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Study and development of a combined method for reducing the size of the uncontrolled near-surface layer during ultrasonic electromagnetic-acoustic testing of ferromagnetic metal products

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Abstract

Ultrasonic methods and tools are widely used in measurements, for quality inspection in industry, research, diagnostics in medicine, etc. Thus, in industry, ultrasonic methods account for more than 60% of all quality control of materials and products. Recently, the electromagnetic-acoustic (EMA) method of ultrasonic testing (UT) has been widely implemented, since it offers significant advantages over traditional methods, which require a contact liquid. EMA provides high performance, requires no clean-up of the surface of a test object (TO), does not require a contact liquid, etc. But there are also disadvantages, one of which is the presence of an uncontrolled near-surface zone caused by free electrical high-frequency oscillations (ringing) in the circuits of the device elements with EMA transducers (EMAT) after completion of the probing pulse. Having analysed existing developments, it has been established that the main method of the ringing suppression is the EMAT load on the resistance of semiconductor elements after completion of the probing pulse. This approach is only partially effective due to the voltage drop on the semiconductor elements during the high-current pulse passage. According to the study it is possible to significantly reduce the duration of the ringing and, accordingly, the size of the uncontrolled near-surface zone by compensating for the accumulated energy in the EMA elements of the device, as well as suppressing the EMAT ringing. A means for generating a group of pulses to ensure the operation of the ultrasonic device has been developed. The effectiveness of the developed control method has been confirmed experimentally.

Keywords: study; metal product; ultrasonic; control; EMAT; ringing; surface layer; burst pulse; pulse duration; ferromagnetic.

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Introduction

Traditional methods and means of ultrasonic measurements, quality control and diagnostics of materials and products offer both advantages [1] and disadvantages [2–3]. Among the advantages are: high sensitivity; productivity; safety, etc. Among the disadvantages, the most frequently cited is the need to use a contact liquid, to clean the surface of the introduction and reception of ultrasonic (US) pulses [1–4], etc. However, information sources do not pay sufficient attention to discussing the issue related to the quality control of the surface layer of the material. The presence, for example, of defects in the uncontrolled ("dead zone") leads to accelerated damage to products in operation and to significant material losses [2, 4]. This is especially true for transport, nuclear, oil and gas industries [5] and many others. The main reason for the presence of a "dead zone" is the duration of the probing ultrasonic pulse together with damped vibrations (ringing). In this case, the uncontrolled near-surface layer can reach 40 mm or more [2, 4–6].

The ringing is tackled by all the methods of excitation and reception of ultrasonic pulses [1–2, 5–8]. For traditional methods, as a rule, damping [1, 5] of piezoelectric elements of transducers is used, which leads to a decrease in sensitivity. For non-contact methods, for example, an electromagnetic-acoustic one, the ringing suppression is used by loading the EMA of a transducer onto a semiconductor element [6–8]. But this method does not significantly reduce the duration of the ringing, since there is a drop in the supply voltage on semiconductor elements [9] when a powerful current passes through. When using EMAT, such a voltage drop can reach 10 V or more [4, 6].

It is obvious that the main reason for the presence of a long-term "ringing" is the accumulation of electrical energy: in the blocks of generating a burst signal, in the elements of the probe pulse generator (PPG), in the EMAT and the amplifier of ultrasonic signals (AUS). The result is oscillatory electrical processes that are not fully compensated by known methods and means [6, 8] and, as a result, the uncontrolled surface layer of the metal product increases, and the quality of the product may decrease. Therefore, study and developments aimed at reducing the size of the "dead zone" of metal products are relevant.

Purpose of the study

Reducing the size of the uncontrolled near-surface layer of ferromagnetic metal products using burst ultrasonic pulses excited and received by compatible EMA transducers.

Development of a method for ultrasonic electromagnetic-acoustic testing of ferromagnetic products with a low "dead zone" value

Based on the results of known [6–8, 10–16] and conducted experimental studies, the authors have developed a combined method for reducing the "dead zone" of ultrasonic control using the example of using EMAT for ultrasonic control of ferromagnetic metal products manufactured and used for various purposes: pipes, rails, blanks, beams, channels, etc.

The new method simultaneously uses the physical effect of compensation for the accumulated electrical energy in the elements (PPG, EMAT, AUS) of the ultrasonic control device and suppression of the ringing using the results of [8]. The essence of the method is explained by the data shown in Fig. 1.

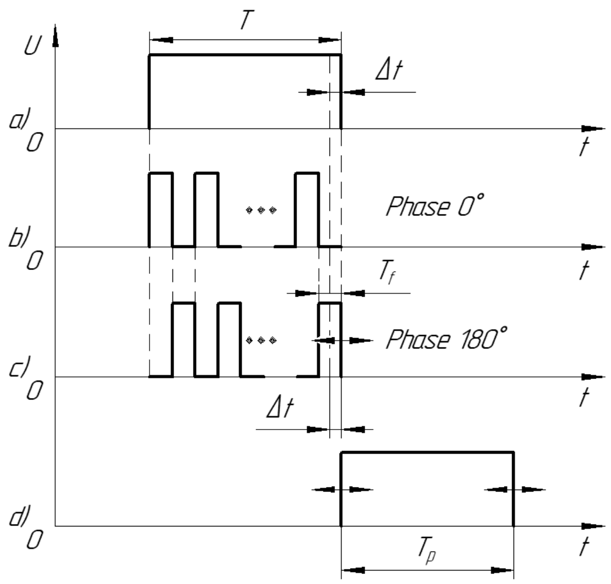


Fig. 1. Timing diagram of generating a burst pulse for powering the PPG with combined ringing reduction and suppression

Fig. 1 shows: U is voltage; t is time; T is the duration of the excitation burst pulse (scan *a*) of the EMAT; f is frequency; Δt is the change in the duration of the last half-period of the burst signal, generated by a pulse with a duration of T; T_f is the duration of the half-period in the burst signal; T_p is the duration of the pulse of suppression of high-frequency oscillations in the EMAT inductance coil after the probing pulse (scan *d*).

Together, scans *b* and *c* provide the generation of a radio pulse of current in the EMAT and, accordingly, the excitation of ultrasonic pulses in a test object (TO).

In Fig. 1, the change in the last half-period T_f on scan *b* with a phase of 1800 by the value Δt makes it possible to significantly compensate for the remaining accumulated energy from the previous half-period (the last half-period on scan *b*, Fig. 1). As a result, the voltage on the EMAT after completion of the probing pulse will be smaller and, accordingly, the voltage drop on the ringing suppression device will also be smaller, which ultimately leads to a reduction in the "dead zone" of the TO surface.

The next stage of the ringing suppression directly on the high-frequency EMAT coil is performed according to the technical solution [8]. As a result, the total ringing value is significantly reduced, which is confirmed by experimental data in Fig. 2.

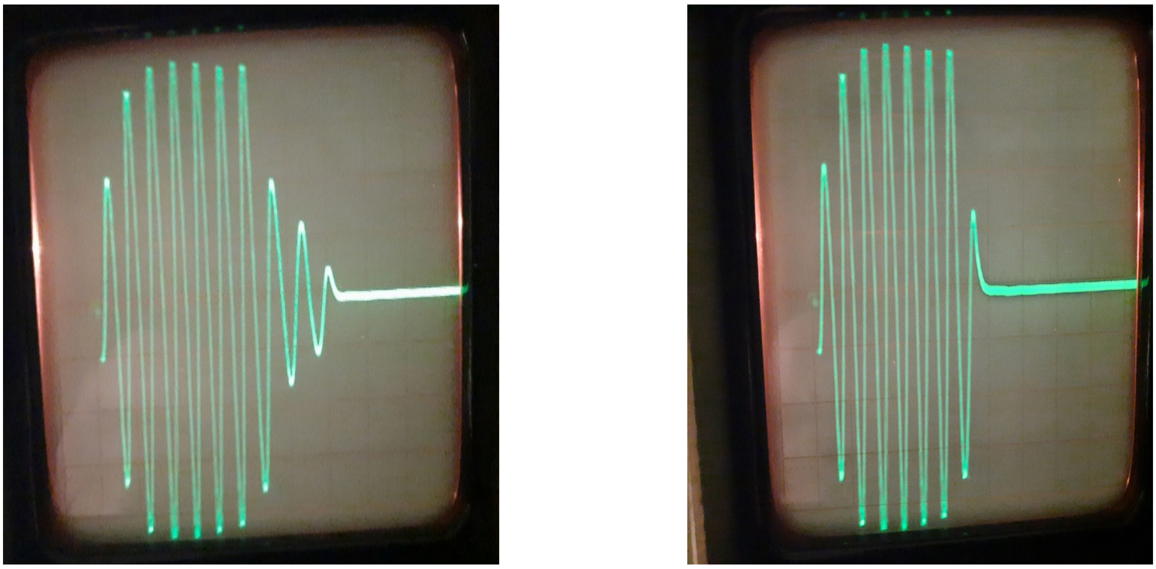
The scheme explaining the reduction of the near-surface "dead zone" of ultrasonic control of EMAT using the proposed combined method is explained by the data shown in Fig. 3.

Fig. 3 indicates: 1 is a EMAT; 2 are ultrasonic pulses; 3 is a defect; 4 is a TO; h_1 is the thickness of the uncontrolled near-surface layer when using a traditional method of the "ringing" suppression; h_2 is the thickness of the uncontrolled near-surface layer when using the developed complex method of the "ringing" suppression.

The time sweeps on the screen of a recording device will have the following shape accordingly (Fig. 4). Fig. 4 shows: A is an amplitude; A_{prob} is the maximum amplitude of the probing pulse; t is time; A_d is the amplitude of the ultrasonic pulse reflected from the defect; t_{prob} is the duration of the probing pulse; $t_{rng.1}$ is the duration of the probing pulse and "ringing" when using a traditional method of the "ringing" suppression; $t_{rng.2}$ is the duration of the probing pulse and "ringing" when using the developed method of the "ringing" suppression.

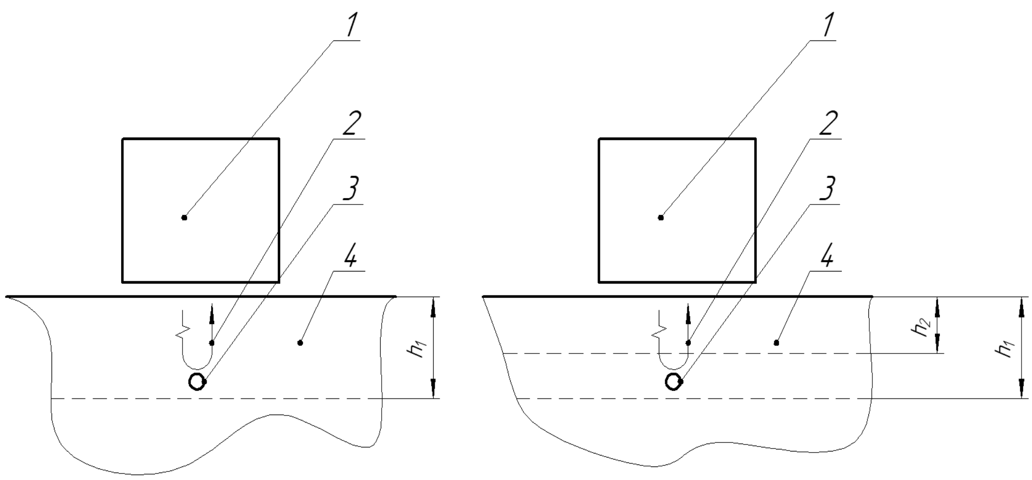
Analysis of the data shown in Fig. 4 allows us to determine the following: for the traditional suppression method [6–8], the thickness of the uncontrolled near-surface layer will be h_1 = C $t_{rng.1}$/2, and h_2 = C $t_{rng.2}$/2, where C is the propagation speed of ultrasonic waves in the TO material. That is, $h_1 >> h_2$, see Fig. 3.

As a result, a method was formulated that ensures an increase in the quality of ultrasonic inspection of a TO by reducing the "dead zone" of control (the thickness of the near-surface layer of the TO metal, Fig. 3–4).



a b

Fig. 2. Experimental time sweeps of PPG probing pulses on the high-frequency EMAT coil: *a* – by traditional method of the ringing suppression [8] (without changing the duration of the last half-period of the burst pulse); *b* – with additional changing the duration of the last half-period of the burst pulse



a b

Fig. 3. Schematic representation of the process of detecting a defect in the near-surface layer of the TO when using the traditional method of suppressing the "ringing" *a* and the developed method *b*

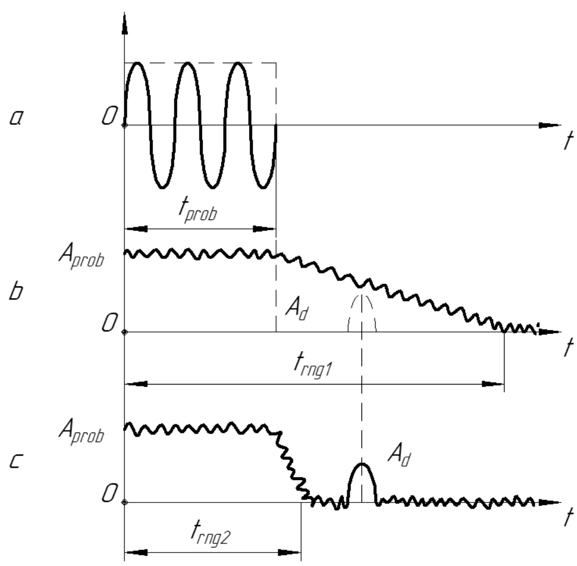


Fig. 4. Conditional time sweeps on the flaw detector screen when using a traditional method of the "ringing" suppression *b* (Fig. 3*a*) and the developed method *c* (Fig. 3*b*). (*a* – idealized sweep of the shape of the probing ultrasonic pulse)

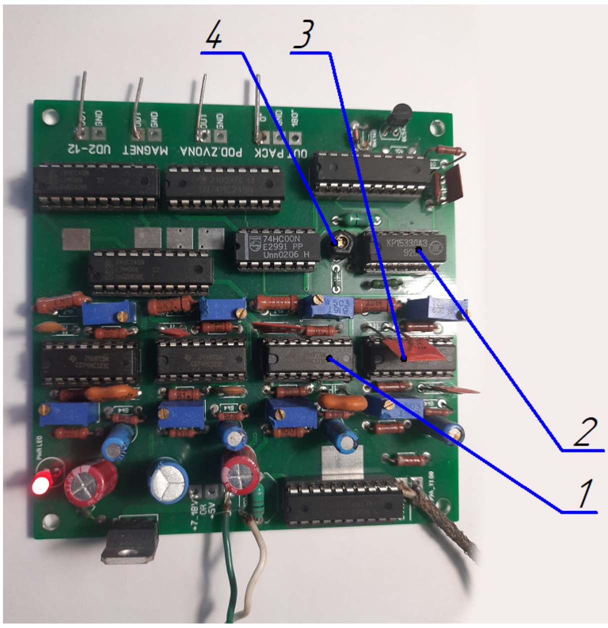


Fig. 5. Device for generating pulses of the duration of a burst signal, a high-frequency burst, a ringing suppression pulse and others necessary for the operation of an ultrasonic control device

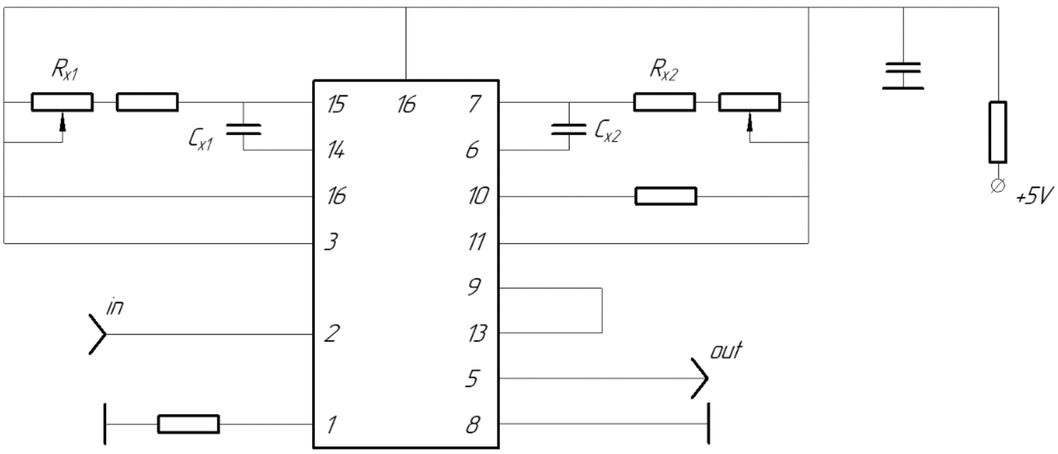


Fig. 6. Block with a waiting multivibrator with adjustment of the duration of the on and off pulse of generating a burst high-frequency signal against the sync pulse

The method of reducing the "dead zone" of ultrasonic inspection by electromagnetic-acoustic means establishes the following technological operations: excitation and interaction in a local area of the surface layer of a ferromagnetic metal product of a constant or pulsed magnetic field and a pulsed burst high-frequency electromagnetic field with a given filling frequency. As a result of the interaction of these fields, ultrasonic pulses are excited in the TO and then are received. In this case, the excitation of the burst high-frequency electromagnetic field is performed with the adjustment of the time duration of the last half-period of the filling frequency of the burst signal, the value of which is determined experimentally when setting up the control device on samples of the TO material, the quality of which is subject to assessment. The setting criterion is the minimum value of the uncontrolled surface layer of the metal product. At the same time, electrical oscillations are suppressed in the high-frequency coil of the electromagnetic-acoustic converter after completion of the probing current pulse in the EMAT by damping [8] by the straight-through resistance of semiconductor elements for the time required to receive ultrasonic pulses from the TO. To ensure the implementation of the developed method, a device for generating the necessary signals has been developed, the image of which is shown in Fig. 5.

Fig. 5 shows: 1 is a block for generating a pulse of a duration of a high-frequency burst signal (scan *a* in Fig. 1); 2 is a block for generating antiphase pulses (scans *b* and *c* in Fig. 1); 3 is a block for generating a ringing suppression pulse (scan *d* in Fig. 1).

Blocks 1 and 3 are made according to a typical circuit based on the 1533АГ3 microcircuit without using microprocessor technology, which is due to the need to exclude broadband noise from the operation of the clock generator. It is possible to generate pulses with a time duration that is necessary for exciting probing burst high-frequency pulses with adjustment of the duration of the last half-pulse of filling the burst with the given frequency, for example, according to the scheme shown in Fig. 6.

The leading edge of the pulse is regulated by a variable resistor R_{x1}, and the trailing edge by a variable resistor R_{x2}, respectively.

The block shown in Fig. 6 is turned on when a synchronizing pulse with a duration of about 1 μs is applied to input 2 of the microcircuit. The resulting pulse is generated at output 5 of the microcircuit.

Block 2 of antiphase pulse generation is made on the КР1533ЛА3 microcircuit. The frequency of filling the burst pulse is regulated by a variable capacitor, position 4, Fig. 5.

Experimental studies of the method and the "ringing" suppression block together with EMAT indicate that when the device is set up on samples of ferromagnetic materials (carbon steels), the value of the uncontrolled near-surface layer is reduced by almost 40%.

Conclusions

An electromagnetic-acoustic method of ultrasonic quality inspection of ferromagnetic products has been developed, which makes it possible to reduce the size of the uncontrolled surface layer of metal, the essence of which is to compensate for the accumulated electrical energy in the elements of a testing object and simultaneously suppress the ringing in the high-frequency coil of the EMAT after completion of the probing burst pulse.

A device for generating pulses necessary for the implementation of the developed method in a device for electromagnetic-acoustic control of ferromagnetic metal products has been developed and manufactured.

Дослідження та розробка комбінованого методу зменшення величини неконтрольованого приповерхневого шару при ультразвуковому електромагнітно-акустичному контролі феромагнітних металовиробів

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Анотація

Ультразвукові методи й засоби широко використовуються при вимірюваннях, для контролю якості в промисловості, дослідженнях та діагностиці в медицині тощо. Так у промисловості ультразвукові методи у всьому об'ємі контролю якості матеріалів і виробів займають понад 60%. Останнім часом почалося широке використання електромагнітно-акустичного (ЕМА) методу ультразвукового контролю (УЗК), оскільки він має суттєві переваги відносно традиційних методів із використанням контактної рідини. Він забезпечує високу продуктивність без потреби зачищати поверхню об'єкта контролю (ОК) і не використовує контактну рідину та інші. Але є й недоліки, один з яких полягає в наявності неконтрольованої приповерхневої зони, обумовленої вільними електричними високочастотними коливаннями (дзвоном) у ланцюгах елементів приладу з ЕМА перетворювачами (ЕМАП) після завершення дії зондуючого імпульсу. Аналізом відомих розробок встановлено, що основним методом пригнічення дзвону є навантаження ЕМАП на опір напівпровідникових елементів після завершення дії зондуючого імпульсу живлення перетворювача. Такий підхід дає лише частковий ефект через падіння напруги на напівпровідникових елементах при проходженні імпульсу потужного струму. Дослідженнями авторів показано, що значною мірою зменшити тривалість дзвону і, відповідно, величину неконтрольованої приповерхневої зони можливо завдяки компенсації накопиченої енергії в елементах ЕМА приладу, а також пригнічення дзвону ЕМАП. Розроблено засіб для формування групи імпульсів, необхідних для забезпечення роботи ультразвукового приладу. Ефективність розробленого методу контролю підтверджено експериментально.

Ключові слова: дослідження; металовиріб; ультразвуковий; контроль; ЕМАП; дзвін; приповерхневий шар; пакетний імпульс; тривалість імпульсу; феромагнітний.

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