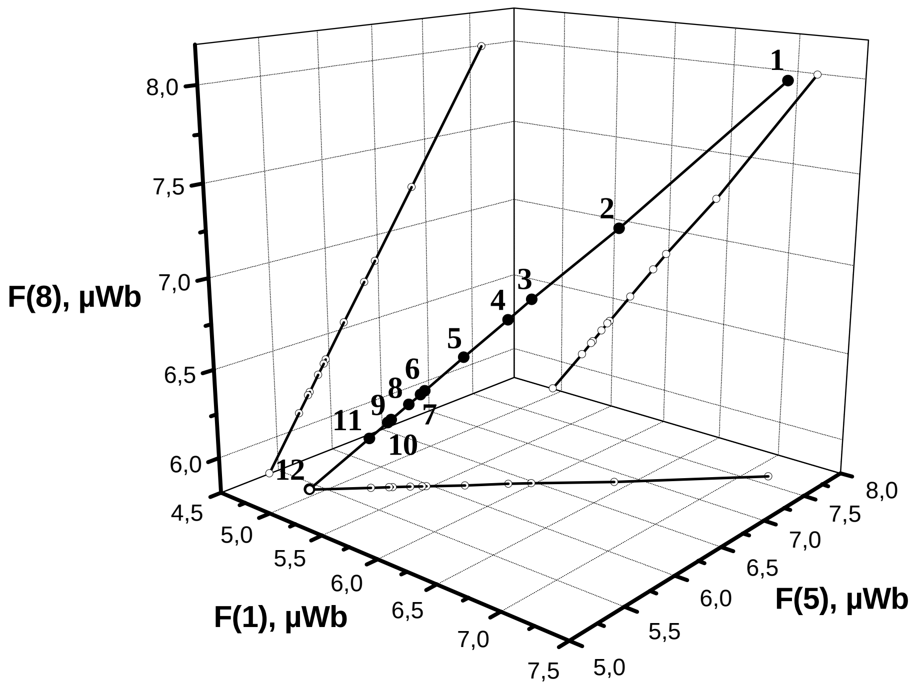
A calculated parameter of the field was the magnetic flow through three measuring coils, which have equal radius and are located between internal and external screens of the transducer on distances 1, 5 and 8 mm from the surface. Computations were carried out with using optimal size and optimal direction of currents in the magnetizing coils. The results for various combinations of properties of the layers and the core are given in **tab. 1**.

Tab. 1. Distribution of the magnetic flux F, μWb, above the surface of the layered sample

Point number	Distribution of C in the sample, %	Distance z from the surface of the sample, mm		
		1	5	8
1	0,28-0,28-0,28-0,28	7,148	7,628	7,996
2	0,36-0,28-0,28-0,28	6,396	6,859	7,232
3	0,36-0,36-0,36-0,28	5,979	6,472	6,849
4	0,46-0,28-0,28-0,28	5,867	6,362	6,739
5	0,46-0,36-0,28-0,28	5,661	6,152	6,537
6	0,46-0,46-0,28-0,28	5,472	5,971	6,351
7	0,60-0,46-0,28-0,28	5,451	5,951	6,331
8	0,60-0,60-0,28-0,28	5,395	5,895	6,276
9	0,60-0,46-0,36-0,28	5,310	5,811	6,192
10	0,46-0,46-0,46-0,28	5,294	5,795	6,176
11	0,60-0,60-0,60-0,28	5,205	5,707	6,088
12	0,60-0,60-0,60-0,60	4,914	5,419	5,803

It follows from **tab. 1** that replacement of properties of any layer results in changing of the flux in each measuring coil. Hence, the field in any point of space contains information about properties of all layers. Therefore, for detection of the testing parameter in each layer it is enough to know the flux through any coil.

According to the offered procedure, calibration dependence should be constructed in phase space of an informative parameter of the secondary field, and the parameter is measured (or computed) in nonequivalent points. When the number of layers is equal to three, the dependence is three-dimensional and in general case looks like a grid [3]. In this example, the informative parameter of the field is the magnetic flux through the measuring coils of the transducer and the calibration dependence is a direct line in three-dimensional space; it is presented in **fig. 3**.



F(1), F(5), F(8) are computational values of the magnetic flux F through the measuring coils, which located accordingly on distances 1, 5 and 8 mm from the surface of the sample; 1-12 are the numbers of the points (see **tab. 1**)

Fig. 3. Calibration dependence in the space of the magnetic flow and three projections of the dependence onto the coordinate planes

It is visible on **fig. 3** that in the space of the magnetic flow all points, which correspond to carbon's contents on the layers and the core (that is to carbon's distribution over the depth), are built in one straight line without superimposing. It is possible to show that it is true for any other combinations of carbon in the layers too. In other words, the calculated values of the flux satisfy to the equation of a direct line in three-dimensional space within the fourth sign after a point. Therefore, the calibration direct line allows solving the inverse task; in other words, one can determine contents of carbon in layers of the testing object by measuring of distribution of the magnetic flux above the object's surface. It is correctly also for general case when calibration dependence is a grid and in the role of carbon may act another property uniquely connected with magnetic properties of the object (hardiness, internal strengths, etc.).

References

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