Contact ultrasonic transducers for mechanical scanning systems

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Abstract

In this article the low frequency contact transducers for mechanical scanning systems are considered. The important part of the contact scanning transducer is protector which can be replaceable if it is wearing away. The two kinds of the replaceable protectors are investigated. The first, the planar protector the thickness of which may be from 0.25 mm up to 3.0 mm and the second, the convex protector having the surface of acoustic contact, diameter of which may be from 0 up to 7 mm were made. Ultrasonic signals and their frequency responses are presented for the planar and the convex protectors. The amplitude of ultrasonic signals depends on the thickness of the protector. For the planar protector the amplitude of the ultrasonic signals decreases when the thickness of the protector increases. For the convex protector the amplitude of the ultrasonic signals increases when the planar part of the protector increases.

Keyword: mechanical scanning system, contact transducer, protector with variable thickness, contact area, convex protector

Introduction

Ultrasonic transducers are widely used in various fields including nondestructive testing, materials characterization and medical diagnosis. However, requirements for possibilities of the ultrasonic transducers increase with appearance of new materials and new technologies of the materials characterization. In some cases, the objects under a test have multilayer structures, which consist of a few layers possessing different acoustic and mechanical properties. These multilayer structures basically consist of polymer materials or polymer materials and metal sheets, which have essential losses of the propagating ultrasonic waves. Also, the layers of different materials are joined by the glue, which gives the additional losses of the ultrasonic waves, basically due to mismatching of the acoustic impedances.

Different ultrasonic methods and transducers can be implemented into non-destructive testing systems, like air-coupled, immersion and contact. The air-coupled methods [1 – 3] are very attractive and successfully used for the investigation of composite materials, multi-layered plastics and metallic products. However, the air-coupled ultrasonic investigations have a few short comings. The main of them is significant mismatch of the acoustic impedances between the ultrasonic transducers, air and the material under the test. The total losses depend on the transducer losses, the losses inside the material of the test object and the losses in air. Usually, they are from – 120 dB up to – 180 dB. In order to decrease the losses of air-coupled transducers, the active aperture of the transducer could be increased, but simultaneously the achievable spatial resolution becomes lower.

The immersion methods are very attractive as the transduction losses due to different acoustic properties of matching layers of the transducers, an immersion liquid and the material of the object substantially decrease [4 – 7]. They allow using rather high frequencies in the investigations. A few ultrasonic through – transmission techniques were used for immersion and air-coupled investigations [4]. The immersion system was used in the frequency range from 1 MHz up to 10 MHz and the air-coupled system 120 kHz to 400 kHz. The critical defects were detected using both through – transmission techniques, although the immersion technique has the best resolution and sensitivity. However, sometimes the air-coupled technique is preferable to be used, because it does not require water coupling.

A very attractive way is to use both immersion and contact methods together [5 – 7]. One of the transducers (transmitting) was mounted on the edge of the plate under investigation and the receiving transducer was scanned over the plate [5]. It allowed excition of the S_0 mode ant to get the mode transformation of the S_0 mode to the A_0 mode on the welded seams effectively. The scanning of the receiver was performed in water over the surface of the steel plate having thickness of 8 mm.

A similar method of measurement was suggested by Mažeika et. al. [6], where the contact type transmitting transducer was permanently fixed by epoxy glue on one side of the aluminum plate. The receiving transducer was placed at the distance of 10 mm over the opposite surface of the plate and scanned along two perpendicular directions. In this method only the symmetric S_0 mode was investigated [6].

The investigation of CFRP rods was carried out in water using the transmitter glued to the edge of the rod [7]. The receiver was scanned over the surface of the rod in order to pick-up the leaky waves. It was shown that the internal delamination in the CFRP rod are not obstacles for propagating ultrasonic guided waves.

In non-destructive inspection of aerospace materials and structures, the immersion ultrasonic inspection is often not allowed due to water ingress into the internal structure. For example, the composite sandwiches, the foam type and honeycomb type structures can not tolerate water ingression. Therefore, the most promising methods for investigation of such materials are contact type methods. However, the appropriate contact method must be adapted according to the properties of the object under investigation and particular measurement conditions.

The aim of this work is to investigate the wide-band contact type ultrasonic transducers with intention to use them with mechanical scanning systems of composite materials.

The design of the scanning transducer

The low frequency contact type transducers [8 – 10] are widely used in acoustic emission applications at frequencies from 100 kHz up to 1 MHz. The conical transducers were developed for that purpose [8 – 9]. Such type of transducers operates as a high-sensitivity, wide-band device for registration of the normal component of displacements. The small conical piezoelement was implemented inside a large housing having dimensions of 25 mm × 37 mm without matching layers. Therefore, they were used to measure the displacement at a fixed point only.

To use the conical piezoelectric transducers as point type source of acoustic waves has been investigated by Evans et al. [10]. The piezoceramic disc having diameter of 3 mm has been mounted on the planar part of the conical waveguide, the tip of which had the diameter close to 1 mm. The brass shim having thickness of 50 μm was bounded to the tip and served as a wear protector. However, this construction is unsuitable for a long-term contact scanning.

The contact type ultrasonic transducers which are used in the mechanical scanning arrangements must eet a few requirements. At first, during the long-term scanning characteristics of the piezoelectric transducer should not change. Therefore, the material of the transducer protector must be made of sufficiently "hard" material possessing wear proof. In order to achieve the best transmission of the acoustic waves from the piezoelectric element to the investigated object the acoustic impedance of the protector should be close to the acoustic impedance of the material of the investigated object. At second, the lateral dimensions and a weight of transducer must be as small as possible. Therefore, the minimal distance between the transmitter and the receiver will be increased, also the small weight will not load the assembly of the mechanical scanner. At third, the transducer must be wide-band because large number of different modes of guided waves exists in multi-layered structures, when the piezoelectric transducer is exited by a short pulse.

Very important part of the considered transducers is a replaceable protector. The basis of the scanning contact type transducer consists of the constant part of the low frequency wide-band transducer [11] and replaceable part (Fig. 1). The constant part of the transducer consists of a piezoelectric element 1, a constant protector 2 and damper 3. The piezoelectric element is connected to the connector 5 using two wires 4. The connector 5 is fixed into the cap of the housing 6. The housing of the transducer 7 is filled with a mixture of epoxy and lead oxide. This arrangement was swivelled around by a layer of a soft material 9 and mounted into the housing 7. The replaceable part of transducer consist of the replaceable protector 10 and a fixing ring 11, which has a screw inside. The fixing ring is used to press the replaceable protector 10 to the constant protector 2.

A few types of the replaceable protectors can be used in constructions of the contact type scanning transducers. It depends on the scope where the scanning transducers are applied. The investigation was made for planar and convex protectors. In both cases, the replaceable protectors were made of glass fibre plastic as the constant protector. It provides good transmission of the ultrasonic waves from the constant protector to the replaceable protector. Also the fibre glass material has good mechanical properties and the resistance against wearing to be used as the contact type protector.

The shape of the planar replaceable protector is shown in Fig. 2. In Table 1 the thickness values of the planar replaceable protector are presented.

The wearing thickness of the replaceable protector was from 0 mm up to 1.412 mm (Table 2), when the diameter of the contact area changes from 0 mm up to 7.0 mm.

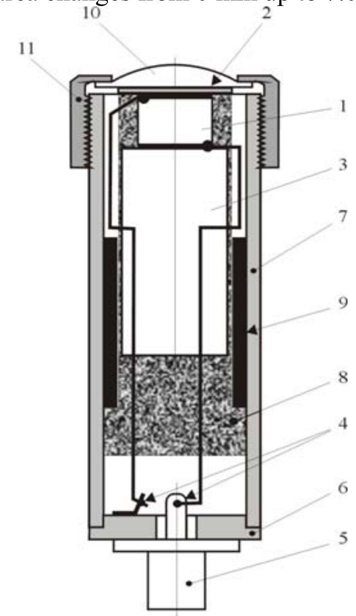

Fig. 1. **Cross-section of the low frequency ultrasonic transducer: 1 – piezoelement; 2 – protector; 3 – damper; 4 – connection wires; 5 – connector; 6 – cap of the housing; 7 – housing; 8 – damping compound; 9 – soft material layer; 10 – replaceable protector; 11 – fixing ring**

Table 1. T**he thickness values of the planar replaceable protector**

Sample No.	Thickness, mm
01	0.25
02	0.45
03	1.0
04	1.5
05	2.0
06	3.0

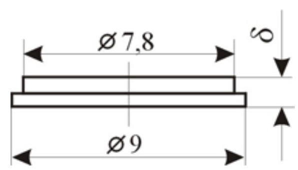

Fig. 2. **The shape of the planar replaceable protector**

The shape of the convex replaceable protector is shows in Fig. 3.

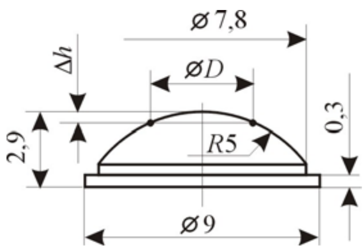

Fig. 3. **The shape of the convex replaceable protector**

Table 2 **The dimensions of the convex replaceable protector**

Sample No.	Wearing thickness, Δh, mm	The contact area, mm^2	Diameter of the contact area, mm
00	0	0	0
01	0.03	0.79	1
02	0.101	3.14	2
03	0.234	7.07	3
04	0.422	12.56	4
05	0.662	12.63	5
06	0.995	28.26	6
07	1.412	38.47	7

Experimental investigations

The characteristics of the developed low frequency contact type transducers have been investigated. The characteristics were measured for the pair of transducers by attaching the transmitting and the receiving transducers "face-to-face". The acoustic contact was provided by a coupling liquid. At first, the reference signal of the transducers without the protectors was obtained. Two different methods were used to get the responses of the transducers. The transmitter was excited by the three periods burst of the 220 kHz frequency. In the second one, the short excitation pulse (0.5 μs) was used in order to get the pulse response of the transducer. The received ultrasonic signal from the two transducers without the replaceable protector is shown in Fig. 4. The excitation pulse consists of the three periods burst with the amplitude of 20 V. The estimated losses of the transmitter and receiver were – 56 dB.

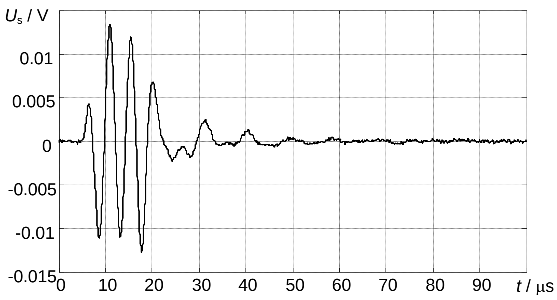

Fig. 4. **The ultrasonic signal of the transducers without the replaceable protector**

The frequency response of the single reference transducer is shown in Fig. 5. The frequency bandwidth of the contact transducer was from 40 kHz up to 640 kHz (at –10 dB) and from 25 kHz to 780 kHz (at -20 dB).

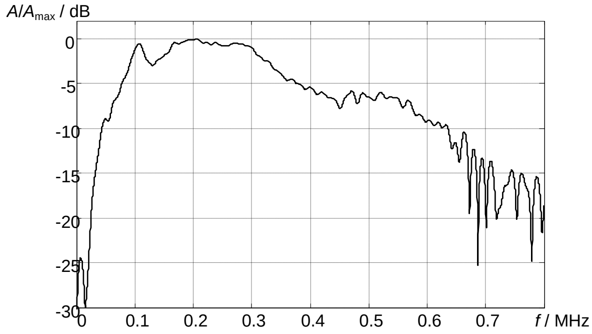

Fig. 5. **The frequency response of the reference transducer**

In the case when the thickness of the contact planar protector slightly increases (from 0.2 mm up to 0.45 mm), the amplitude of received signal slightly decreases (Fig. 6a and b). It means that the characteristics of the contact transducers slightly change when their thickness decrease. The frequency responses for both cases are shown in Fig. 7a and b. The frequency responses of the transducer with the contact planar protector show less oscillations at the higher frequencies and is more uniform at the lower frequencies.

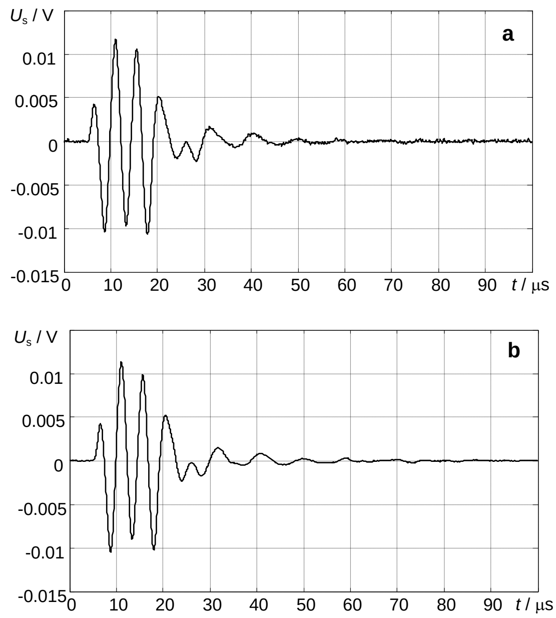

Fig. 6. **Ultrasonic signals of the transducer with the replaceable protector of different thicknesses: a – thickness – 0.2 mm; b – thickness – 0.45 mm**

The increasing of the thickness of the planar protector decrease the amplitude of signals (Fig. 8a and b) and the waveform of the ultrasonic signals is changed. For this reason to use the thick protector is not reasonable. Therefore, if the replaceable protector of the contact type transducer wears during the scanning it can be simply replaced by another protector.

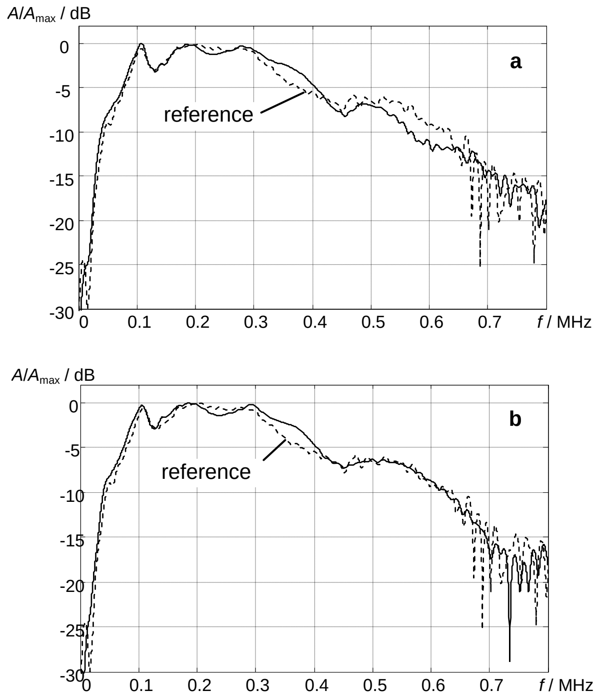

Fig. 7. **The frequency response of the transducers with the replaceable planar protector of different thicknesses: a – thickness – 0.2 mm; b – thickness – 0.45 mm**

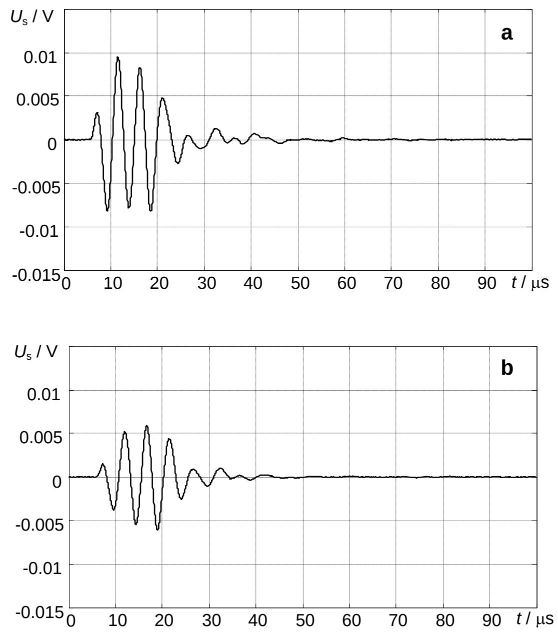

Fig. 8. **Ultrasonic signals of the transducer with the replaceable protector of different thicknesses: a – thickness – 2.0 mm; b – thickness – 3.0 mm**

The obtained frequency responses in the case of the contact planar protector was used (Fig. 9a and Fig. 9b), show the higher losses at the higher frequencies in comparison with the lower frequencies.

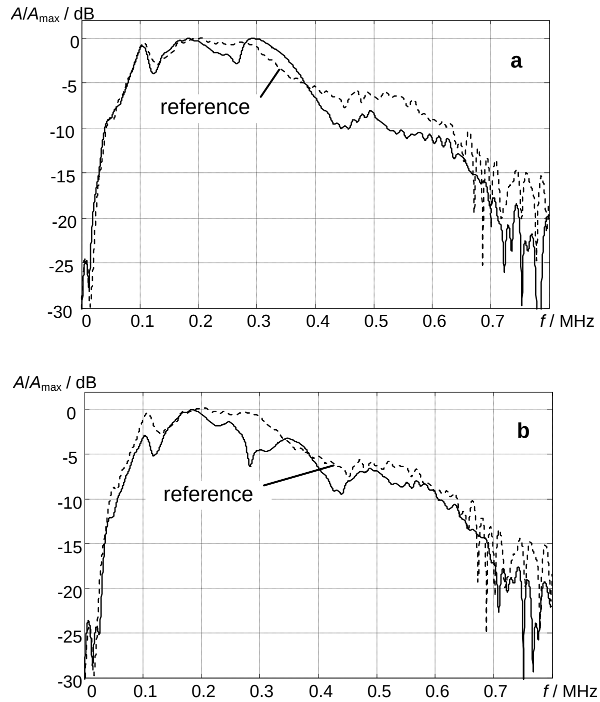

Fig. 9. **The frequency response of the transducers with the replaceable protector of different thicknesses: a – 2 mm; b – 3 mm**

However, the oscillations start at higher frequencies. In the frequency response obtained in the case of the planar protector with thickness of 2 mm, it is possible to see that the first oscillation begins at 720 kHz (the oscillations of the reference frequency response begin at the 670 kHz).

Fig. 10 presents the results of the experimental investigation of the planar protectors having the thickness denoted in Table 1. The losses in the protectors with different thicknesses (from 0.2 mm up to 3 mm) increase up to 2 times. Then the losses for the two protectors will increase up to 4 times or -12 dB in the case when the pair of the transmitter and receiver will be used.

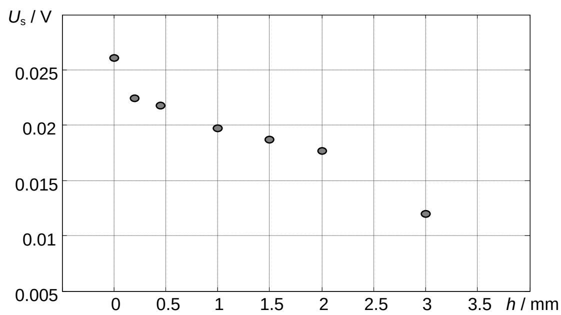

Fig. 10. **Dependence of the amplitude of the ultrasonic signal on the thickness of the protector**

The protector of the variable area of the acoustic contact (convex protector shown in Fig. 3) was attached to receiving contact type transducer using the coupling liquid. Another transmitting planar transducer was used without variable area protector. The ultrasonic signal of the receiving transducer with the convex protector possessing the equivalent diameter of the contact area of 0 mm is shown in Fig. 11. The amplitude and the duration of the excitation pulse were the same as previously described. The frequency response is shown in Fig. 12.

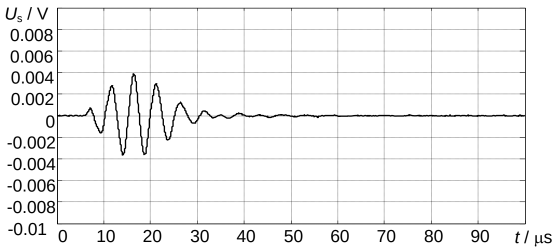

Fig. 11. **The ultrasonic signal of the receiving transducer with the convex protector (the equivalent diameter of the contact area 0 mm)**

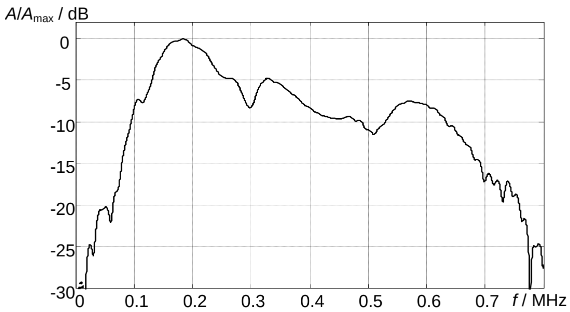

Fig. 12. **The frequency response of the transducer with the convex protector (the equivalent diameter of the contact area 0 mm)**

The point type protector with the equivalent diameter of the contact area close to 0 mm is useful for reception of ultrasonic guided waves, it allows to determine the actual dimensions of the defects inside composite materials. However, the use of the point type protector in mechanical scanning systems has shortcoming as the tip of the protector wears out very fast. A part of the protector becomes plane, the area of which increases during the long term scanning.

The ultrasonic signal of the transducer with the convex protector having the equivalent diameter of 3 mm of the contact area is shown in Fig. 13. The amplitude of the signal increases 2 times without the significant changes of the waveform.

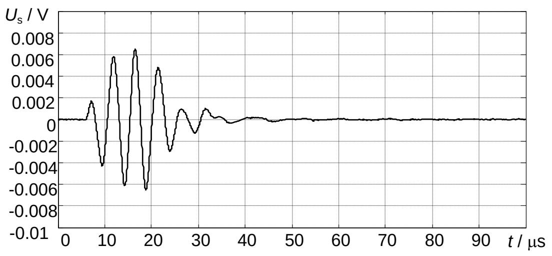

Fig. 13. **The ultrasonic signal of the transducer with the convex protector (the equivalent diameter of the contact area 3 mm)**

The frequency response of the transducer with the convex protector having the equivalent diameter of 3 mm of the contact area is shown in Fig. 14. There is a region of frequency response decreasing at the 300 kHz.

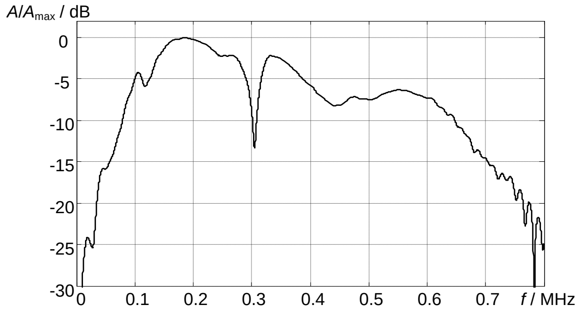

Fig. 14. **The frequency response of the transducer with the convex protector (the equivalent diameter of the contact area 3 mm)**

The experimental investigations of the convex protectors with planar area of the acoustic contact were carried out for the diameters from 1 mm up to 7 mm (Table 2). The dependence of the amplitude of the ultrasonic signal on the diameter of the contact area is shown in Fig. 15. The maximum amplitude of the signal is obtained when the planar part of the protector is the same as the area of the attached piezoelectric element. The signal increases 4 times when the diameter of the planar part of the protector increases from 1 mm up to 6 mm. So, wearing away of the convex protector of the transducer during the scanning causes increasing of the signal amplitude.

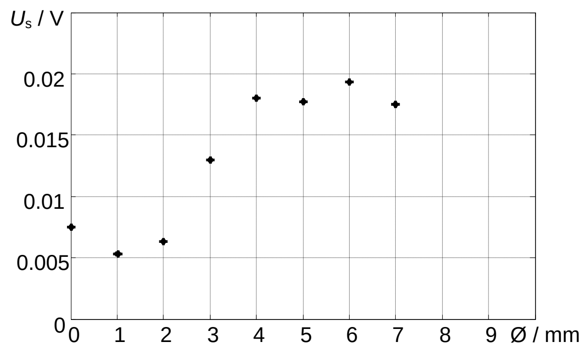

Fig. 15. **The dependence of the amplitude of the ultrasonic signal in the case of convex protectors with different diameters of the contact area**

Conclusions

The low frequency contact type ultrasonic transducers for mechanical scanning systems were developed. The replaceable protectors can be used. Two types of the protectors were proposed: the planar protectors thicknesses of which change from 0.25 mm up to 3.0 mm and the convex protectors for of with the flat areas the diameters which change from 0 up to 7 mm.

The experimental investigations were carried out and the ultrasonic signals and the appropriate frequency responses were analysed for the planar and the convex protectors.

The amplitudes of the ultrasonic signals depend on the thickness of the protectors. For the planar protectors the amplitude of the ultrasonic signals decrease when the thickness of the protector increase. For the convex protector the amplitude of the ultrasonic signals increases when the planar area of the protector increases.

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Kontaktiniai ultragarsiniai keitikliai mechaninėms skenavimo sistemoms

Reziumė

Nagrinėjamieji žemojo dažnio ultragarsiniai pjezoelektriniai keitikliai skirti daugiasluoksnių kompozitų tyrimams kontaktiniais skenavimo metodais. Pjezokeitiklio konstrukciją sudaro plačiajuostis keitiklis su korpusu ir plokščiu pereinamuoju sluoksniu, prie kurio jungiamas papildomas tos pačios medžiagos suderinimo sluoksnis. Papildomas suderinimo sluoksnis gali būti plokščias arba sferiškai išgaubtas. Jis tvirtinamas fiksatoriumi, kuris suspaudžia abu sluoksnius. Atlikti plokštiems ir sferiškai išgaubtiems papildomiems sluoksniams reikalingi pjezoelektrinių keitiklių charakteristikų matavimai. Gautosios dažninės ultragarso signalo charakteristikos parodė, kad sluoksnių storis daugiau veikia signalo amplitudę, o ne dažnines charakteristikas.

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