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NOVEL SMALL-APERTURE TRANSDUCERS BASED ON MAGNETOSTRICTIVE EFFECT FOR DIAGNOSTIC SYSTEMS

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Small-aperture transducers based on the magnetostrictive effect for the emission and reception of signals in the ultrasonic range in solid materials have been developed. The article discusses their design features and specifications. Attention is paid to the features of the choice of materials, shapes, and geometrical dimensions of the excitation coil, damper, and magnet. Structural and electrical circuits of the developed transducers are given. Some design and technological solutions have been proposed that can increase the radiation power by 10 times, and resolution by 2-3 times, compared with existing analogs. The area of the radiating part of the sensor is from 0.07 to 0.2 mm^2. Such transducers can be used in various diagnostic systems to detect defects in power equipment, aircraft products, industrial equipment, etc. References 22, figures 10, tables 4.

Keywords: magnetostrictive effect, sensor, ferromagnet, Curie point, magnetic field, magnetic induction, non-destructive testing.

1 Introduction. The relevance of the research topic is due to the widespread use of ultrasonic methods for monitoring and diagnosing solids, especially in energy (energy equipment of the thermal power plants, nuclear power plants, etc.). Acoustic methods are widely used in physical research, in particular, they allow the study of various phenomena in solids. In the general case, several types of elastic waves can propagate in a medium, the characteristics of which carry information about the various properties of the medium [1].

Along with bulk (longitudinal and transverse) elastic waves, surface waves are widely used in research. Improving the experimental technique, expanding the frequency range of elastic waves (up to 10^9 Hz), together with the development of theoretical ideas about the mechanism of propagation of elastic waves in solids, has led to the widespread use of ultrasonic methods in scientific and practical research.

In particular, information on the physicomechanical properties of metals and alloys, the nature of phase transitions, and the magnitude of interatomic interaction forces can be obtained using modern diagnostic systems, including based on acoustic methods [2-9]. The high sensitivity of ultrasonic methods [10] to inhomogeneities of the medium and variations in its physicomechanical properties led to the creation and development of ultrasonic diagnostic methods, which makes it possible to study materials that are “opaque” for other methods. On their basis, specialized systems for diagnostics and control of solids are created in real-life conditions [11].

2 Analysis of existing systems and sensors

2.1. Ultrasonic field control systems. The low speed of elastic waves (five orders of magnitude lower than the speed of propagation of electromagnetic waves), as well as the small value of the wavelength of the same frequency, allows to create of microminiature high-performance information processing devices (delay lines, filters, coding systems, etc.). The use of nonlinear effects associated with the propagation of ultrasonic waves in solids led to the creation of frequency multipliers, mixers, parametric amplifiers, as well as instruments for the correlation analysis of signals.

Currently, magnetostrictive effects are mainly used to create ultrasonic resonant transducers and are used in industry for processing brittle materials, welding, washing, cleaning, and the like.

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Typically, such transducers operate at their resonant frequency of mechanical vibrations, since in this case, the conversion of energy from one form to another is most effective. Thin sheet metal magnetostrictive transducers perform better in the low-frequency ultrasonic range (from 20 to 50 kHz) and at frequencies above 100 kHz, they have a very low efficiency [12, 13].

Inverse magnetostrictive effects make it possible to build numerous sensors that can be used to measure forces, displacements, accelerations, and other mechanical quantities in various automation systems [14].

Table 1 shows a comparison of known systems for monitoring the characteristics of the ultrasonic field with piezoelectric transducers (PET) and the proposed system with low-aperture magnetostrictive transducers (MST).

Table 1

Parameter	**PET's system**	**MST's system**
Waves' types	Longitudinal transverse surface	Longitudinal transverse surface
The minimum area of the transducer, mm^2	1− 4	0.07 − 0.2
Longitudinal resolution, mm	0.5 − 1.0	0.02 − 0.05
Transverse resolution, mm	2.0 − 3.0	0.3 − 0.5
Frequency range, MHz	0.5 − 10.0	0.5 − 10.0
Transducers manufacturing technology	Requires complex processes	Enough lab conditions

Existing systems have a low resolution, limiting the accuracy of determining the characteristics of the acoustic field. In addition, they are of limited use in monitoring objects of complex shape and objects used at high temperatures during their operation, since the Curie temperature for most PETs does not exceed 100 ºC. The Curie point (the temperature at which the magnetostrictive effect disappears) for most magnetostrictive materials is in the range of 600 – 1200 ºC, which significantly exceeds the Curie temperature for PETs [15, 16]. This feature allows the use of magnetostrictive transducers at high temperatures, which is necessary to control heated bodies (boilers, pipes, heat exchangers, etc.) directly during their operation in heat supply systems [17].

2.2. Features of the functioning of magnetostrictive transducers. A significant part of magnetostrictive measuring information transducers is made up of linear displacement transducers based on magnetostrictive delay lines. Magnetostrictive position transducers (MPT) quite justifiably took an active place among the position sensors on the market [18]. This is due primarily to their high reliability, vibration resistance, as well as a significant range of transformations, and relatively low cost.

Today, the world leaders in the development and production of MPT are such companies as MTS (USA), Balluff (Germany), Schlumberger Industries (France), and others. Analysts of these firms point to more than 1,500 areas of use of MPT. The transducers of these firms have a permissible error in measuring the displacement of not more than 1 mm; a range of operating temperatures of application – from -200 to +200 °C; measured displacement - from 0 to 6000 mm; have high noise immunity and minimum power consumption [19].

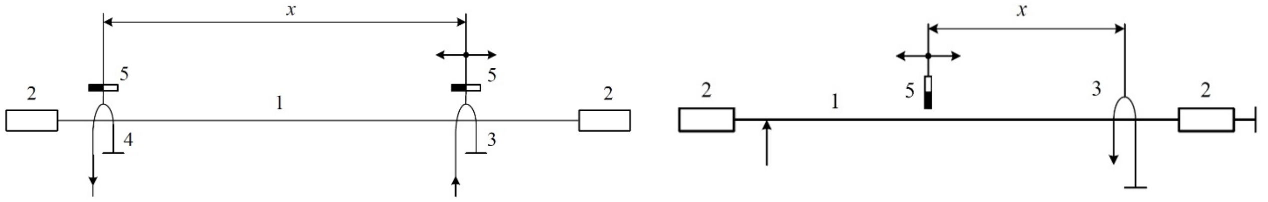
Table 2 shows the characteristics of MPT by Gefran, Balluff, KSR-Kuebler and MTS Sensors.

Table 2

Parameters	**Ballufff**	**Gefran**	**KSR-Kucbler**	**MTS Sensors**
Measuring displacement, mm	0 − 5500	50 − 4000	200 − 6000	50 − 5500
Working temperature, °C	-40 −+85	-30 − +90	-45 − +125, -200 − +200 (for high and low temperatures)	-200 − +125
Measurement errors, mm	<1	<1	<1	0.13 − 0.8
Power voltage, V	to 24	24	10 − 30	10.5 − 28

Depending on the type of wave motion used, MPT based on volume and surface acoustic waves (SAWs) is known. MPT uses SAWs until they have found wide application since SAWs practically do not allow contactless excitation and reading of ultrasonic vibrations (attenuation of about 80 dB), that is, they do not allow constructing a mechanically smoothly adjustable delay line in a wide range of transformations.

A simplified functional diagram of a MPT that operates on longitudinal ultrasonic waves is shown in Fig. 1, *a.*



a ***b***

Fig. 1

The basis of the MPT is a mechanically continuously adjustable ultrasonic delay line with a ferromagnetic wire, tubular or tape waveguide *1*, the excitation and reading of ultrasonic pulses which is carried out by magnetostrictive method.

The main elements of the MPT are input *4* and output *3* electro-acoustic transducers (EAT), acoustically connected to a common waveguide, at the ends of which dampers *2* are located.

After applying a pulse of the excitation current to coil *3* in the area of the waveguide *1* under the coil, a longitudinal ultrasonic wave is excited due to the Joule effect, propagates in both directions along the waveguide. The wave propagates to the right and attenuates in the damper *2*. The wave propagates to the left, due to the Villari effect, generates an electromotive force in the read coil *4* of the output EAT after a time t_x proportional to the position x. Propagating further, the wave is absorbed by the damper *2*.

Information about the movement (position) of the coil *3* is the time interval of the propagation of the ultrasonic signal along the waveguide between the MSTs:

$$t_x = pX / V_{pr}, \tag{1}$$

where x is the generalized linear displacement; p is the sensitivity coefficient, which is determined by the method of formation of the time interval; V_{pr} is the propagation velocity of a longitudinal ultrasonic wave along the waveguide, which is determined by the equation

$$V_{pr} = \sqrt{\frac{E}{\rho}} \left[1 - \left(\pi \nu \frac{R}{\lambda} \right)^2 \right], \tag{2}$$

where E − elastic modulus of the waveguide material; ρ is the specific gravity of the waveguide material; ν − the Poisson's ratio (for metals ~ 0.3); R − radius of the circumference of the cross-section of the waveguide; λ − length of the longitudinal ultrasonic wave for which the velocity is determined.

Speed without dispersion is expressed as follows:

$$V_{pr} = \sqrt{E/\rho}. \tag{3}$$

The basic design of the MPT position on torsion waves is shown in Fig. 1, *b*.

The movable element of the MPT of this type is a permanent magnet 4, and the excitation current pulse is supplied directly to the waveguide. A circular magnetic field is formed around the waveguide, which interacts with the longitudinal magnetic field of a permanent magnet. As a result of this, the magnetic field in the interaction zone changes abruptly and, due to the direct magnetostrictive effect (Wiedemann effect), a torsional ultrasonic wave arises in the waveguide and propagates along the waveguide. Having reached the reading zone, the ultrasonic pulse is converted into an electric pulse, and a time interval proportional to the movement is formed at the output of the MPT.

The installation at the end of the conversion range of an additional immovable permanent magnet allows to create of an additional reference time interval and implements the equations of logometric and differential conversion.

The use of MPT to determine the displacement of the float in storage tanks for various liquids allows the creation of high-precision ultrasonic level gauges and flow meters.

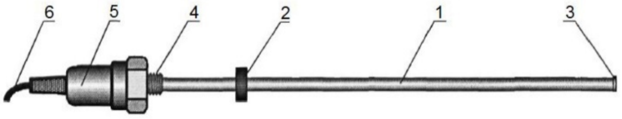


Fig. 2

Fig. 2 shows the design of MPT, which can be recommended for use in normal and special operating conditions, including in thermal engineering facilities.

The transducer includes a linear acoustic waveguide (oscillator) located in a protective sealed enclosure *1*, and a magnetic positioning element *2*, which can be moved along the enclosure *1*. A linear section of enclosure *1* from the sealed plug *3* to the threaded connection *4* is a measuring part of the transducer. A magnetostrictive transducer with matching and damping devices, which are hermetically closed by a protective cover *5*, is placed between the threaded connection *4* and the electric cable *6*. An information signal on the movement of the magnetic positioning element *2* through an electric cable *6* is transmitted to the secondary transducers.

Such transducers are widely used to control the level and flow rate of liquid in containers for various purposes. The waveguide length can reach 10 m or more with a distance measurement error of less than 1 mm.

From the above analysis of existing magnetostrictive sensors, it follows that they are widely used in various fields of technology, but rarely used in the systems of ultrasonic diagnostics of solids, which are the most important objects.

In this connection, some questions arise: if the magnetostrictive delay line is "cut", can the transducers be used to excite and receive ultrasonic waves in a solid? Will the radiation power be sufficient? Enough sensitivity of the receiving transducers? What geometric dimensions can be controlled?

It should also be noted that the excitation and reception of ultrasonic vibrations in a solid can only be achieved using magnetostrictive transducers that excite longitudinal waves.

The purpose of the work is to develop approaches to the creation of magnetostrictive transducers for control and diagnosing systems of the technical condition of metal and composite structures and experimental studies of the ultrasonic testing system developed on their basis.

3. Approaches to the creation of magnetostrictive transducers

3.1. Choice of material for the manufacture of the waveguide and its technological processing

The waveguide is one of the most important elements of MSTs. The parameters of the materials of the waveguides, with the exception of the saturation magnetization and the Curie temperature, are very sensitive to the chemical composition of the material and the presence of impurities.

Therefore, in order to obtain high values of magnetostrictive parameters, various types of heats performed in induction furnaces under vacuum should be used. Of the available and relatively cheap materials, it is advisable to use the iron-cobalt permendur alloy in the form of a cylindrical profile wire with a diameter of 0.3 to 2.0 mm, which makes it possible to increase the sensitivity of MSTs by an order of magnitude compared to traditional nickel wire.

The efficiency of MST is largely dependent on electromagnetic and mechanical energy losses in ferromagnetic materials. Electromagnetic losses account for the bulk of total losses. They consist of eddy current losses (Foucault currents), which depend on the electrical resistivity of the waveguide material and magnetic hysteresis losses, which are estimated by the coercive force of the material. The effectiveness of materials is the greater, than greater the value of magnetostrictive susceptibility, coefficient of magnetomechanical coupling, saturation magnetostriction and the lower their electromagnetic losses.

The materials for these magnetostrictive devices must also have a sufficiently large modulus of elasticity to provide high rigidity. It is understood that the issue of material cost is also important.

Iron-aluminum alloys and iron-cobalt alloys have good magnetostrictive properties. The maximum value of saturation magnetostriction is reached at 65–70% of the cobalt content and is $\lambda_s = 90\cdot10^{-6}$. Iron-cobalt alloys have a high value of elastic modulus and good magnetic properties: a record value of saturation induction and a fairly high magnetic permeability.

A high value of saturation magnetostriction $\lambda_s = 70\cdot10^{-6}$ is maintained at a cobalt content of 40-45%. With a lower cobalt content, magnetostriction decreases sharply. The industry produces two types of iron-cobalt alloys with a content of 65% Co (K65 alloy) and 49% Co with the addition of 2% vanadium to improve machinability (K49F2 permendure). Both alloys have a high value of elastic modulus and good magnetic properties – a record value of saturation induction B_s=2.4 T and a sufficiently high magnetic permeability. At the same time, K49F2 alloy has somewhat better magnetic, and K65 alloy has mechanical properties. Low electrical resistance and, accordingly, high eddy current losses in the K65 alloy make it less suitable in the ultrasound technique. A slightly higher cost, about 4 times more than nickel, cannot serve as an obstacle to the use of these alloys in modern highly automated monitoring systems for heating equipment. The most suitable material for small aperture magnetostrictive transducers is K49F2 alloy (permendure).

3.2. Choice of material, shape, and geometric dimensions of the damper

Acoustic waveguide dampers are introduced into the design of the transducers to reduce the level of spurious reflected signals from the ends of the waveguides. To this end, the end of the waveguide is equipped with special devices, as a result of which the specific attenuation of the ultrasonic wave in the end sections of the waveguides smoothly increases to such a value that the level of signals reflected from the ends of the waveguide does not exceed the permissible value.

Modern transducers for dampers most often use leather, rubber, gum, metal, etc. (Fig. 3: *a* – cylindrical single layer, *b* – cylindrical multi-element, *c* – drop-shaped multilayer, *d* – drop-shaped single layer). However, these dampers have a complex structure, large overall dimensions, and a limited temperature range (-40 ... + 110 °C).

The best absorbing properties are of dampers of a drop-shaped single layer of medium size (diameter about 5 mm).

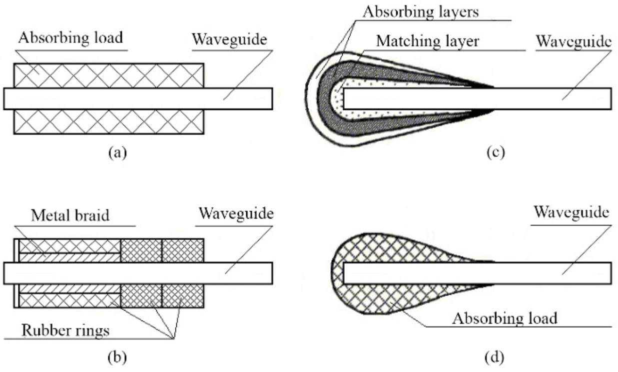


Fig. 3

Experimental research has shown that single-layer drop-shaped dampers with a diameter of 1.5 ... 10 mm for waveguides with a diameter of 0.3 ... 2.0 mm have good absorbing properties. Such dampers were made from epoxy resin ED-20, mixed with tungsten powder in a weight ratio of 1 to 2. The absorption coefficient in this case is more than 20 dB.

3.3. Choice of material, shape, and geometric dimensions of the field coil

The dependence of the electromechanical coupling coefficient of the waveguide material k_μ on the ratio of the winding diameter to the diameter of the acoustic waveguide d_{win}/d_{wave} is shown in Fig. 4.

Fig. 4 shows that when d_{win} /d_{wave} = 2, the coefficient of use of the magnetic properties of the waveguide is about 0.1; that is 10 times worse than when winding the wire directly on the waveguide. From this, we can conclude that the excitation coil should be single-layer, contain a small number of turns, and be wound directly on the waveguide.

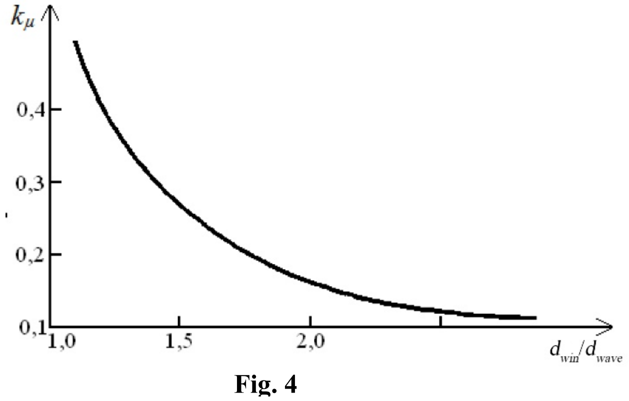


Fig. 4

From the analysis of the data obtained, the following conclusions can be drawn:

- a slight increase in the distance between the turns of the coil and the waveguide leads to a noticeable decrease in the magnitude of the received signal, which becomes especially noticeable with increasing frequency;

- with an increase in the frequency of filling oscillations of radio pulses, the electromechanical coupling coefficient decreases, which leads to a decrease in the magnitude of the received signals.

Therefore, it is necessary to fabricate the excitation coils of the MST with a minimum distance of the turns from the waveguide.

The transducer winding can be made of wire, for example, PETV-2 0,063, TU 16-502.003-82, which is applied to the outer surface of the waveguide.

If the transducer operates at the same frequency, then the winding can be multi-sectional. Each next section is wound on the previous meeting and at a half-wave distance from the previous winding. The number of sections should be paired. This allows increasing the sensitivity several times.

3.4. Choice of material, dimensions, and residual magnetization of a permanent magnet

The following requirements for permanent magnet magnetic materials for low-aperture MSTs are determined:

- residual magnetic induction B_r≥14000 G;
- coercive force H_c≥530 E;
- Curie temperature is more than +760 °C;
- range of working temperatures: -80…+ 200 °C;
- high mechanical strength.

For most cases of manufacturing small-aperture MSTs, it is quite sufficient to use rod permanent magnets from magnetically hard materials. Good results have been obtained using neodymium bar magnets 1 mm in diameter and 5 mm long, glued directly onto the excitation winding.

4. Development of a control system

4.1. Development of small-aperture ultrasonic sensors. Unlike a liquid, elastic waves of various types arise and propagate in a solid, the characteristics of which contain information about the properties of controlled objects and defects in their internal structure. Along with body (longitudinal and transverse) elastic waves, surface waves are widely used in research.

For the emission and reception of ultrasonic waves in diagnostic systems, PET with a significant working surface area is most often used. In most cases, this is advisable, because in this case, the radiation pattern of the transducer has a pronounced maximum in the direction of radiation. This provides sufficient energy for the signal reflected from the inhomogeneity. However, there are several technical problems where the use of such transducers is impossible. These are the tasks of measuring the characteristics of the ultrasonic field in bodies of small sizes, in bodies with a complex surface shape, in heated bodies, and the like [20].

To solve them, it can use small apertures ultrasonic magnetostrictive transducers, a simplified design of which is shown in Fig. 5, where *1* is the body, *2* is an ultrasonic mirror, *3* is a waveguide of magnetostrictive material, *4* is an excitation coil, *5* is a permanent magnet, *6* is a damper. Figure 6 shows a line of such transducers in one housing, where *7* is a filler and *8* is a magnetic screen.

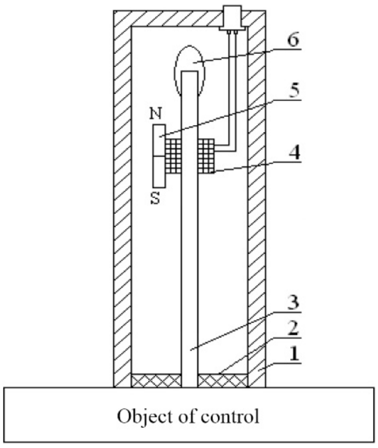


Fig. 5

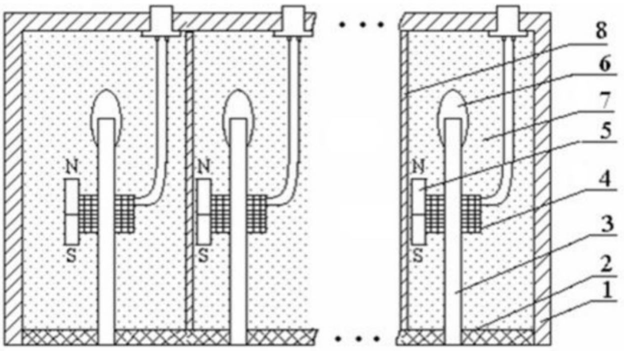


Fig. 6

The main parameters and characteristics of magnetostrictive transducers substantially depend on the design of the transducer itself, the accuracy of the manufacture of its elements and parts, as well as on the technological processes of processing the materials from which the transducers are made [21, 22].

4.2. Block diagrams of control units

As described above, a small aperture magnetostrictive radiator has a small emitting surface area, which makes it possible to create a spherical (non-directional) longitudinal wave in a controlled sample. Therefore, for the normal operation of the ultrasonic monitoring system, it is necessary to ensure sufficient radiation power.

Figure 7 shows a block diagram of a block of powerful MST with acoustic summation of signals in a waveguide. The proposed technical solution provides an increase in the intensity of the emitted signal by N^2 times, where N is the number of summation channels.

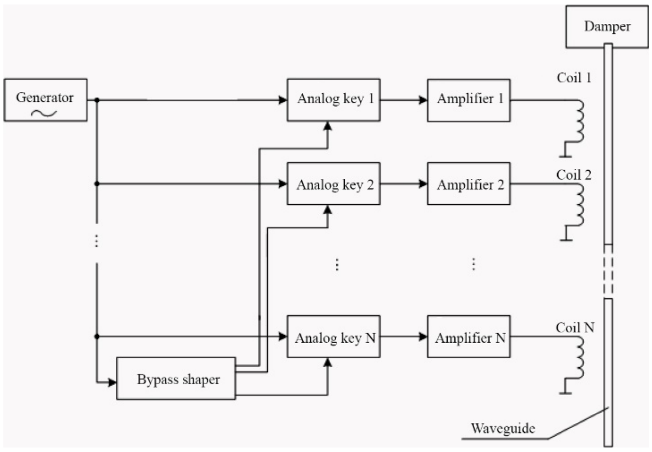


Fig. 7

The time dependence of acoustic pressure under the N-th excitation coil is described by the following expressions:

$$
\begin{aligned}
&p_1(t)=u_1(t)+(n-1)a/V_{np}\cdot K\cdot e^{-\beta(n-1)a},\\
&p_2(t)=u_2(t)+(n-2)a/V_{np}\cdot K\cdot e^{-\beta(n-2)a},\\
&p_i(t)=u_i(t)+(n-i)a/V_{np}\cdot K\cdot e^{-\beta(n-i)a},\\
&p_N(t)=u_N(t)\cdot K,
\end{aligned}
\tag{4}
$$

where $u_i(t)$ is the electrical signal on the i-th excitation coil; K is the coupling coefficient of the electromechanical coupling; β is the attenuation coefficient of the ultrasonic signal in the waveguide; a is the distance between the excitation coils; n is the number of the excitation coil, N is the number of excitation channels (number of coils).

The diameter of the radiating surface of the transducer (the diameter of the waveguide) is 0.3 −0.5 mm. The transducer operates at a frequency of 1 MHz. With this ratio of the diameter of the transducer and the frequency of the carrier oscillation of the radio pulse, an ultrasonic longitudinal wave with a directivity pattern in the form of a hemisphere is emitted into the test sample. The distances between the excitation coils are equal to one longitudinal wavelength in the waveguide. The signals to the excitation coils are delayed in time concerning the previous coils for one period of the carrier oscillation. Thus, at the end of the waveguide, the signals from each coil arrive simultaneously and in phase, which provides an acoustic summation of the signals in the waveguide and allows to increase in the amplitude of the emitted signal by N times, and the radiation power by N^2 times.

However, the distances between the coils are determined based on the frequency of the carrier oscillation. Thus, for different frequencies of the carrier oscillation, it is necessary to produce various emitters.

The number of channels in a radiating MST can be any, but it should be borne in mind that the displacement of the particles of the waveguide should not exceed the value of elastic deformations, since this can lead to the destruction of the waveguide.

A single transducer allows to determine the fact of the presence or absence of a defect but does not allow determining its spatial position in the sample. In addition, to determine the size and location of the defect, it is necessary to perform a mechanical scan of the surface of the controlled sample and apply complex calculation algorithms. This disadvantage can be eliminated by using rulers and matrixes of transducers.

5 Experimental results

The structural diagram of the ultrasonic control system with small aperture transducers is shown in Fig. 8.

In the analysis and calculation of the acoustic path, the requirements for the hardware of the device for generating an electric radio-pulse excitation signal and receiving an ultrasonic signal from a small-aperture MST were determined.

The frequency of filling the radio pulse is 0.1 ... 10 MHz. The pulse duration is 1 ... 8 periods of filling oscillation. The amplitude value of the voltage to the emitters should be more than 5 V, with a load of less than 1 Ohm. The input impedance of the receiving amplifier must be more than 2 kOhm. The amplification factor is more than 2500 times.

Based on the requirements, circuits were developed and an electronic unit manufactured. Technical characteristics of the electronic unit for the formation and acceptance of radio pulse signals are shown in Table 3.

Figure 9 shows a photo of a part of a sample of riveted joint parts marked with a black arrow.

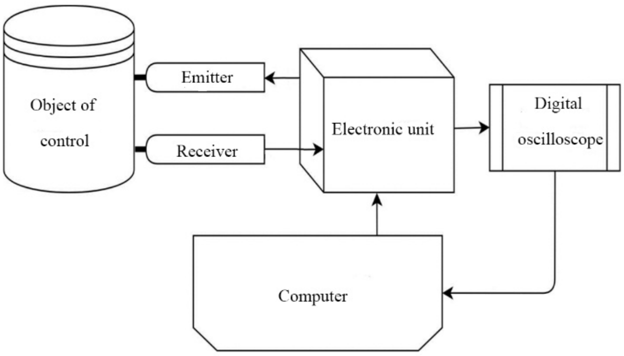


Fig. 8

Table 3

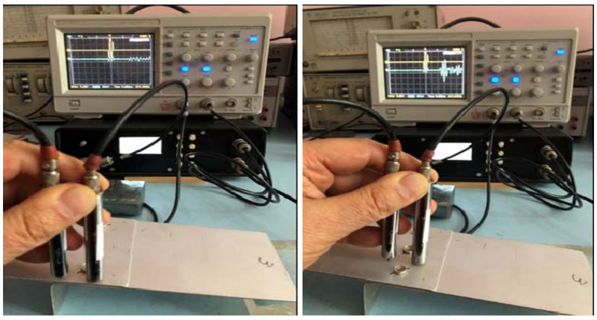
Parameter	Value
Frequency of filling of the radio pulse signal, MHz	0.1; 0.25; 0.5; 1.0; 2.5; 5.0; 10.0
Duration of the radio pulse, the number of periods of filling oscillation	1 … 8
Amplitude value of the voltage to the emitters at a load of 0.5 Ohm, V	0 … 10
Amplifier input impedance, kOhm	more 3.0
The maximum output voltage, V	10
Amplification factor	5000

The crack was grown artificially by repeated variable bending loads on the part. A crack occurs in the region of rivets since here the mechanical stress is 3-4 times higher than the stress in other parts of the specimen.

Using the equipment described above, ultrasonic testing of this part was carried out at various sites in the rivet area. The location of the transducers on the sample and the waveforms of the received signals are shown in Fig. 10 (*a* – with a crack, *b* – without breaking the integrity).

As can be seen from the oscillograms of the received sensor signals, when the ultrasonic wave passes through the crack, the signal decreases by more than 10 times (Fig. 10, *a*). Thus, most of the wave energy is reflected from the crack.

Fig. 9



a ***b***

Fig. 10

The results of experimental studies are shown in Table 4.

Table 4

	No crack	With crack [*L*=2 cm]	With crack [*L*=3 cm]	Measurement error
t, μs	13.8	14.3	16.8	0.1
$2U_m$, V	5	0.5	0.45	0.02

The delay time for the signal to pass through the cracked portion of the sample increased by $0.5\cdot10^{-6}$ from the distance between the transducers L=2 cm and $3\cdot10^{-6}$ s at L=3 cm compared to the delay time during the signal passed through the defect-free portion of the sample. The change in the delay time and the amplitude of the signal is due to a change in the signal path between the transducers.

6 Conclusions

Small-aperture magnetostrictive transducers have a small area of the radiating surface, which allows obtaining an almost circular radiation pattern for surface ultrasonic waves.

Surface waves have a small penetration depth, which is convenient for detecting surface cracks.

A significant advantage of MSTs is the Curie point for most common magnetostrictive materials is in the range of 600 ... 1200 °C, which is much higher than the Curie temperature for piezoelectric transducers. In addition, the zone for converting an acoustic signal into an electrical one is located at some distance (5 ... 1000 mm or more) from the point of contact with the test object, unlike piezoelectric transducers. These features allow to use of low-aperture MSTs at high temperatures, which is necessary to control heated objects (boilers, pipes, heat exchangers, etc.) directly in the process of their operation.

The use of low-aperture magnetostrictive sensors in ultrasonic control systems also allows to control with high reliability of the distribution of acoustic pressure on the surface of the elements of ultrasonic phased array antennas, as well as other parameters and characteristics of modern ultrasonic sensors.

Methods for improving the characteristics of low-aperture MSTs have been developed and experimentally investigated that have increased the radiation power by ≥10 times, sensitivity and resolution - by 2-4 times with a radiating surface area of not more than 0.2 mm^2.

Based on the proposed methods for improving the characteristics of MSTs, experimental transducers were created and their laboratory tests were carried out, confirming the effectiveness of the proposed scientific and technical solutions.

Acoustic contact of magnetostrictive transducers with the object of control can be provided without the use of special contact liquids. When using contact fluid, the amplitude of the received signal increases by 2 ... 3 times, which is useful during controlling large parts.

With a known distance between the emitter and the receiver of ultrasonic vibrations (when two transducers are located in the same housing), the propagation velocity of the ultrasonic wave in the controlled sample can be determined, and later it can be used to calculate the size of the crack and its location.

It seems advisable to direct further research to an in-depth study of the transformation and interference of various types of waves in ultrasonic tracts and the development of methods for monitoring various objects.

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НОВІ МАЛОАПЕРТУРНІ ПЕРЕТВОРЮВАЧІ НА ОСНОВІ МАГНІТОСТРИКЦІЙНОГО ЕФЕКТУ ДЛЯ ДІАГНОСТИЧНИХ СИСТЕМ

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Розроблено малоапертурні перетворювачі на основі магнітострикційного ефекту для випромінювання та прийому сигналів ультразвукового діапазону в твердих матеріалах. У статті розглядаються їхні конструктивні особливості та технічні характеристики. Звертається увага на особливості вибору матеріалів, форми та геометричних розмірів котушки збудження, демпфера та магніту. Наведено структурні та електричні схеми розроблених перетворювачів. Запропоновано ряд конструкторсько-технологічних рішень, що надають змогу збільшити потужність випромінювання в 10 разів, а роздільну здатність – у 2-3 рази в порівнянні з існуючими аналогами. Площа випромінюючої частини сенсора становить від 0,07 до 0,2 мм^2*. Такі перетворювачі можуть використовуватися в різних діагностичних системах для виявлення дефектів енергетичного обладнання, авіаційних деталей, промислового обладнання тощо.* Бібл. 22, рис. 10, табл. 4.

Ключові слова: магнітострикційний ефект, сенсор, феромагнетик, точка Кюрі, магнітне поле, магнітна індукція, неруйнівний контроль.

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