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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 reverberative 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 reverberative 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:

$$F_L = f(J, H),$$

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 .

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

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.

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

where Q_{ij} 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 used as a reverberant EMAT sensor, if the sensor receives a reflected signal.

Each technique developed for a PET method is 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 meandrovoy coil on an specimen.

For the magnetostriction mechanism:

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

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):

$$E^i + E^m \approx (\mu_0 H)^2 P_2, \quad (2)$$

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:

$$E^m \approx (\mu M)^2 P_3, \quad (3)$$

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:

$$E^i \approx (B)^2 P_4, \quad (4)$$

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: $B = \mu\mu_0 H$, $\lambda = f(H)$ [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.