Electromagnetic and Acoustic Transformation of Surface Acoustic Waves and Its Application in Various Tasks

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Additional information is available at the end of the chapter

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1. Introduction

1.1. Electromagnetic and acoustic transformation

Electromagnetic and acoustic transformation (EMAT) is transformation of high-pitched electromagnetic oscillations in the inductive sensor over a specimen into acoustic oscillations in the specimen. For the transformation to be performed the padding constant magnetic field is required. This process is referred to as a direct EMAT. Further oscillations are extended in the specimen in the shape of acoustic waves. Acoustic waves can be deduced outside by means of revertive EMAT when acoustic oscillations in the surface layer of a specimen will be transformed to electromagnetic oscillations in the receiving sensor. The overall process is as follows: a direct EMAT, a distribution of acoustic waves and a revertive EMAT, which is in practice referred to as a double EMAT or just EMAT [1, 2].

Materials in which EMAT is possible to occur:

- ferromagnetics, i.e. substances which possess electrical conductivity, magnetic properties, and magnetostriction (e.g. iron, nickel, steels);
- the conductors which have no essential magnetic properties (e.g. copper, aluminum);
- materials possessed at least one of following properties: magnetism, conduction, magnetostriction (ferrite, amorphous, rare-earth materials).

EMAT mechanisms

EMAT may proceed by three basic mechanisms.

1. A vortical current mechanism (Lorentz force mechanism). Electrons in a surface layer will fluctuate under the influence of Lorentz force:

$$F_L = f\ \left(J, H\right),$$

where J is a current density, H is a magnetic field.

In conductors this thin layer is called as a skin layer.

2. A magnetic mechanism. This mechanism defines power interaction of an alternative electromagnetic field of the sensor, h, and a constant magnetic field of a specimen, H.

$$F_m = f\ \left(h,\ H,\ \mu_{ij}\right),$$

where μ_{ij} is a tensor of magnetic conductivity of a material.

3. A magnetostriction mechanism. For the materials possessing magnetostriction, this mechanism is responsible for changing linear dimensions of microvolumes in the surface layer of a specimen under the sensor depending on the alternative field of the sensor.

$$F_\lambda = f\ \left(Q_{ij},\ M\right),$$

where Qij is a tensor of magnetoelastic communication, M is magnetization of a specimen.

The first and the second mechanisms are often considered as one which is referred to as an electromagnetic or electrodynamic mechanism of transformation.

Technical realization of EMAT

In technical realization terms EMAT is defined a non-contact method of generation and reception of acoustic waves (ultrasonic waves). The method of generation and reception of ultrasonic waves by means of piezoelectric transducers (PET) appears to be the nearest and best analog in this field. Therefore, the technical methods developed for PET methods generally are appropriate for EMAT methods as well.

There are two main techniques, i.e. a resonance technique and a pulse technique.

1. A resonance technique. A small specimen (a cylinder or a rectangular parallelepiped) is placed into solenoid in order to create a magnetic field. By means of a round wire EMA coil which is put on the specimen the loose oscillations are generated in it. A standing waves resonance is reached by changing the frequency of generation. Thus receiving EMA coil shows a signal maximum. A resonance technique is hard to realizing for a PET method, because the contact is required. These problems are easily solved by the non-contact EMAT method.

An amplitude of the received signal, a resonance frequency, a size of a magnetic field are the key information parameters. The attenuation and Q-factor of the system is possible to define.

2. A pulse technique. Short electric pulses of the generator are transformed to acoustic waves by means of EMAT. These pulses are of high-pitched filling. The generation

EMAT sensor can be to used as a revertive EMAT sensor, if the sensor receives a reflected signal.

Each technique developed for a PET method are suitable for pulse EMAT (an echo method, a shadow method etc.).

Key informational parameters of the pulse technique: amplitude of the received signal, speed of a wave, size of a magnetic field, wave attenuation.

2. The surface acoustic waves

Classically the term «the surface acoustic waves» (SAW) is considered to involve the extending of the waves along the surface of the solid and vacuum; waves poorly fade extending along the surface boundary, the waves quickly fade when moving away from surface boundary into a solid. It concerns only Rayleigh waves and the Guljaev-Blyushteyna waves but in piezocrystals.

There is an expanded treatment of the term «the surface acoustic waves» [3]. Firstly, surface waves at the boundary of the solid body and the gases are considered. It allows Stonly waves and the waves of leak being referred to SAW. They have vertical polarization and a quasyrayleigh structure. Secondly, the expanded treatment considers waves in a layer on the solid body surfaces, or waves with the inhomogeneous elastic properties which are observed in a closely to a surface layer. Loves waves and generalized Lamb waves are considered as well. Thirdly, if the wave extending along the surface is thought to be the main factor, the waves in plates, i.e. Lamb waves and horizontal polarization waves (SH-wave) can be referred to surface waves.

3. Electromagnetic and acoustic transformation of surface acoustic waves

The surface waves in a solid body can be generated in the different ways. The most widespread way is the way using PET. The main advantages of the EMA method of SAW generation in comparison with PET consist of a) not – contact generation and SAW receiving and b)availability to use different SAW which are hardly generated by PET. To reach this purpose it is enough to change a configuration of the wire EMA coil as well as its orientation regarding the magnetic field.

From the practical point of view Rayleigh and Lamb waves being waves vertical polarization as well as SH–waves and Love waves being waves of horizontal polarization are of great interest.

1. Waves of vertical polarization.

The Rayleigh wave can be generated and received by means of meandr EMAT at the normal and tangential magnetic field, H_z and H_x (fig. 1). The double EMAT effectiveness is characterized by the amplitude of the received signal in the receiving coil (E). He is measured in volt usually.

On tangential magnetizing (H_x) the amplitude of the received signal according to the mechanisms of transformation is described by the following approximate formulas[1, 4].

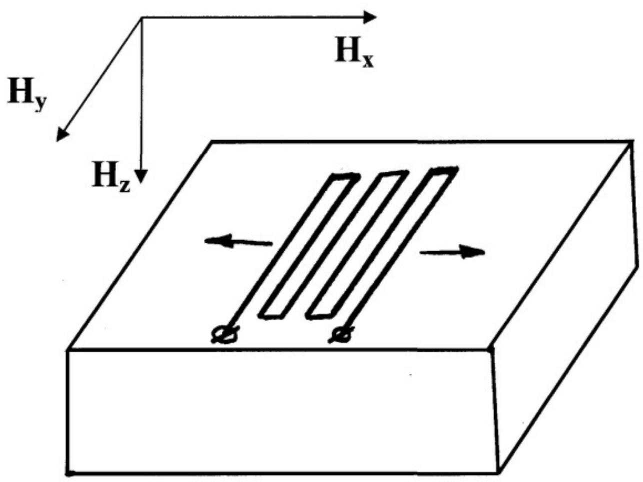

Figure 1. Position of the meandrovy coil on an specimen.

For the magnetostriction mechanism:

$$E^{ms} \approx \frac{1}{\mu_d}\left(\frac{d\lambda}{dH}\right)^2 P_1, \tag{1}$$

where μ_d is differential magnetic permeability, λ is the linear magnetostriction ($\lambda = \Delta l/l$ is specific elongation of the specimen), P_1 is constant factor which depends from parametres of the generating sensor, the reception sensor; physical constants of a material (for example, density, electroconductivity); strengthenings of a reception path, H is a magnetic intensity.

For the sum of vortical current and magnetic mechanisms (the electrodynamic mechanism):

$$E^i + E^m \approx (\mu_0 H\ )^2 P_2, \tag{2}$$

where μ_0 is a permeability of vacuum, P_2 is constant factor the similar P_1.

At normal magnetization (H_z).

For the magnetic mechanism:

$$E^m \approx (\mu M)^2 P_3, \tag{3}$$

where, μ M are magnetic conductivity and magnetization of the material in this orientation, P_3 is constant factor the similar P_1.

For the vortical current mechanism:

$$E^i \approx (B)^2 P_4, \tag{4}$$

where B is a magnetic induction, P_4 is constant factor the similar P_1.

The dependence of the amplitude of the received signal (E) on the magnetic field size, the so-called «field curve EMAT» is the total characteristic EMAT SAW [5]. Two sensor (such as in fig. 1) place on a surface of the sample. One sensor generates the surface wave, the second sensor accepts a wave. The accepted signal strengthen and measure in volt. Often E normalized in relation to any value E (for example, to the maximum value) and receive abs. units. This size postpone on axis Y. The magnetic field size in the sample is shown on an axis X (B (T) or H (A/cm), as $B=\mu\mu_0 H$).

Fig. 2 shows a typical field curve for Rayleigh waves EMAT taking ARMCO iron as an example (curve 1). The curves for the transformation mechanisms calculated on the basis of equation (1) and (2) are presented in fig.2 as well (curve 2 and 3, accordingly). At calculation of the equations use known functions for a material: $B=\mu\mu_0 H$, λ = f(H) [12].

The amplitude of the signal (E) is normalized concerning a maximum.

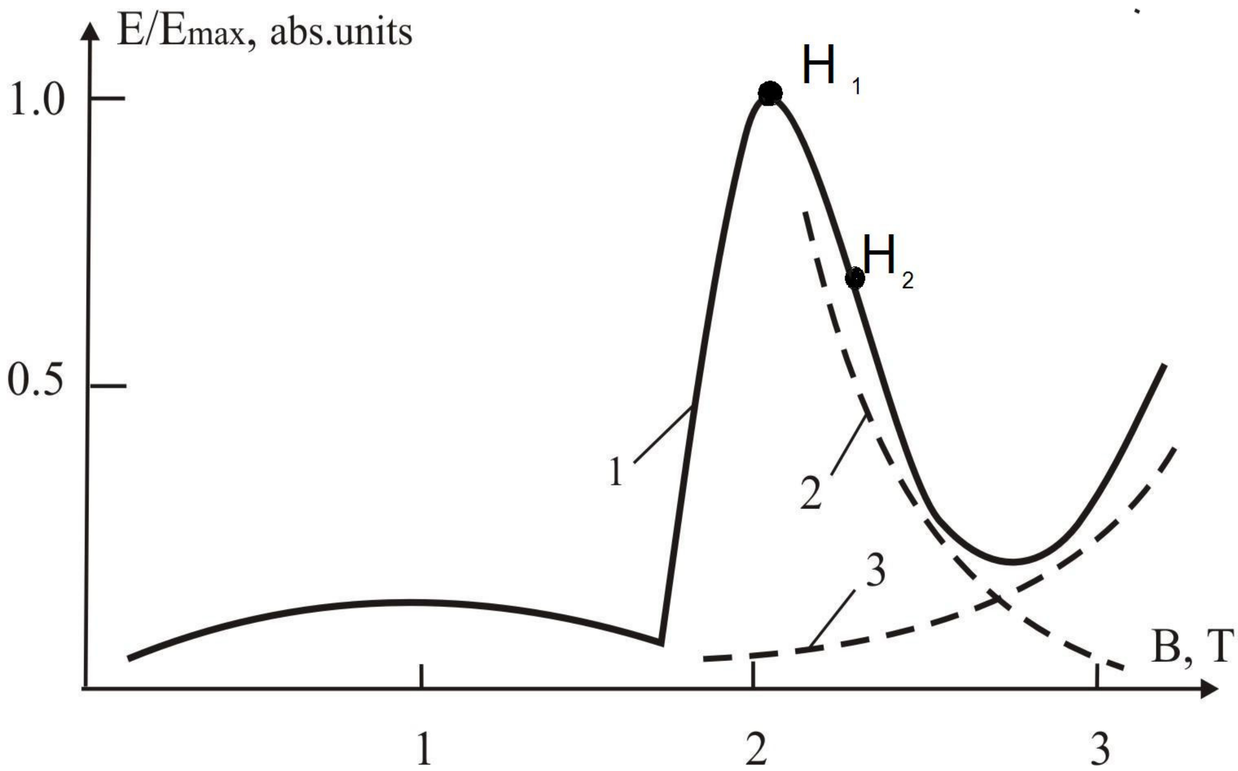

Figure 2. The experimental EMAT field curve of Rayleigh waves in a tangential field for iron (curve 1). The theoretical curve 2, 3 are presented equations (1) and (2).

An EMAT field curve of Rayleigh waves registered in a normal magnetic field(curve 1) and the curves 2, 3 calculated using (3) and (4) are shown in fig.3. As seen from fig.2 and fig.3 the experimental process is well described by the formulas.

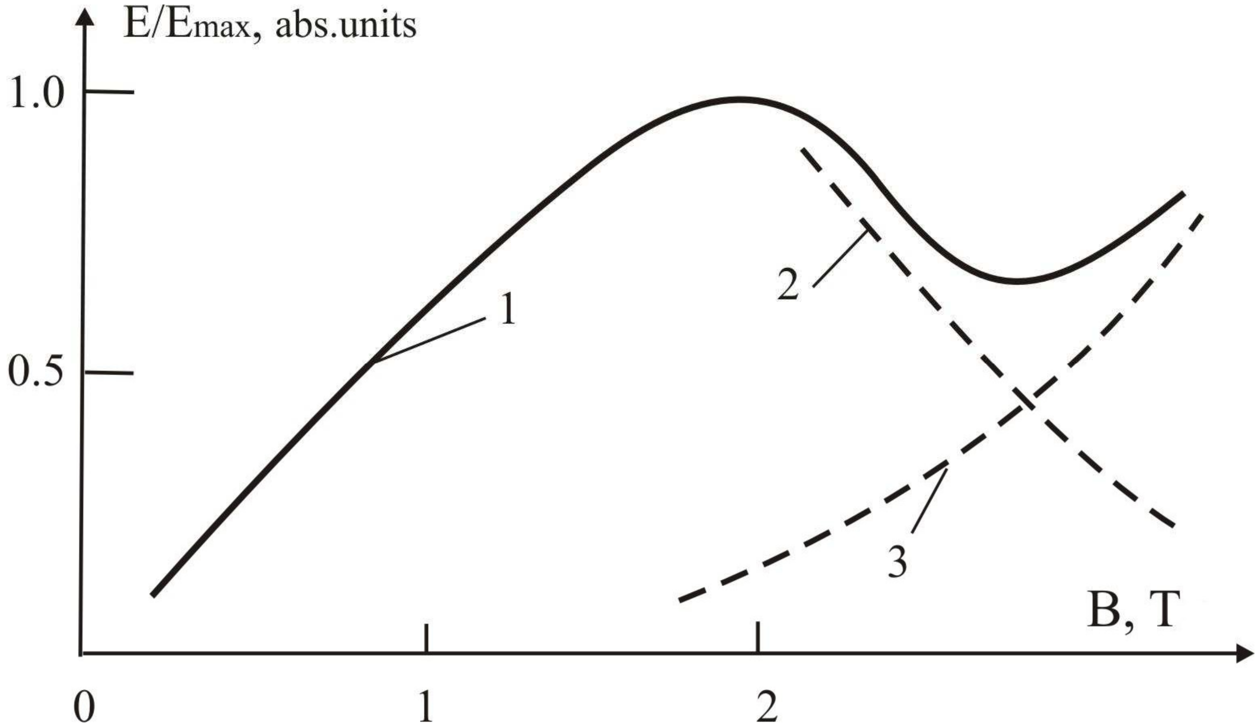

Figure 3. 1 – is the experimental EMAT field curve of Rayleigh waves in a normal field for iron. The theoretical curve 2, 3 are presented equations (3) and (4).

2. Waves of horizontal polarization.

Waves of horizontal polarization are generated in a case when current elements of the meander coil are parallel to a magnetic field. In this case the elementary volumes of the specimen under the EMA coil are in the cross fields, i.e. under the big constant magnetize field and the small variable magnetic field of the coil. Such an arrangement results in shear modes of horizontal polarization which are synchronized under EMA current elements of the coil (fig. 1 field H_y).

The following simplified formula [6] is derived based on the theoretical calculation for SH waves in a **d-** thick specimen [6]:

$$E_{SH} \approx \frac{1}{d}\left(\frac{\lambda}{H}\right)^2 P_5, \tag{5}$$

where P_5 is constant factor the similar P_1.

A structurally similar formula is deduced for the waves of horizontal polarization in the layer (Love waves), but a layer thickness and some known restrictions concerning speeds ratio should be taken into consideration.

The experimental field curve of EMAT of SH waves in ARMCO iron is presented in fig. 4.

If I construct the chart of the equation (5) on this coordinates, I also will see good coincidence to experiment.

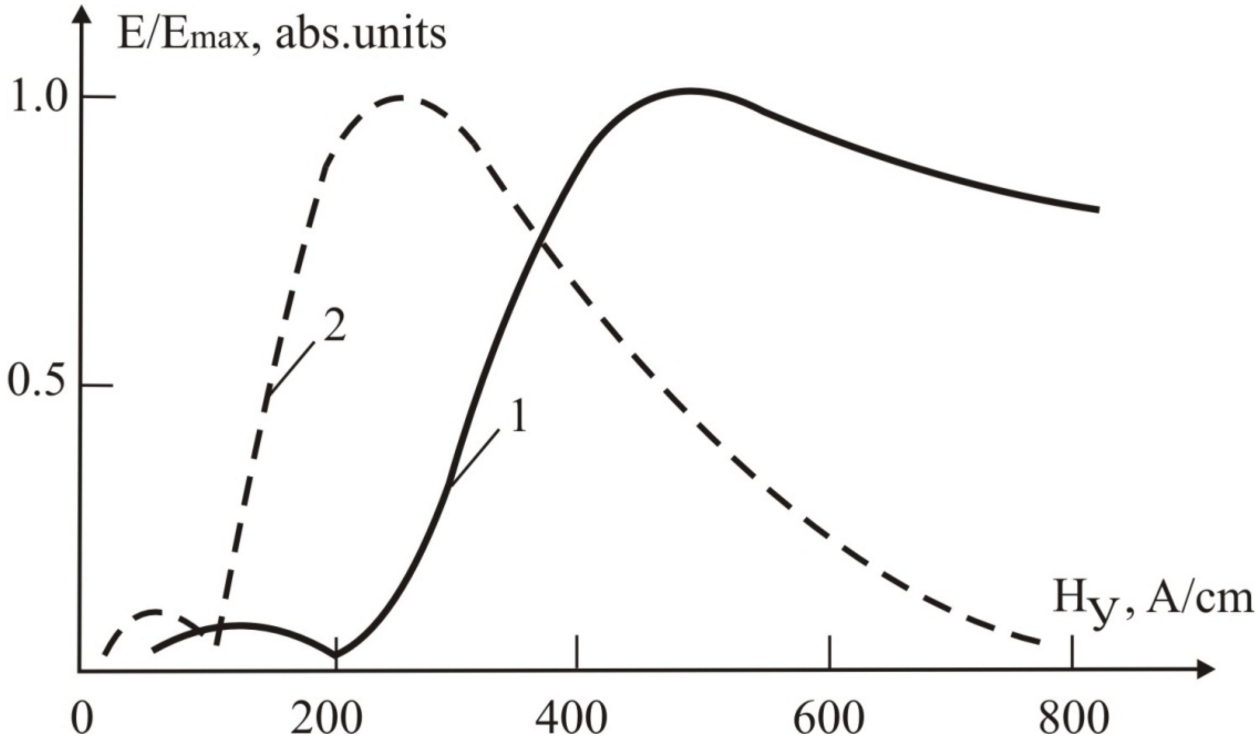

Figure 4. The experimental field curve of EMAT of SH waves in iron (1), in comparison with Rayleigh waves (2).

Love waves have been studied using 20-80 microns thick nickel films applied on the surface of an aluminum substrate. The field curve is presented on fig. 5.

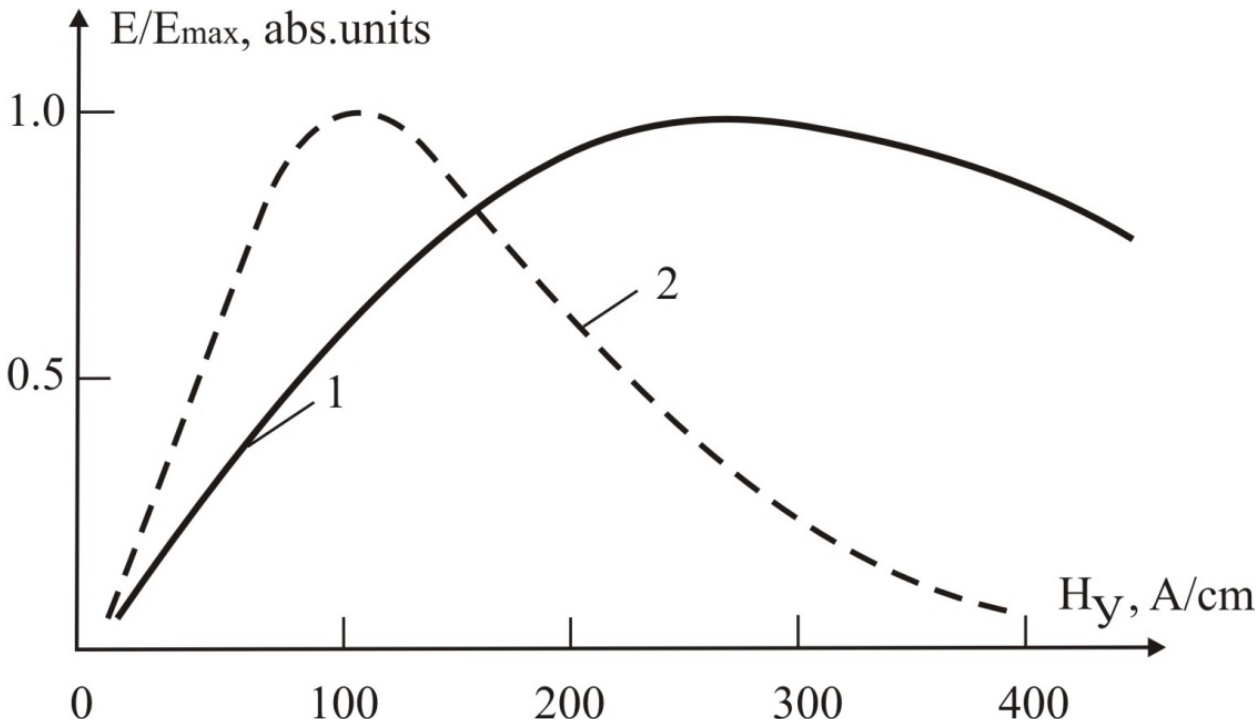

Figure 5. The experimental field curve of EMAT of Love waves in a nickel film on an aluminum substrate (1), in comparison with Rayleigh waves (2).

SAW identification

SAW identification is essential in studying EMAT of the surface wave experimentally.

SAW signals should be distinguished from the signals of other waves. E.g. from the volume waves signals starting from the surface of the specimen to its depth at different angles with interfering reflections in the receiving EMA sensor. It is also necessary for SAW to be recognized in between.

Basic identification methods

1. Pulp method. It involves simple damping by a finger of the surface of the specimen which strongly affects the SAW wave amplitudes but doesn't affect other waves. As long as it is a subjective method to make it being more objective a method of buttered drops is used. Using a pipette to drop the oil from the same height an identical damping is obtained. It allows distinguishing even the Rayleigh surface waves from SH waves. In the same conditions using a 6-drop method a 28 % decrease of Rayleigh wave amplitude and a 7 % decrease of SH waves are observed.
2. A Rayleigh wave C_R strongly differs from longitudinal waves C_l in speed, its speed being slightly differs from the speed of transverse waves C_t (C_R= 0, 87 -0, 96 C_t). A zero mode of a SH wave speed is equal to C_t. To be more sure in distinguishing from a Rayleigh wave the accuracy of speed determination is be within 0, 5 %.
3. A sensor driving method is based on the following: if a generating sensor moves regarding to the receiving one, the signals on the a receiving oscilloscope screen move synchronously.

Thus, we can tell the following.

- We understand work electromagnetic and acoustic transformation of surface acoustic waves in the theory and in practice.
- It is understood how to choose operating mode electromagnetic and acoustic transformation of surface acoustic waves for the decision various applied problems.

4. Using EMAT surface acoustic waves

4.1. Non-destructive testing

4.1.1. Defectoscopy of the surface defects

Using an ultrasonic method for testing materials and products EMAT incorporates all the advantages of ultrasonic testing methods. A piezoelectric transducers (PET) method is similar to EMAT. The main ultrasonic techniques developed for PET, are applied to EMAT.

In fig. 6 the design of EMA of the Rayleigh wave converter on the basis of Π-shaped electromagnets [7] is shown.

The sensor consists of two identical half-cells: Π-shaped electromagnet 3 and meandrovy coil 5, 6. Both converters are located in the case 2 and are filled in with a filler 4. One half-cell generates the surface wave in a specimen 1, another accepts the surface waves. It is a separate testing regime. It is possible to use the combined testing regime when one half-cell generates a wave and accepts the signal reflected from defect.

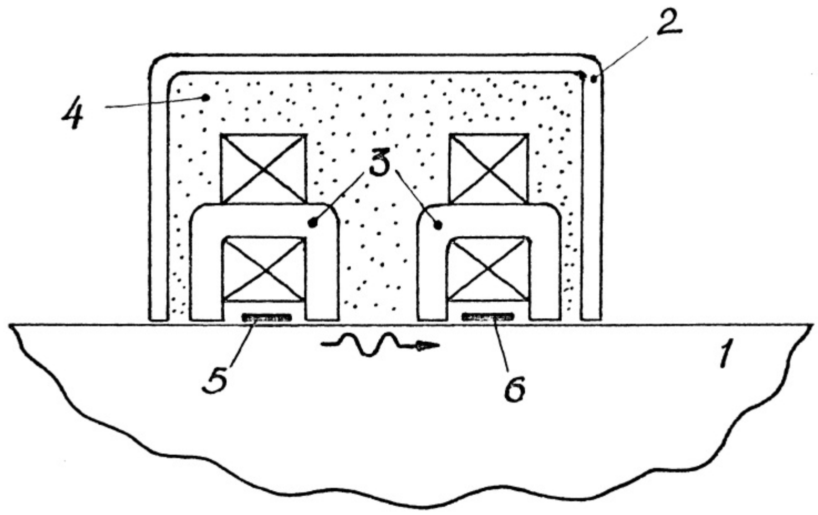

Figure 6. Design of the EMAT sensor of waves of Reley. 1-an specimen, 2 - a housing, 3 - electromagnets, 4 - filler, 5, 6 - generating and receiving EMA coils.

A magnetic field can be created the strong permanent magnets, but in this case it will be uncontrollable. Electromagnets permits operating a magnetic field, choosing the working point on field curve EMAT.

EMAT loses to a way PET in sensitivity, but in this case a contact is not required. It is meant it that using the EMAT method an immediate contact between EMA of the sensor and a specimen is not needed, and the sensor can operates through air or other gaps. For example, the layer of scale or paint isn't an absolute obstacle for EMAT. The amplitude of the received signal has been recognized to be strongly dependent on the gap size. It is due to two factors: 1) an electromagnetic field of EMA of the sensor in a gap called “the sensor – an specimen surface” decreases according to the exponential curve law, 2) a magnetic field of the specimen decreases as a gap occurs. For ferromagnetic materials the field curve of Rayleigh waves EMAT effectiveness has a characteristic maximum defined by the magnetostriction mechanism (fig. 2). The amplitude of the received signal depends on a working point choice in a field curve.

Usually the working point at non-destructive monitoring is chosen at top of the main maximum of the field curve (point H_1 in fiq.2). The maximal receiving signal is obtained in this way. For most ferromagnetic materials this maximum lies within 100 – 300A/cm magnetic fields. The same effectiveness using the vortical current mechanism is reached in magnetic fields about 5000A/cm in size.

If the working point of monitoring is chosen at the maximum top (H1 in fig. 2), the emergence of the gap in a magnetic circuit will result in decreasing the magneticfield in size and falling transformation effectiveness, i.e., the amplitude of the received signal. However, if the working point is chosen on the slope of the field curve (H2), a magnetic field decreases with the gap increasing which leads to the transformation effectiveness. Thus, both factors, i.e., the removal of EMA of the coil from a surface of the specimen and a magnetic field decrease in an specimen compensate each other. [8].

If the gap between the coil and the surface is introduced before the measurements are carried out the measurement results are more reliable. In this case the uncontrollable gap less influences on the received signal. If the working point is chosen in the slope of the field curve the signal received does not depend on the gap (fig. 7).

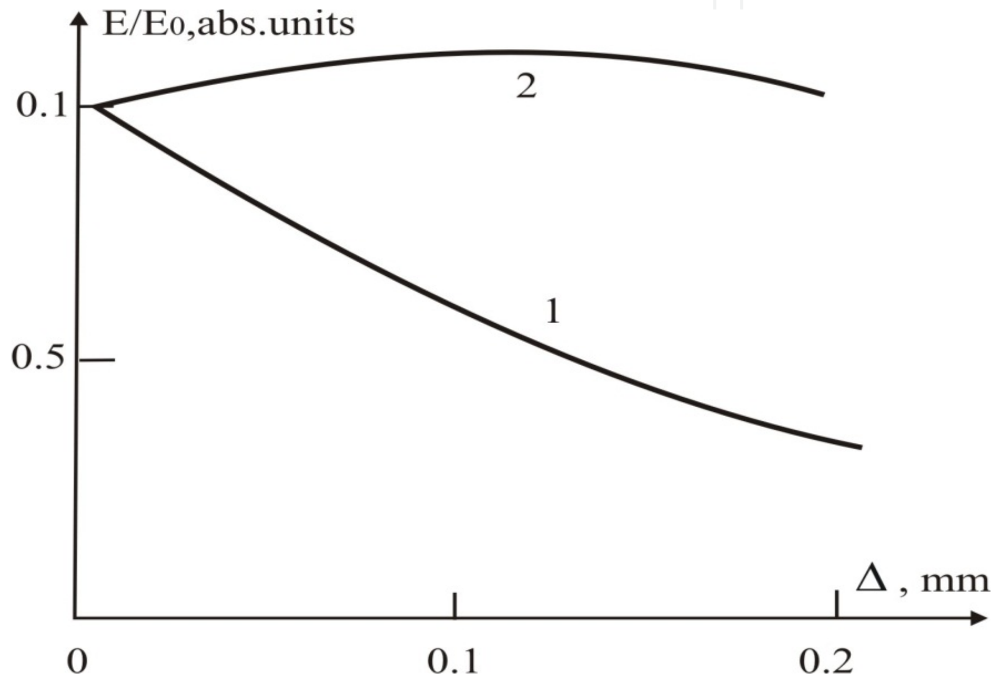

Figure 7. Dependence of the received signal from dimension of the gap between sensor and specimen at the working point H_1(1), at the working point H_2 and preliminary gap (2).

The experiments on detection of model defects showed that by means of EMA of the converter of Rayleigh waves presented in fig. 6, it is possible to reveal the surface defects such as cracks 5мм in length, 0, 5мм in depth. Such defects come to light both at reflection from the defect, and when weakening a signal passing the defect (weakening of 20 %).

4.1.2. Structurescopy of metals

Structural changes are well recognized by EMAT in ferromagnetic materials taking place in technological processes. This results from the fact that at EMAT four subsystems are involved in a material: magnetic, electric, magnetoelastic and elastic. All these factors influence informational parameters of the EMAT method.

Thus, if a dependence between the parameters of the technological process and the information parameters of the method of one subsystem is not a one- direction dependence the EMAT method can be used.

So the dependence between the amplitude of the received signal of Rayleigh waves sensor (fig. 6) and the hardness of the steel 38ХГС specimens being treated at different temperatures is practically linear. To increase the specimen hardness it was treated at high temperatures. The coefficient of correlation was equal to 0, 92. It allows EMAT controlling.

Another structural component is anisotropy of the material properties which can be also measured by the sensor described above. The sensor is rotated on the specimen surface showing the information parameters change. However, the data can be distorted due to different factors.

To overcome this trouble a meander -curve sensor was suggested to be curved into a ring (fig. 8) [9].

In this case each element of the dl coil generates SAW in K1 and K2 directions. In general two circular waves are observed: a coverging to the center wave and a diverging from the center one. A converging to the O point wave then turns into a diverging wave. It is received by the same circular EMA coil when the wave moves under it.

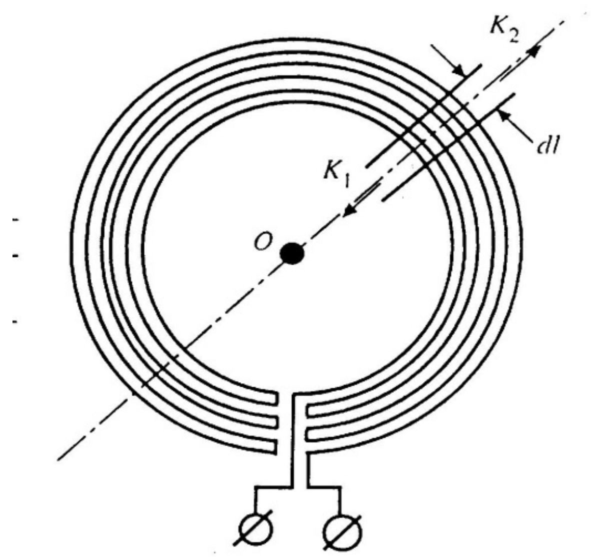

Figure 8. Circular EMAT sensor.

Two case of magnetizing are likely to observed for the circular EMA sensor. In case of normal magnetizing a rod electromagnet is used (fig. 9a), and in case of a tangential magnetizing it is realized by means of a cylindrical m-shaped electromagnet (fig. 9b). Cracks are revealed by such a sensor.

But the most interesting area for the sensor to be applied is in controlling anisotropy of sheet ferromagnetic materials. It allows revealing three types of anisotropy: elastic, magnetoelastic and magnetic.

At generation and reception of a circular surface wave in a completely isotropic metal we have the individual fine-bored received pulse which is a superposition of the signals from all directions (fig. 10a). In case of elastic anisotropy (anisotropy of sound speed) signals in the different directions take different time. And the received pulse extends, or splits into a number of pulses. An elastic anisotropy of the material is characterized by the pulse duration or the distance between extreme pulses (fig. 10b).

The amplitude of the obtained pulses (A1, A2) demonstrates the effectiveness of EMAT in different directions which is defined by magnetoelastic properties of a material. Magnetoelastic anisotropy of materials is defined by the amplitude distinction of pulses.

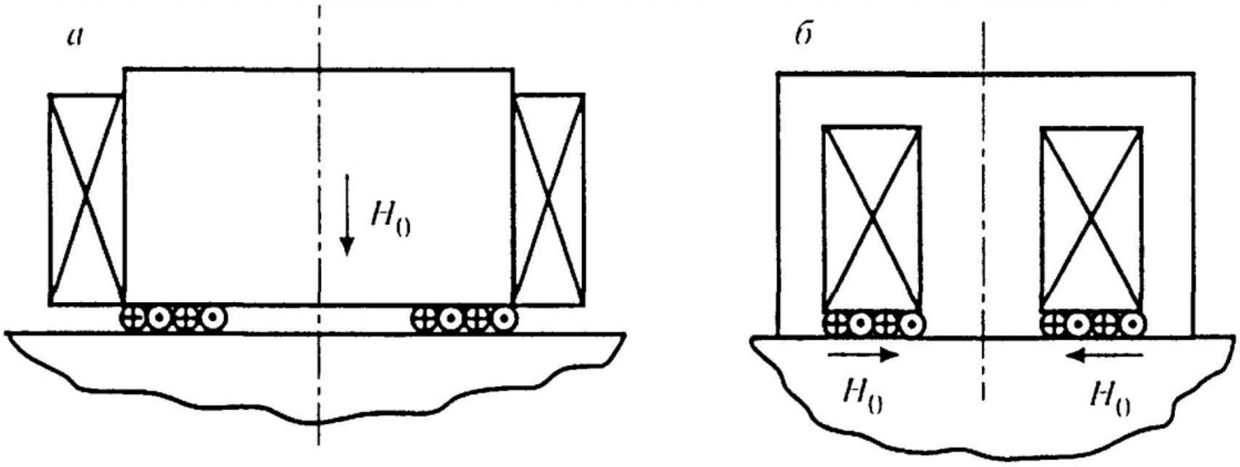

Figure 9. Tangential (a) and normal (в) magnetization of EMAT sensor.

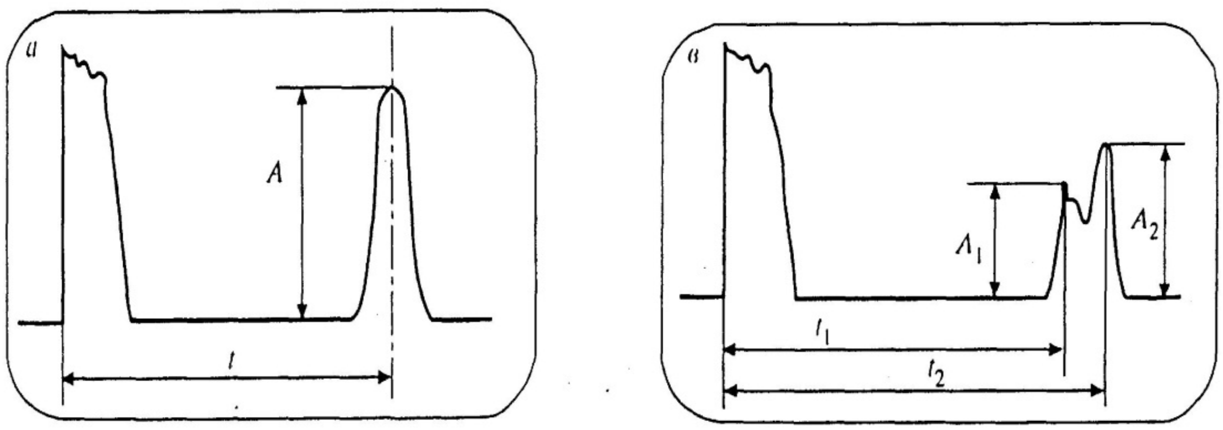

Figure 10. Oscillograms of signals, isotropic material (a), non-isotropic material (b), which are received by means circular EMAT sensor.

The magnetic anisotropy of a sheet is shown as follows. Effectiveness of EMAT from a magnetize field has a maximum. In case of a magnetic anisotropy the maximum of EMAT signal is reached in different directions at different currents of magnetization. Thus, on changing a magnetization current for an isotropic material the range of optimal currents is narrow, and for a magnetic anisotropic material the range is wider the one mentioned above.

The developed technique was tested on various materials and showed high effectiveness.

4.1.3. Tension controlling

EMAT SAW enables tension and operational loadings controlling. For this purpose the sensor (fig.6) was used. The sensor platform area is to be 30 x 60мм. Adjusting to obtain a magnetostriction maximum the amplitude of the received signal is an information parameter.

At stretching the specimen made of steel 25 in the elastic area it has been shown that the amplitude behaves depending on the positions of the sensor i.e. lengthwise and crosswise of the loading. Thus dependence is almost linear.

On measuring the sound speed, it has been found out that in the elastic area it changes less than 0, 5 %. Hence, at controlling tension concerning the sound speed more precise equipment and computer processing of signals should be applied.

The studying of the field curve of Rayleigh waves EMAT under «the sensor is along loading» shows that at specimen stretching in the elastic area and at the beginning of the area plastic deformation both the amplitude of the received signal and an optimal field of magnetizing (a field of the maximal signal in the EMAT curve) for a magnetostriction maximum have changed. It depends on whether magnetostriction is positive or negative [10].

For materials with the negative magnetostriction of saturation, λ_s, (nickel, constructional steel) the dependence is as follows.

Fig. 11 shows the dependence of the maximum point of the field curve of EMAT on loading, the maximum point being normalized in relation with its initial value. At the initial stage of a loading the amplitude of the maximum grows, and this maximum is displaced to the area of the bigger fields. Then, in the area of the inflection point a decrease of a maximum value is observed. The inflection point lies in the area of the elasticity limit (the conditional point where the size of permanent deformations makes 0, 05 %).

It can be explained from the physical point of view. In [4] it is noted that at $\lambda_s \sigma<0$ pulling stresses of σ are considered to be positive, two factors being competitive: on the one hand the energy of a magnetic field, , on the other hand the crystallographic anisotropy and magnetoelastic energies. Tension in a metal makes a magnetization vector turn perpendicular to the magnetic field. As a result, it is more difficult to obtain an amplitude maximum of EMAT.

The amplitude of the EMA signal is described by formula (1). As the loading in the elastic area increases magnetic conductivity, μ, decreases, and the parameter $\frac{d\lambda}{dH_0}$ grows. It results in the received signal growth. At larger loadings there is tension which leads to the signal decrease. So a maximum occurs in the elasticity limit.

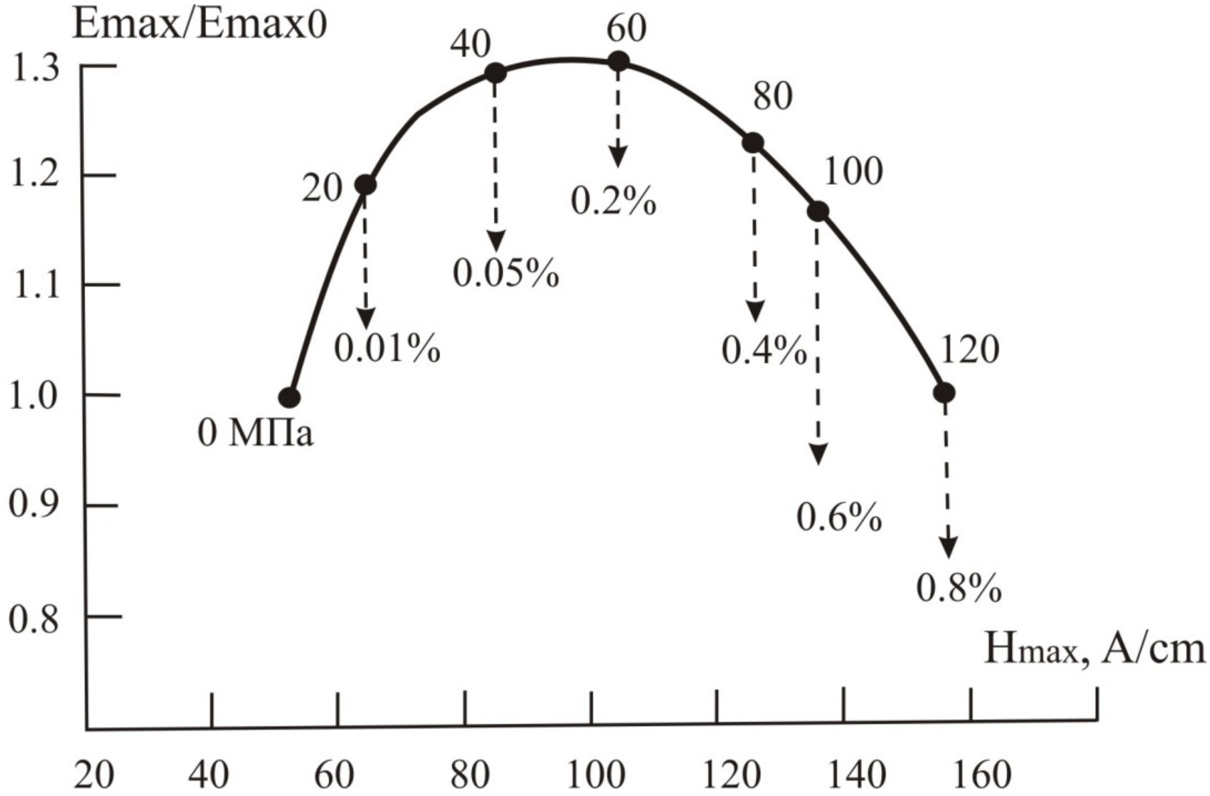

Figure 11. The shift of the maximum point of a field curve of Rayleigh waves EMAT in nickel from the loading (the loading is given in MPa, and the length change after loading is given in percent).

If materials have a positive magnetostriction of saturation, the behaviour of the maximum of the field curve for Rayleigh waves EMAT is essentially different. Using alloy H18 (18% Ni, 82 % Fe) λ_s› 0 as an example it is shown that a received EMA signal unequivocally falls (fig. 12). As to a magnetic field first an optimal magnetic field decreases and then it becomes larger, the change takes place at the point close to a limit of material elasticity. It can be also explained from the physical point of view.

Thus, it has been shown that using Rayleigh waves EMAT at least two information parameters are obtained which are used for the applied loadings to be characterized.

It can be carried out either by calibration curves at monitoring or without calibration curves if the tendency of change of parameters EMA is used.

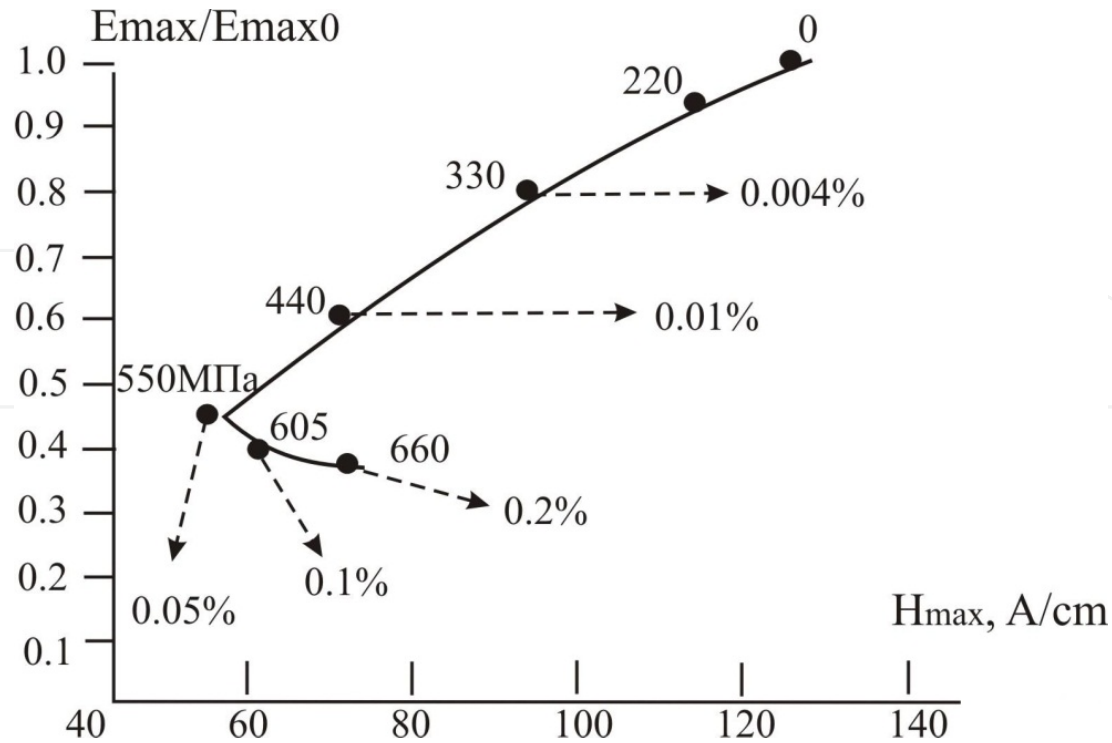

Figure 12. The shift of the maximum point of a field curve of Rayleigh waves EMAT in H18 alloy from the loading (the loading is given in MPa, and the length change after loading is given in percent).

4.2. Physical study of materials

It has been shown that the EMAT SAW method are defined by different subsystems of the material. Information on the parameters of the material related to these subsystems is revealed by the information parameters of the EMA method.

4.2.1. Magnetostriction assessment of a material

Magnetostriction is one of the important characteristics of a material. Due to the wide use of these materials in science and industry the assessment of magnetostriction properties of a material is of great importance.

The main characteristic of magnetostriction properties of a material is the field curve of magnetostriction, i.e., dependence of the linear magnetostriction, λ, on a magnetic field. Though from the practical point of view it is enough to know magnetostriction of saturation, λ_s.

At magnetostriction measurement the method based on tension resistivity of sensors stuck by glue on an specimen is the most extensively used. There are some shortcomings in this method. Alternatively a quick test based on non-contact EMAT SAW [11] may be suggested.

So for Rayleigh waves EMAT formula (1) is used. The task is as following: based on the known curve of EMAT we are to obtain a curve of magnetostriction, $\lambda = f(H)$. It is clear that from curve (1) a field curve of magnetostriction can be obtained by the integration method only. This process is difficult and inaccurate.

Horizontal polarization waves EMAT (SH wave) is more preferable to be used to obtain λ =f(H). A field curve of SH waves EMAT is described by the simplified formula:

$$E_{SH} \approx \frac{1}{\mu d}\left(\frac{\lambda}{H}\right)^2 P \tag{7}$$

where - $P = \rho C_t / \sigma$ is a material parameter, μ is a static magnetic conductivity, d is a sheet thickness, ρ is material density, C_t is a speed of shift waves, σ is an electrical conductivity.

Thus we obtain :

$$\lambda = \sqrt{\frac{E_{SH} d}{P}} H \sqrt{\mu} \tag{8}$$

Knowing B=f (H) it is easy to calculate μ=f (H), and then knowing the material parameters it quite easy to calculate a curve λ=f (H).

The calculations above have been used to obtain λ=f (H) for four materials: iron, cobalt, nickel, permendur (brand 49КФ2). Fig. 1 presents the orientation scheme of the magnetic Hy field for EMAT of SH waves. Fig. 13 shows field characteristics of EMAT of the materials mentioned above. In fig. 14á field characteristics of the magnetostriction module calculated on the basis of formula (8) are presented. Fig. 14б shows the same curves based on data [12]. High curves coincidence is observed.

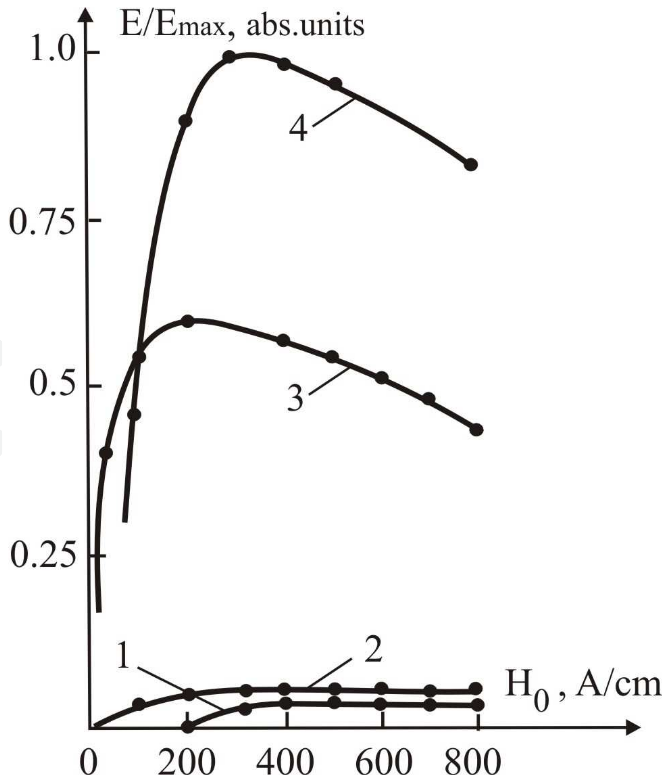

Figure 13. The experimental EMAT field curve of SH- waves (1-iron, 2 - cobalt, 3 – alloy 49КФ2, 4 – nickel).

In 800A/cm fields magnetostriction of materials approaches saturation. To obtain the quantitative value of saturation magnetostriction the required data were obtained by a method of tension resistors. The comparative table on the magnetostriction of saturation received by an EMAT method and a method of resistance strain gages is given in table 1.

As shown in the table, the relative ratios for the EMA method are obtained with an accuracy of 5-7 %.

It should be noted that EMA method allows defining the magnetostriction module λ only. A sign of magnetostriction is complicated to be defined, but it is quite possible. To carry it out it is necessary to observe a phase of the received signal and then to compare it with a signal phase of the known material.

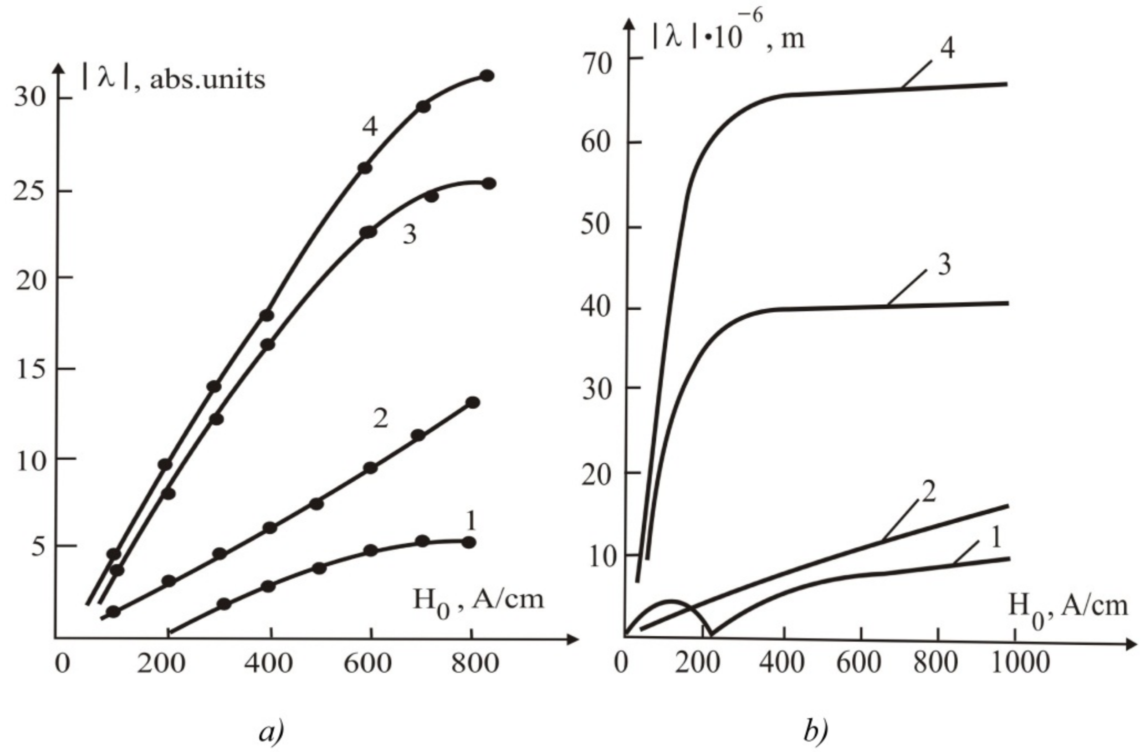

Figure 14. Field curves of the magnetostriction module calculated based on the experimental data (a) the data are given according to literature data [12] (b) (1-iron, 2 - cobalt, 3 - alloy 49KФ2 (Permendur), 4 – nickel).

Material	$\lambda_{max}/\lambda_{max\ Fe}$ EMA method	$\lambda_{max}/\lambda_{max\ Fe}$ Tenzometod
Fe	1	1
Co	2, 6	2, 8
Ni	5, 2	5, 0
49KΦ2	6, 2	6, 5

Table 1. The comparative table on the magnetostriction of saturation received by an EMAT method and a method of resistance strain gages.

4.2.2. Assessment of other characteristics of a material

Electric properties of ferromagnetic materials can be estimated using the amplitude of the received signal in large magnetic fields (more than 800A/cm). EMAT effectiveness depends on the electrical conductivity of a material under the same conditions.

Magnetic properties of a material can be estimated by the location of the magnetostriction maximum.

Two parameters are used to estimate elastic properties of a material:

Firstly, a sound speed in a material. To measure the speed of the Rayleigh surface wave, C_R, and the speed of horizontal polarization waves, C_{SH}, the techniques described are employed. Here, it is should be considered that C_{SH} for a zero mode is equal to the speed of shift waves of the material, $C_{t,}$. These measurements enables estimating the elastic constants of a material such as shift modulus and a Poisson's ratio. The constants defined allows us to determine the remained elastic modules of a material.

Secondly, sound attenuation in a material is estimated by EMAT SAW methods. In this case two receiving EMA coils are used.

Having defined the attenuation parameter it is easy to find such important production characteristics as good quality of the system and an internal friction parameter of a material.

4.3. Prospects of use of EMAT SAW

The main examples of using the surface waves EMAT are presented in the paper only. The use of EMAT SAW in non-destructive monitoring as well as in studying new materials and the phenomena is possible in the nearest future.

Love waves EMAT may be used for non-destructive monitoring of coatings and thin films and for their thickness measurements as well. SH waves EMAT of can be applied in cylindrical specimens where such waves are known to be generated and received very efficiently.

One can find papers on the use of surface waves EMAT to study magnetic phenomena in rare-earth metals. At the increased or decreased temperatures of the specimens it is easier to apply the EMAT method than the method of piezoelements.

When studying various acoustic waves the EMAT method is more perspective due to easy generation of acoustic waves.

There are combined methods of generating and receiving acoustic waves where EMAT is used together with other methods, for example, with laser methods and with methods of an optical interferometry.

All we said above allows us to draw a conclusion that the EMAT methods are very promising in the future.

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