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ELECTROMAGNETIC-ACOUSTIC TRANSDUCER WITH A COMBINED MAGNETIZATION

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ABSTRACT

The use of methods and means for excitation ultrasonic pulses of transverse waves using electromagnetic-acoustic transducers is becoming increasingly widespread in industry. However, transducers based on permanent powerful magnets have disadvantages, which consist in their strong attraction to ferromagnetic products and in the adhesion of ferromagnetic particles, which leads to distortion of the results of non-destructive testing and a decrease in sensitivity. Over time, such magnets gradually lose their magnetic properties. The known transducers with a pulsed magnetization can only operate with low probing frequencies due to heating. It is proposed to use permanent magnets with a relatively low magnetic field induction and additional pulsed magnetization simultaneously. Such a technical solution increases the sensitivity of the inspection and significantly reduces the attraction of the transducer to a ferromagnetic product, and also makes it possible to significantly increase the frequency of probing the test object.

KEYWORDS: ferromagnetic product, non-destructive testing, ultrasonic pulses, electromagnetic-acoustic transducer, magnetic field, pulsed magnetization

INTRODUCTION

Ultrasonic wave pulses are often used for non-destructive testing of metal products, most often ferromagnetic ones [1]. In conventional testing using a contact fluid, it is necessary to remove rust, paint, dirt, etc. from the surface of objects [1–3], which leads to significant material losses. The problem can be solved by using the electromagnetic-acoustic (EMA) method of excitation and reception of ultrasonic pulses [2, 4–6], which does not require special cleaning of the surface of metal products such as pipes, sheets, billets, etc.

It is known that the sensitivity of the EMA method of excitation and reception of ultrasonic pulses is quadratically dependent on the magnitude of magnetic field induction [4–5]. That is why many experts develop EMA transducers (EMAT) with high-power magnetic field sources [7]. However, a contradiction arises. On the one hand, the sensitivity of the EMAT increases, and on the other hand, the force of attraction of the EMAT to the test object (TO) made of ferromagnetic material grows significantly. In addition, exfoliated ferromagnetic particles, such as scale, adhere to the EMAT, which leads to the formation of powerful interference [8]. To eliminate the mentioned disadvantages, many researchers propose the use of pulsed magnetic field sources [9–16], which have the ability to obtain a powerful magnetic field at pulsed magnet supply currents of 2–3 kA. However, the coils of the pulsed source heat up quickly [9], which makes it impossible to perform flaw detection and thickness measurement of the TO with the required frequency of probing a metal product.

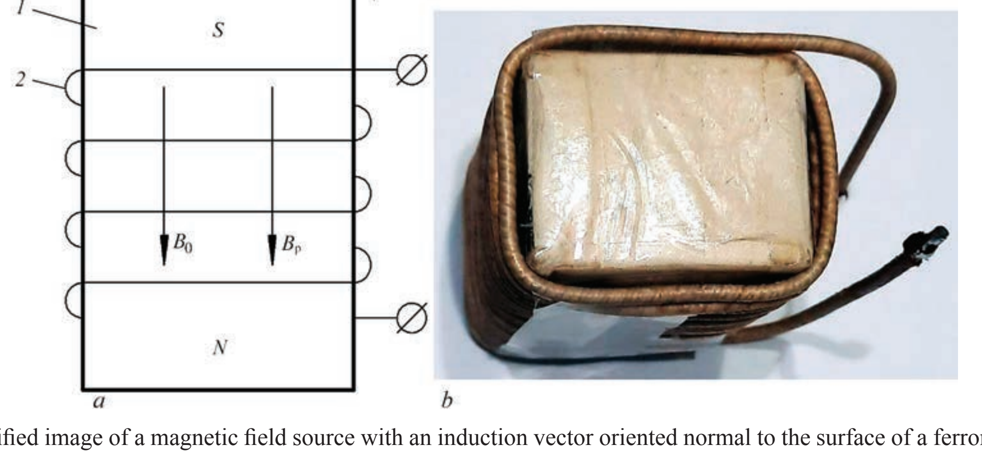

Figure 1. Simplified image of a magnetic field source with an induction vector oriented normal to the surface of a ferromagnetic metal product: design of the MFC (*a*) and its image (*b*); *1* — permanent magnet; *2* — pulsed magnetization coil; B_0 — magnetic field induction magnitude generated in the pulsed magnetization coil; B_p — pulsed magnetic field induction magnitude

This paper presents the results of improving EMAT by using a permanent magnet of low power and a pulsed magnetization at powering the coils of a magnetic field source with a current of less than 2 kA. Such an approach can significantly reduce the above disadvantages of the known EMAT.

AIM OF RESEARCH

is the comparative analysis of EMAT sensitivity with a combined magnetization.

EMAT WITH A COMBINED MAGNETIZATION AND ITS RESEARCH PROCEDURE

Let us consider, as an example, a combined EMAT for excitation and reception of ultrasonic shear wave pulses in a ferromagnetic metal product normal to its surface. The base of the proposed EMAT is a magnetic field source (MFS), which can be represented in the way as shown in Figure 1. In the simplest version, it is a permanent magnet and a pulsed magnetization coil.

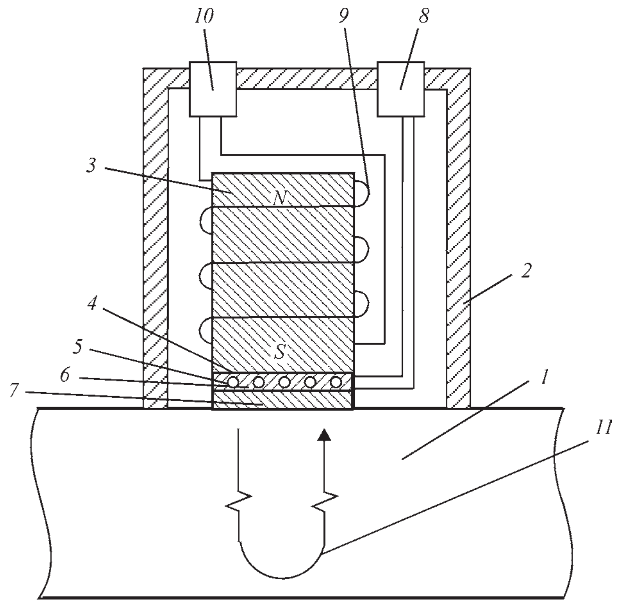

Figure 2. Simplified design of EMAT with a permanent and pulsed magnetization: *1* — ferromagnetic conductive metal product; *2* — casing; *3* — permanent magnet; *4* — pole of a permanent magnet *3*; *5* — plane high-frequency inductance coil; *6* — dielectric base; *7* — protector; *8* — electrical connector for powering high-frequency inductance coil *5*; *9* — pulsed magnetization coil; *10* — electrical connector for powering pulsed magnetization coil *9*; *11* — ultrasonic wave pulses in the TO

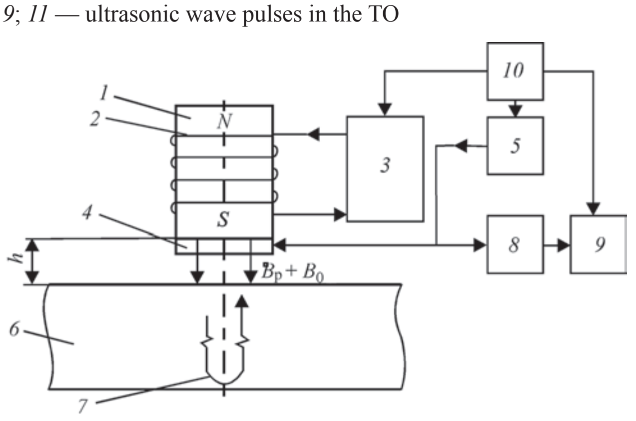

Figure 3. Test bench for studying capabilities of EMAT with a combined magnetization

Obviously, the MFC elements should meet a number of requirements: the permanent magnet material should be resistant to heat and have low electrical conductivity; the dimensions of the permanent magnet should provide a preferential orientation of the magnetic field induction vector normal to the TO surface (the cross-section of the magnet pole should be in the range of 30×30–50×50 mm^2, height 50–60 mm [9]) and a specified working area of the magnet action, which overlaps the working area of the high-frequency inductance coil [4]; the pulse magnetization coil should have a minimum inductance, which is necessary to form a short magnetization pulse.

A simplified mock-up of a combined EMAT based on a magnetic field source with a combined magnetization can be made as follows (Figure 2). The arrows in the volume of a ferromagnetic conductive metal product show the directions of propagation of ultrasonic pulses.

To perform the research, a mock-up (simplified unit) was made, the diagram of which is shown in Figure 3. The magnetic field source consists of a permanent magnet *1* based on NeFeB metal-ceramic, on which a magnetization coil 2 is wound (see Figure 1). The coil is powered from the unit *3* by magnetization current pulses. The high-frequency inductance coil *4* is powered by high-frequency current pulses from the unit *5*. The ultrasonic pulses *7* excited in the product

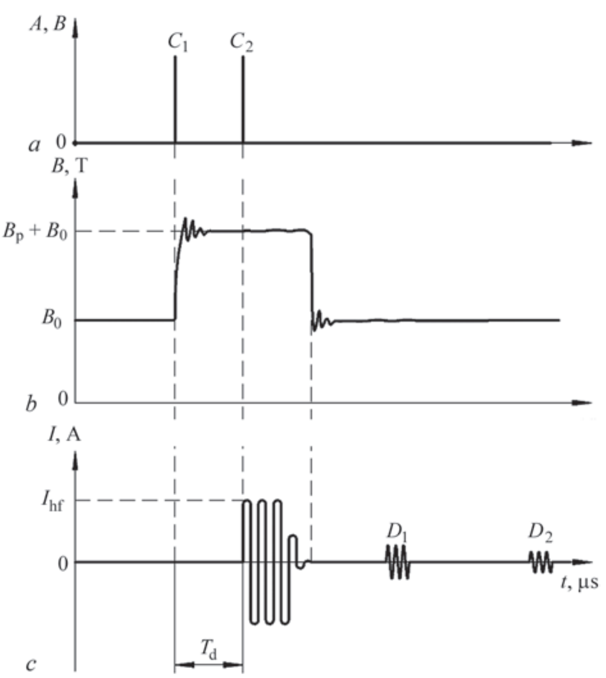

Figure 4. Functional diagram of operation of the test bench with a combined magnetization of the TO by one cycle of ultrasonic pulse probing

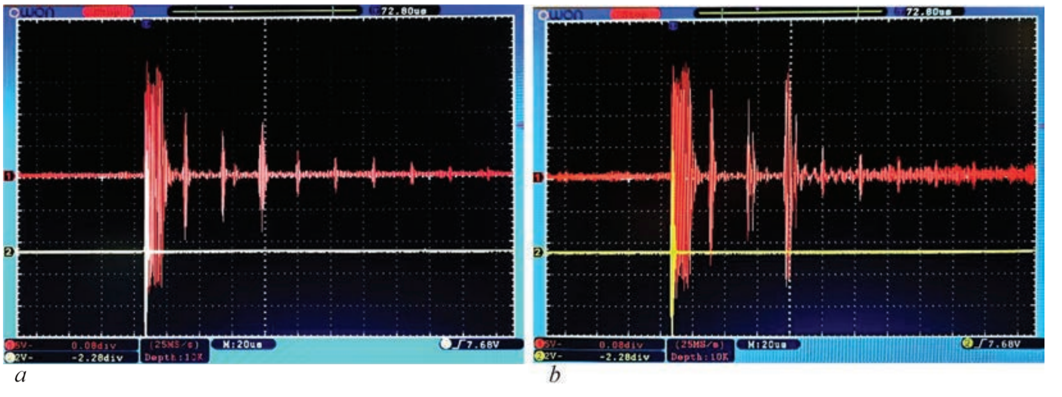

Figure 5. Realizations with sequences of bottom pulses reflected in the TO received in the absence of a pulsed magnetization (*a*) and with the combined operation of a permanent and pulsed magnetization (*b*)

6 are reflected from the metal volume and received by the high-frequency coil *4*. The ultrasonic pulses *7* received from the product *6* are amplified by the unit *8*, from which they are transmitted to the unit *9*, where they are processed and visualized. The control and synchronization of the bench elements is performed by the unit *10*. $B_p + B_0$ is the direction of the induction vector of the resulting magnetic field.

During research, the dimensions of the permanent magnet were 30×40×60 mm. The magnet material was made on the base of NeFeB. The pulse magnet coil had 21 turns of the wire with a diameter of 2.4 mm. The distance from the pole of the magnetic field source to the TO surface made of 39 mm thick st45 steel was 10.6 mm. The peak current in the magnetization coil reached 270 A. The delay of the high-frequency packet pulse relative to the start of the magnetization pulse exceeded 50 μs. The duration of the high-frequency packet pulse was equal to three periods of the 2.3 MHz filling frequency.

Figure 4 shows a functional diagram of operation of the combined magnetization test bench.

The test bench operates as follows. The EMAT is placed above the surface of the TO *6*, so that the distance from the pole of the permanent magnet *1* to the metal product *6* amounts to *h* (usually several millimetres). A permanent magnetic field B_0 is formed in the surface layer of the TO. The control and synchronization unit *10* transmits a synchronizing pulse C_1 to the unit *3* (Figure 4, *a*). The unit *3* excites a current pulse in the magnetization coil *2* with a time duration of several tens of microseconds, which excites the induction B_p in the surface layer of the TO. The magnetic fields generated by the magnetization coil *2* and magnet *1* coincide in direction and consist of $B_p + B_0$ (Figure 4, *b*). Next, the control and synchronization unit *10* transmits a synchronizing pulse C_2 (Figure 4, *a*) to the unit *5* with a delay T_d, which excites a packet pulse of high-frequency current in the high-frequency inductance coil *4*. As a result, a high-frequency eddy current I_{hf} is excited in the surface layer of the TO *6* in the zone of action of $B_p + B_0$ (Figure 4, c). The interaction of the magnetic field $B_p + B_0$ and the eddy current I_{hf} in the surface layer of the TO *6* due to the electromagnetic-acoustic conversion leads to the excitation of ultrasonic packet pulses in a metal product (Figure 3, position *7*). The ultrasonic pulses reflected from the TO *6*, e.g. bottom signals D_1 and D_2, are received by the high-frequency inductance coil *4* by means of an inverse electromagneto-acoustic conversion. The electric pulses received and converted by the coil *4*, which carry information about the quality of the metal product *6*, are amplified by a low-noise unit *8* (Figure 3), from which they are transmitted to the unit *9*, where they are processed and visualized.

As a result, due to the additional magnetic field B_p, the power of the excited ultrasonic pulse increases significantly and, accordingly, the sensitivity of ultrasonic testing grows, since the ratio of the amplitude of the useful signal to the amplitude of the noise increases. This conclusion is confirmed by the results of experimental studies (Figure 5) performed with the use of the bench (Figure 3).

From the analysis of the data obtained during the experimental studies, it was found that an increase in the amplitude of the bottom pulses due to the use of a pulsed magnetization reached 40 %. This means that the sensitivity of testing ferromagnetic metal products grows. In addition, the force of attraction of the magnet to the TO decreased, which improved the process of scanning the surface of the ferromagnetic TO by the operator using a portable EMAT.

CONCLUSIONS

It was found that in order to increase the sensitivity of testing, it is advisable to apply a magnetic field source with a simultaneous use of a permanent and a pulsed magnetic field.

To ensure an increase in the amplitude of the useful signal in relation to noise, it is necessary to delay the action of a high-frequency pulse in relation to the beginning of a magnetization pulse by at least 50 μs.

The use of additional pulsed magnetization makes it possible to increase the amplitude of the bottom pulses in relation to interference by up to 40 % at gaps between the TO and MFC surfaces of more than 10 mm.

Applying this technical solution, the force of attraction of the EMAT against the ferromagnetic TO is reduced, which improved the process of scanning the surface of the ferromagnetic TO by the operator using a portable EMAT.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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