Defence Science Journal, Vol. 67, No. 6, November 2017, pp. 612-616, DOI : 10.14429/dsj.67.11201

Metal Ceramic Segmented Ring Transducer under Deep Submergence Conditions

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ABSTRACT

Segmented ring transducers are widely used for low frequency, broadband, deep submergence applications. These transducers can be made out of piezoceramic wedges or slabs and metallic wedges. Higher diameter, low frequency transducers are generally made out of piezoceramic slabs and metal wedges due to ease of manufacture and low cost. In this paper, metal ceramic segmented ring transducers are modelled using ATILA, a finite element software for the design of underwater transducers. Transducer variants were modelled with different wedge and piezoceramic materials. Transducers modelled were manufactured, assembled and tested. Various stages of manufacture like piezoceramic stacking, transducer assembly, pre-stressing with fibre winding, and encapsulation are explained. Acoustic performances of the transducers manufactured were measured in an open tank and inside a pressurised vessel from 10 bar to 70 bar. Performance parameters like resonance frequency, transmitting voltage response and directivity were measured. Results indicate that the transducer has usable bandwidth of about two octaves and stable response. One of the transducers was also tested in a high pressure test facility at 600 bar to check its pressure withstanding capability.

Keywords: Segmented ring transducer; deep submergence; ATILA

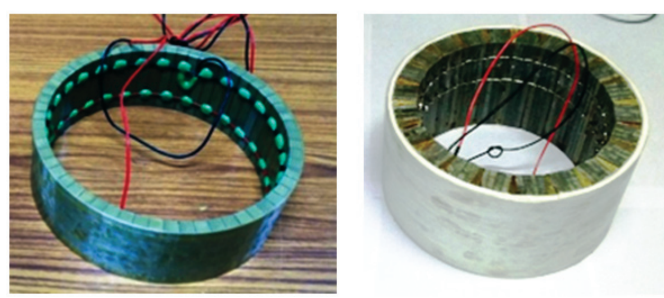
1. INTRODUCTION

Free-flooded segmented ring transducers can be developed for low frequency, broadband, deep submergence applications using piezoceramic wedges or slabs and metallic or non-metallic wedges[1-3] as shown in Fig. 1. A segmented ring transducer with wedge shaped piezoceramic is expensive compared to the simple slab and metal wedge based transducers because, different sizes of ceramic wedges are required for different diameters. Since piezoceramics are weak in tension, sufficient pre-stress is mandatory to apply high power. Pre-stress to the segmented ring can be applied by tightly assembling metallic straps over the assembled transducer, using a pre-stressing ring and wedge, or fibre winding over the assembled segments[1,4,5]. Wedges made out of non-metallic materials like Lucite, Nylon or perforated metallic wedges can be used to bring down the resonance frequency of the segmented ring transducer[6,7]. However, the use of non-metallic wedges reduces the overall response of the transducer[8]. Brass and aluminium are commonly used as wedge material. Aluminium or titanium can be used as wedge material when weight is of prime importance, like dunking sonar application.

PZT4 or PZT8 can be used as active material based on the power handling requirement of the transducer. Encapsulation can be carried out using direct polyurethane over moulding or assembling the transducer in a rubber housing filled with oil[9-11]. Direct rubber moulding is not recommended due to the high temperature process, which can damage the piezoceramic stack and fibre wrapped around the transducer for pre-stress.

Received : 02 March 2017, Revised : 21 August 2017
Accepted : 23 August 2017, Online published : 06 November 2017

In this paper, transducer modelling is carried out using the finite element package ATILA[12] to study the effect of wedge and PZT materials on TVR. The transducer modelled were manufactured and tested. Acoustic performances of the transducers manufactured were measured in an open tank and inside a pressurised vessel from 10 bar to 70 bar. Performance parameters like resonance frequency, TVR and directivity were measured and reported.



(a) (b)

Figure1. Segmented ring with (a) Piezoceramic wedges (b) Piezoceramic slabs and metal wedges.

2. TRANSDUCER DESCRIPTION

The transducer studied in the present paper is assembled with piezoceramic slabs and metal wedges. The segmented ring is assembled with stacks of 5 mm thick slabs. The outer diameter of the assembled ring is wound with fibre glass yarn to provide necessary pre-stress. PZT4 and PZT8 ceramics are used as active materials and brass and aluminium are used as inactive wedge materials to study the effect on TVR. Transducer encapsulation is carried out using direct polyurethane moulding because of the easiness in moulding process.

ATILA, a finite element package for sonar transducer design is used for modelling the transducer. Since the transducer has symmetry along X, Y and Z axes, only 1/8th of the transducer needs to be modelled in water as shown in Fig. 2.

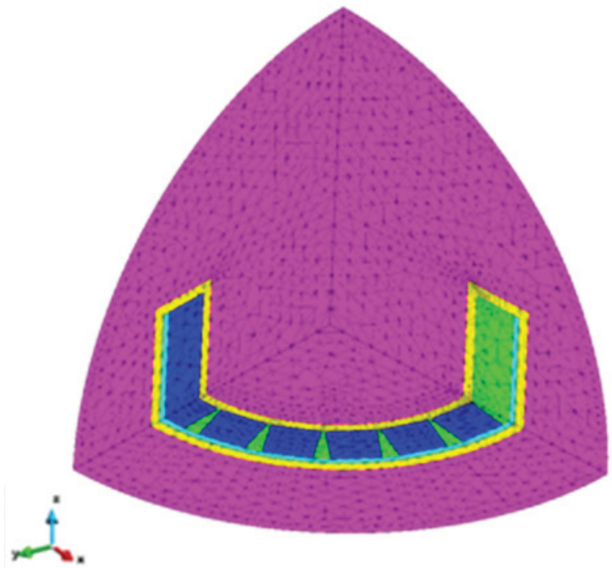


Figure 2. 3D model of the transducer in water.

3. TRANSDUCER MANUFACTURE

The various stages involved in the transducer assembly are piezoceramic stacking, cylinder assembly, pre-stressing with fibre winding and encapsulation. The piezoceramic slabs were selected with high d_{33} (piezoelectricstrain constant) values and nearly identical dimensions from the production lot for the stack assembly.

The wedges were machined to very tight tolerance to avoid major variations on the outer diameter of the transducers. A two-part adhesive with resin and hardener was used to glue the metal wedges and piezoceramic slabs. The piezoceramic stacking was carried out using a special jig in a hydraulic press as shown in Fig. 3(a). The stack was kept under pressure for 24 h for fully curing the adhesive. Piezoceramic stacks with wedges were assembled in another specially designed assembly fixture to form the cylinder using adhesive. The assembled cylinder is shown in Fig. 3(b).

Once the cylinder was assembled, it was subjected to pre-stress by fibre winding it in a winding machine as shown in Fig. 3(c). The winding machine has provision to adjust speed of rotation and tension in the fibre. The pre-stress required was calculated based on the maximum operating voltage[13]. The adhesive was applied on each layer of the fibre for retaining the tension in it. The assembly was kept under tension in the winding machine until the adhesive on the fibre was fully cured. Polyurethane moulding was carried out in special mould tool using a commercially available PU resin, Ezecast, a two-part rigid moulding compound. The mould tool and the moulded transducer are as shown in Figs. 3(d) and 3(e).

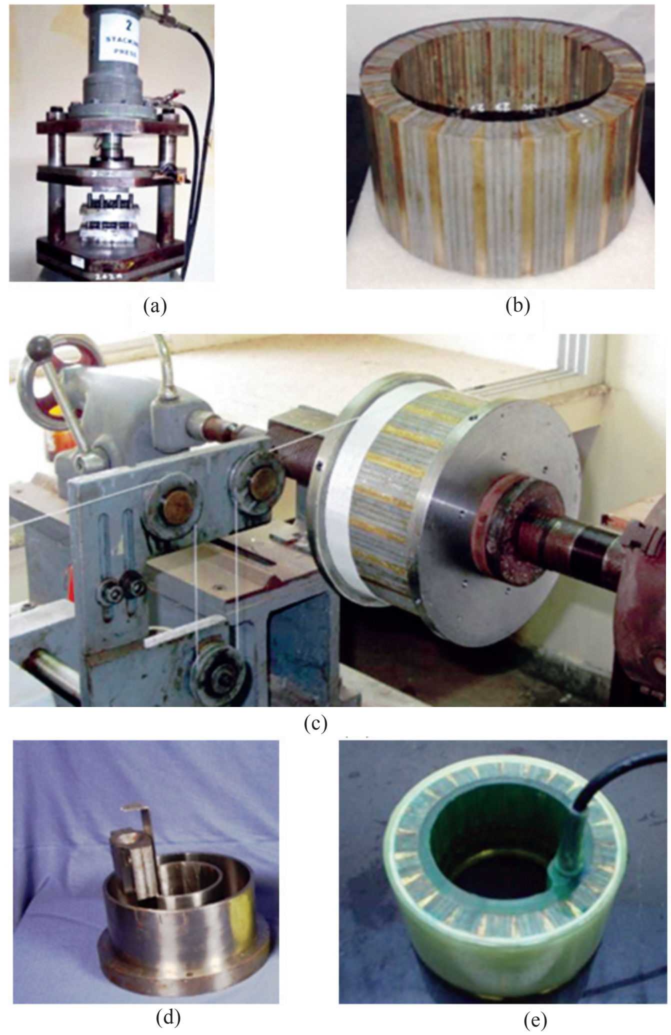


Figure 3. Various stages of transducer manufacture. (a) Piezoceramic stacking under hydraulic load (b) Assembled cylinder (c) Fibre winding (d) PU moulding tool (e) PU moulded transducer.

4. EXPERIMENTAL STUDIES

The transducers manufactured were initially tested in an open tank of 50 m length, 20 m width and 18 m depth. The test facility has an overhead crane, positioning platforms, and necessary instruments for all acoustic measurements. The transducer was positioned at a depth of 10 m and parameters like resonance frequency, TVR and directivity were measured. The measurements were then repeated in the pressurised test chamber[14] as shown in Fig. 4(a). The pressure chamber has a length of 8 m and inner diameter of 3 m. The pressure inside the chamber can be fixed as per requirement and the tests were carried out in steps of 10 bar from 10 bar to 70 bar. One of the transducers was also tested in a high pressure, hyperbaric test facility[15] as shown in Fig. 4(b) from 0 to 600 bar in steps of 50 bar to test the pressure withstanding capability.

5. RESULTS AND DISCUSSIONS

Modelled and measured TVR of the transducer in the open tank are as shown in Fig. 5. TVR values shows it has a usable bandwidth of about two octaves where it has a TVR of above 130 dB. Losses are not included in the model and hence

Figure 4. (a) Pressurised acoustic test chamber[14] and (b) Hyperbaric test facility[15].

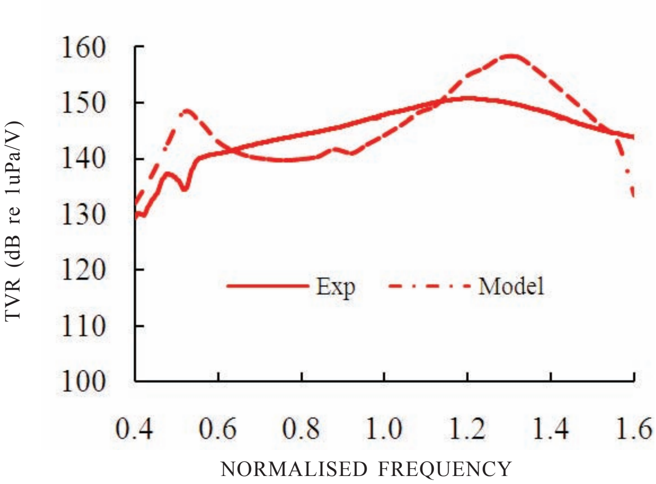


Figure 5. TVR of the transducer.

the values of TVR at resonances are more for the model than the measured values.

The horizontal directivity of the transducer is Omni within 3 dB in the entire usable frequency band. The vertical directivity is directional and the directivity at cavity and hoop mode resonance frequencies are as shown in Fig. 6.

Effect of PZT4 and PZT8 materials on the TVR is as shown in Fig. 7. Both these transducers have aluminium wedges. PZT4 has higher d_{33} value compared to PZT8 and it is reflected in the TVR plots. However, PZT8 has higher voltage handling capability and can be subjected to higher electric power.

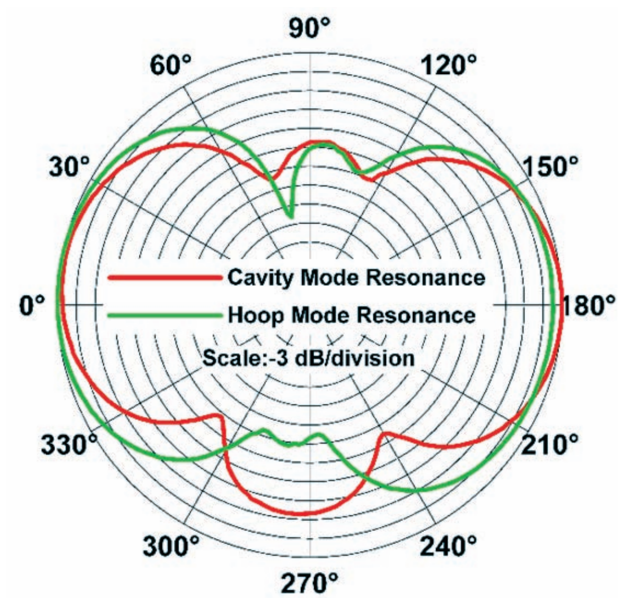


Figure 6. Measured vertical directivity of the transducer at cavity mode and hoop mode resonances.

Effect of wedge materials on TVR is as shown in Fig. 8 and it shows that at the first resonance due to the cavity mode TVR values are identical because of same physical dimensions. However, beyond the first resonance, transducer with brass wedges has about 2 dB higher TVR due to its higher effective coupling coefficient because of its less elastic compliance. The transducer with aluminium wedges weighs about one kilogram less compared to the transducer with brass wedges. Helicopter based dunking sonar where weight is a critical parameter and prefers to operate at lower frequency, transducer with aluminium wedges can be an ideal choice.

After the open tank experiments, transducers were tested in a pressurised vessel for their acoustic performance from 10 bar to 70 bar in steps of 10 bar. Measured conductance and TVR of a transducer under different pressures are shown in Figs. 9 and 10. The frequency vs conductance plot as shows that there is no appreciable change in resonance frequency with change in pressure. However, the TVR plots show that during the low frequency region there is about 2 dB - 5 dB reduction with increase in pressure from 10 bar

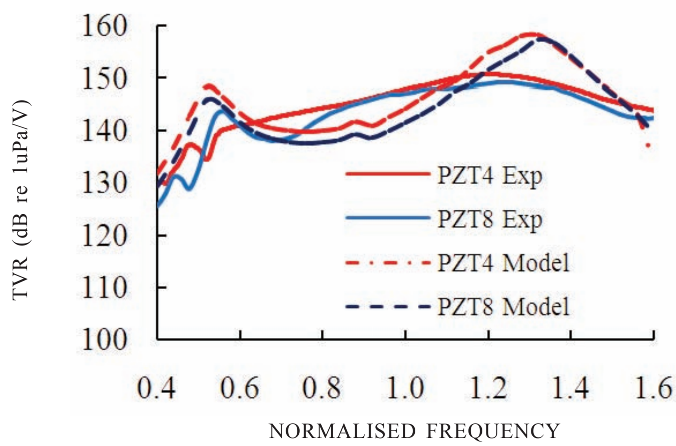


Figure 7. Effect of PZT material on the TVR of the transducer.

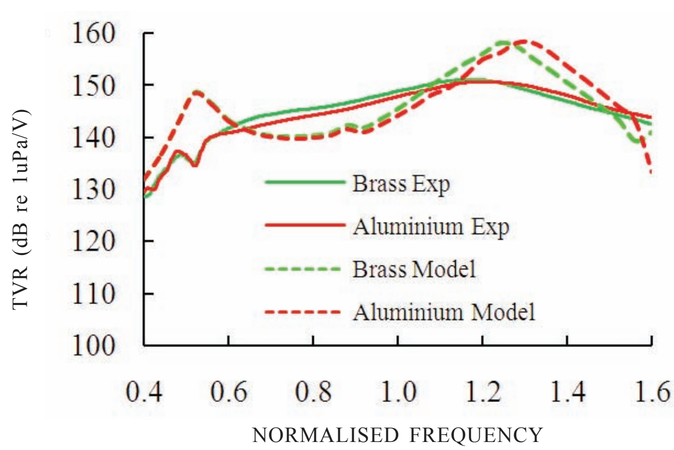


Figure 8. Effect of wedge material on theTVR of the transducer.

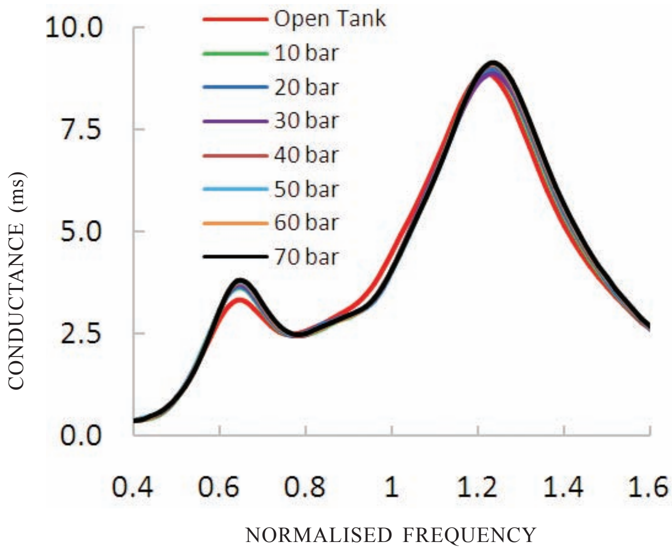


Figure 9. Measured conductance under different pressures.

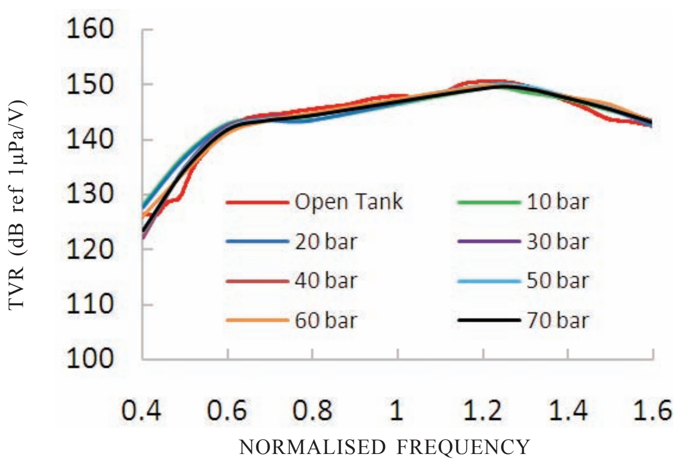


Figure 10. Measured TVR under different pressures.

to 70 bar. But beyond the first resonance the variation is not considerable.

The depth at which the transducer can be subjected to full power to get maximum source level (SL) was also tested at lower pressures from 1 bar to 5 bar and found that beyond 5 bar full power can be applied without distortion in voltage and current. The maximum power that can be applied below 50 m depth is restricted by 5 per cent of total harmonic distortion in voltage and current to prevent cavitation.

After completing the acoustic test in the pressure vessel, the transducer was tested in a high pressure, hyperbaric test facility[15] to test the pressure withstanding capability of the transducer from 0 bar to 600 bar in steps of 50 bar. The dwell time at each of these steps was 15 minutes and at maximum pressure it was held for two hours. Capacitance and insulation resistance were measured to verify the health of the transducer during the test and found to be stable. Acoustic tests were carried out after the pressure test and found consistent with previous measurements.

6. CONCLUSIONS

Segmented ring transducers made with stacks of piezoceramic slabs and metal wedges were assembled and tested. Transducer variants were assembled and tested with different, wedge and ceramic materials. Acoustic performance of the transducers manufactured was measured in an open tank and inside a pressurised vessel from 10 to 70 bar. Results indicate that the transducer has usable bandwidth of about two octaves and has stable response. The brass wedged transducer has about 2 dB higher TVR beyond the first resonance, compared to aluminium wedged transducer. One of the transducers manufactured was also tested up to 600 bar to test its pressure withstanding capability.

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ACKNOWLEDGMENTS

Authors wish to express their sincere thanks to Director, NPOL for permitting to publish this work. Support for manufacture and assembly of transducers by Mr T.K. Vinod, Mr E.R. Ratheesh, Mr K. Gopi and other staff members of transducer group of NPOL is gratefully acknowledged. Permission from Director, NIOT, Chennai and help from the deep sea technology group for conducting the high pressure test at the hyperbaric test facility are also gratefully acknowledged.

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In the present work, he has guided the team and reviewed the manuscript.