Design and Fabrication of a 5 MHz Concave Phased Array Probe

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Abstract:

A 5 MHz, 16-element phased array concave ultrasonic probe for non-destructive testing has been designed, fabricated and tested. To improve the probe's performance its curvature, as opposed to present solutions, was not obtained by adding a corresponding delay wedge, but rather by manufacturing the functional elements (i.e. active material, matching layer) with a curvature. The piezoelectric material used here was a 1-3 composite material.

The finished probe was tested on a steel half circle with the corresponding radius (100 mm) and on the Olympus PAUT test piece. Good results could be obtained. Three transverse holes with a diameter of 1 mm and a distance of 5 mm to one another could be detected and resolved.

Key words:ultrasonic, phased array, 1-3 composite, concave probe

Introduction

Within the field of ultrasonic testing it is very important to match the probe to the test object, not just concerning the properties but also the shape. Present solutions are not yet satisfactory. In the non-medical field probes for curved test objects usually have a corresponding delay wedge. With this comes an increase in energy loss due to additional interfaces. This can be avoided by manufacturing a probe with a curved front. The objective was to develop a technology to apply the curvature to the composite material and the matching layer.

This paper describes the design and fabrication of a 5 MHz phased array ultrasonic probe with a concave transducer. One probe with 16 elements and a curvature radius of 100 mm has been designed, fabricated and tested.

Design and Fabrication Considerations

Using a piezoelectric composite as the active material for a transducer has several advantages as opposed to using a solid piezoelectric ceramic. A large part of the composite consists of epoxy resin, which is relatively soft. Thereforeit is easier to shape the transducer. Furthermore the acoustic mismatch between transducer and test object can be decreased as due to the high fraction of epoxy the

acoustic impedance of the composite can be varied. Third, because of the decreased lateral clamping of the active materialit is possible to obtain a higher electromechanical coupling coefficient of the composite than the one of a thin ceramic plate [1].

When designing a 1-3 composite, the choice of dimensions is very important as to avoid spurious resonances within the operating bandwidth. Reynolds et al. [2] have investigated the problem of lateral modes and Lamb wave modes and give the following equations for predicting the first two Lamb wave mode frequencies [1] and [1]:

$$f_{k1} = \frac{v_{\text{phase}}}{d_0}$$

$$f_{k2} = \frac{\sqrt{2}v_{\text{phase}}}{d_0}$$
(1)

where v_{phase} is the phase velocity in the transverse direction across the composite and d_0 is the pillar-to-pillar spacing within the composite. With the help of these equations the maximum pillar-to-pillar spacing can be calculated and the right dicing blade can be chosen. As mentioned before, the ratio of ceramic to epoxy resin influences the composite's electrical and acoustic parameters. With a microstructure of the composite markedly smaller than the wavelength the

material behaves as an effective homogeneous medium. For this case Smith and Auld [1] published fundamental considerations in terms of modeling the effective material parameters of composites. With this the volume fraction v_{PZT} of the ceramic can be determined and then based on the chosen pillar-to-pillar spacing d_0 the pillar width d_0 can be calculated with the following equation:

$$\frac{b_s^2}{(b_s + d_0)^2} = v_{PZT} \tag{3}.$$

Using the dice-and-fill method to manufacture the 1-3 composite it can only be fabricated flat and the curvature has to be obtained afterwards. Since the matching layer has to be curved as well it is more convenient to bond it to the transducer and apply the curvature then to both of it in one step. The idea was to fabricate a backing block with the desired curvature and shape the transducer by forcing the shape of the backing block on to it.

Fabrication

The 1-3 composite (see Fig. 1) was fabricated with the dice-and-fill method using a PZT ceramic as the active piezoelectricmaterial and a two-component epoxy resinwith a sound velocity of about 3000 m/s for the passive part. A 30 µm blade was used for dicing. To achieve an acoustic impedance of about 13MRayl the pillar width was calculated to 55 µm. After grinding the composite to the necessary thickness to obtain the wanted resonance frequency different metal layers were applied with both PVD and electroplating to manufacture the electrodes. It also assures the later process of bonding a flex-circuit. With a dicing saw the metallizationon one side of the transducerwas cut in to obtain the 16 elements.

Fig. 1. Micrograph of a 1-3 composite for 5 MHz transducers

A mold with the inverse shape of the backing block was fabricated. The backing was then made from a two-component epoxy resin mixed with tungsten powder. Before pouring it in to the mold, this mixture was put in a vacuum chamber where it was stirred to release trapped air bubbles. It was then cured by room temperature.

The matching layer was made of another epoxy resin. The liquid, uncured epoxy was poured directly on to the transducers front and cured by room temperature. For this purpose a special mold was designed to hold the transducer and make sure the epoxy resin doesn't flow to the back of it. This way no additional adhesive layer was necessary. After curing the matching layer was ground to its calculated thickness.

Using hot bar soldering the flex-circuit was bonded on to the back of the transducer.

Figure 2 shows the tool that was specially designed and fabricated for the bonding process of the transducer and the backing block. It has two main purposes; it holds both parts in place during the whole process and appliesenough pressure on to the pieces to ensure a good connection. An epoxy resin was used as adhesive.

After successfully bonding the backing block with the transducer and thereby shaping it a coax cable with a plug was soldered to the flex-circuit. The last step of fabrication was to put the transducer stack in a housing and fill it with epoxy resin.

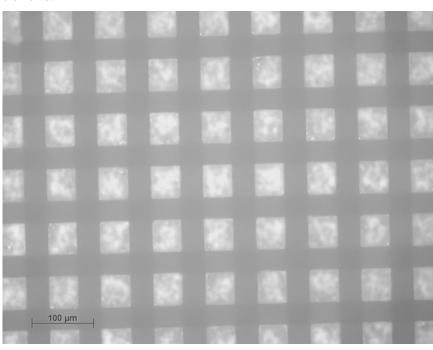




Fig. 2 Tool forbonding transducer with backing

Results

The fabricated probe was tested using our in-house hard- and software. The initial pulse length was 225 ns. First the probe was placed on a steel half circle with the radius 100 mm to verify the probe's overall function. A clear echo of the back wall could be detected in the A-scans of each channel using a gain of 16 dB (see Fig. 3).

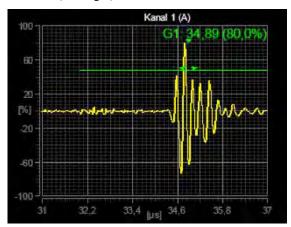


Fig. 3 A-Scan of an element of the finished phased array probe with back wall echo on a steel half circle

With a sector scan (see Fig. 4) the squint angle of the probe was examined. It was determined to 0° .

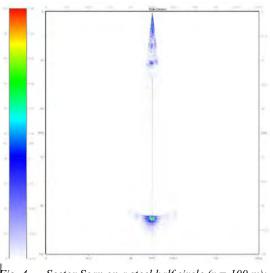


Fig. 4. Sector Scan on a steel half circle (r = 100 m); determined squint angle: 0°

Next, the probe was tested on a PAUT test piecewith several transversal holes. The probe was placed on the upper curved part of it (as indicated in figure 5) and targeted towardsthe three marked transversal holes. They are 1 mm in diameter each and lay 5 mm apart from each other. After adjusting the software parameters (range: 10° - 30° , angular resolution: 0.5° , focus: 56 mm, gain: 16 dB) all three transversal holes could be detected and resolved in the B-scan (see Fig. 6).

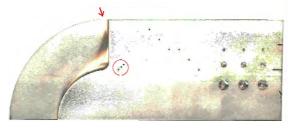


Fig. 5. PAUT test piece with transverse holes (red circle), arrow indicates placement of probe

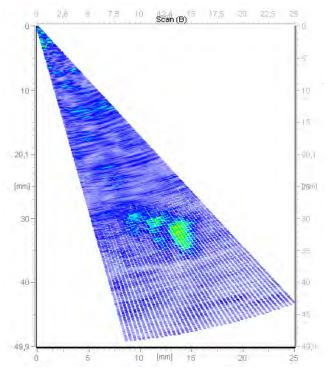


Fig. 6. B-Scan on the PAUT test piece

Conclusions

The developed technique for bending the transducer made of a 1-3 composite was successfully applied to a bending radius of 100 mm. A 5 MHz phased array ultrasonic probe with a concave transducer has been manufactured and tested. The performance of the fabricated probe was satisfactory. Small transversal holes lying close together could be detected and resolved.

It has been shown that 1-3 composite material is suitable for curved structures. We are currently working on applying the technique to smaller bending radiuses.

References

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