PROPERTIES OF LARGE AREA PLANAR HYDROPHONES CONSTRUCTED FROM PVDF COAXIAL CABLE

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1. INTRODUCTION

Piezoelectric polymers, such as PVDF, have some significant advantages compared with traditional piezoelectric ceramics in terms of their sensitivity and acoustic impedance. These polymers have, therefore, been used successfully for hydrophones for medical applications [1] and for sonar arrays. These applications have utilised PVDF in the form of a thin film (typically 0.025mm thick) or a thick film (0.5mm thick). Piezoelectric polymers have also been produced in the form of a coaxial cable for security and detection applications. In one type of cable the PVDF is extruded around a low melting point alloy core and an external electrode applied to form a flexible cable 1.5 mm in diameter (Vibetek 20; manufactured by FOCAS Ltd). This type of cable has a range of pressure sensing applications and has already been used to make low frequency hydrophones by wrapping it around a compressible former, thus taking advantage of the cable's high longitudinal sensitivity [2].

There are a number of calibration and measurement techniques performed in the laboratory which require wideband hydrophones with a high degree of directionality in order to limit the effects of multiple reflections or diffraction on the measurement process. In addition the use of a receiver with high directionality can help to reduce systematic errors associated with the source producing a spectrum of plane waves rather than a single plane wave. For this reason the properties of large area, planar hydrophones constructed using PVDF cable have been investigated.

2. HYDROPHONE CONSTRUCTION

Initial tests were made by winding 1 metre of Vibetek 20 piezoelectric cable into a planar coil with inner and outer diameters of 50 mm and 67 mm respectively. The coil was held together with thread and then waterproofed with a thin insulating layer.

Subsequent hydrophones were constructed as shown in Figure 1 in order to improve the rigidity and stability of the structure. The PVDF cable was threaded through holes in a thin perspex support, 5 mm wide by 1.5 mm thick, and also through two additional side retainers in order to keep the loops regular. The centres of the holes were separated by 1.7 mm so that the windings would not be in contact. Groups of six holes were drilled for a 1m length of cable in order to produce a device with the same dimensions as the initial prototype. Early hydrophones were made from PVDF cable that was already terminated in a coaxial cable although it was subsequently found to be easier to terminate the cable after winding the device.

Once wound the completed coils were encapsulated in a polyurethane potting compound to waterproof the sensor and produce a rugged device. The potting compound was chosen to have an acoustic impedance close to that of water. The final devices were 6 mm thick and 200 mm in diameter. A larger area device was also made in the form of a planar spiral using 2 m of piezoelectric cable. In this case the windings were 10 mm apart and the outer winding had a diameter of 180 mm.

3. TESTING

The majority of experiments were carried out in a tank approximately 1.2 x 1.8 x 1.1 m in size using a truncated parametric array as the acoustic source (see Figure 2). This facility has been described in detail elsewhere [3]. The parametric array was generated by a conventional 50 mm diameter transducer mounted centrally at one end of the tank and truncated by an acoustic low pass filter measuring 0.75 m x 0.43 m held vertically 0.38 m from the transducer. Two waveform generators and a modulator were used to generate the pulse applied to the transducer which consisted of a carrier signal of 890 kHz modulated by a raised cosine bell in the frequency range 10-50 kHz. The use of the parametric array enabled short wideband pulses to be generated, suitable for testing the performance of hydrophones over a wide frequency range (10-120 kHz).

The test hydrophones were supported on the axis of the array and could be rotated about a vertical axis using a rotation stage under computer control. The received signals were captured with a Nicolet Instruments Pro 10 digital storage oscilloscope sampling with 12 bit resolution at 1 MHz. The oscilloscope was used to average and perform initial processing of signals before they were transferred to a PC via an IEEE interface for subsequent processing and storage.

The test hydrophones were compared with a Brüel and Kjær 8103 hydrophone which was calibrated over the frequency range 10 - 150 kHz at the National Physical Laboratory.

4. RESULTS

Figure 3 compares the waveforms (and their spectra) observed with the first un-encapsulated hydrophone and a Brüel and Kjær hydrophone. This shows that the cable hydrophone reproduces a clean, symmetrical waveform with the characteristic shape expected for a parametric array driven with a raised cosine bell pulse. The cable hydrophone output can also be seen to be significantly greater than that obtained with the Brüel and Kjær 8103 (by about 5 dB). These tests showed that the design was free from high frequency resonances in the range of interest but there was evidence of a radial resonance at about 8 kHz. This was confirmed by electrical impedance measurements on the hydrophone.

The use of a potting compound significantly reduced the amplitude of this resonance but also slightly reduced the output of the hydrophones. The one metre coils were found to have a typical sensitivity of -210 dB re 1V per µPa at 40 kHz falling off slowly with frequency (see Figure 4). The output was clearly adequate for making laboratory measurements although the hydrophones were found to be sensitive to electrical pick up, especially if the outer earth electrode was damaged during manufacture. The electrical outputs of the coil, 180 mm spiral and Brüel and Kjær 8103 hydrophones are compared in Figure 5.

The beam patterns obtained by rotating the coil hydrophone (Figure 6) show that the coil hydrophone produced a clean symmetrical response. Some care must be taken in interpreting these diagrams since the measurements were made in the nearfield of the parametric array where the beamwidth is not large compared with the coil diameter. However the results show that at all frequencies the beamwidth is significantly narrower than that expected on the basis of a ring hydrophone. In particular the hydrophone appears to have a quadrapole response at low frequencies, with a deep null at about 45°, when the response would be expected to be almost omnidirectional. This effect has been attributed to the anisotropy of the piezoelectric response of the cable which has a larger piezoelectric coefficient (g_{31}) for axial contraction/extension than g_{33} coefficient for radial compression. In addition the g_{31} coefficient is of opposite sign to the g_{33} coefficient. Thus when the hydrophone is inclined to the incident wavefield parts of the cable tend to be strained along their length producing an electrical output that counteracts the radial contribution.

The 180 mm diameter spiral hydrophone had a sensitivity of -207 dB re 1V per µPa at 40 kHz and had a significantly narrower beamwidth above 20 kHz as shown in Figure 7. In addition all the cable hydrophones had a low reflectivity and high transmissivity rendering them suitable for making reflection loss measurements on materials [3]. They have already been used to make measurements on the transmission loss of inhomogeneous materials where their large area helps to isolate the required plane wave contribution from scattered nearfield contributions.

5. CONCLUSIONS

The results presented show that PVDF cable may be used to produce large area planar hydrophones with a number of advantages for use in the laboratory free-field testing of the acoustic performance of materials. The hydrophones have a smooth frequency response but a complex directional response as a result of the piezoelectric anisotropy of the cable. This anisotropy results in a narrower characteristic beam which is advantageous for free-field measurements. Clearly this type of design is very flexible and can be extended in both size and complexity. Unfortunately, since starting this program of research, Vibetek 20 has ceased to be manufactured. Alternative piezoelectric cables are currently under investigation.

6. ACKNOWLEDGEMENTS

This work has been supported by the D.R.A. UK.

7. REFERENCES

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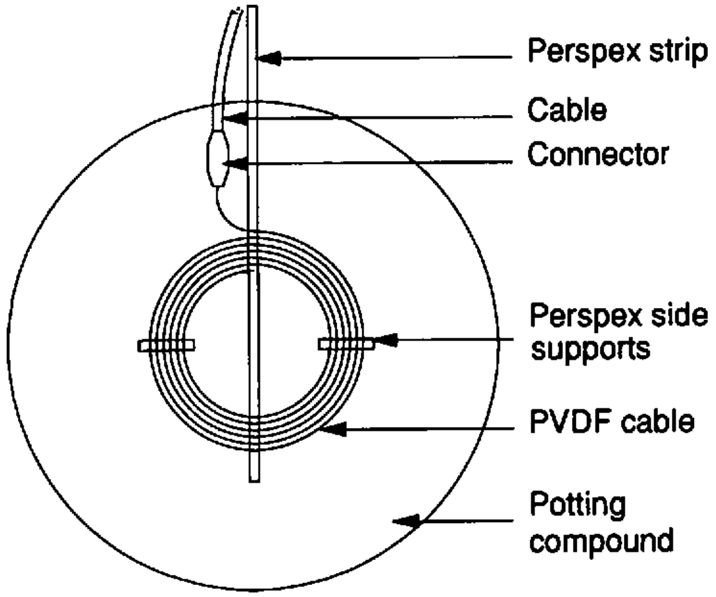

Figure 1. Construction of PVDF cable hydrophone.

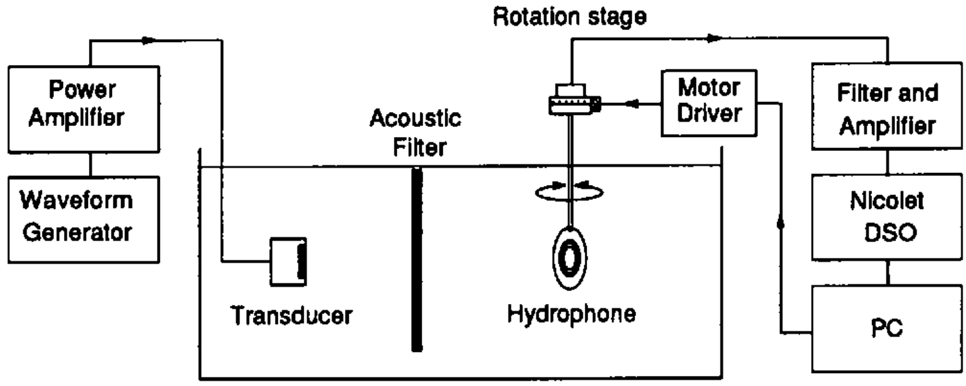

Figure 2. Experimental system used for inter-comparison of hydrophone sensitivities and measurement of hydrophone directionality.

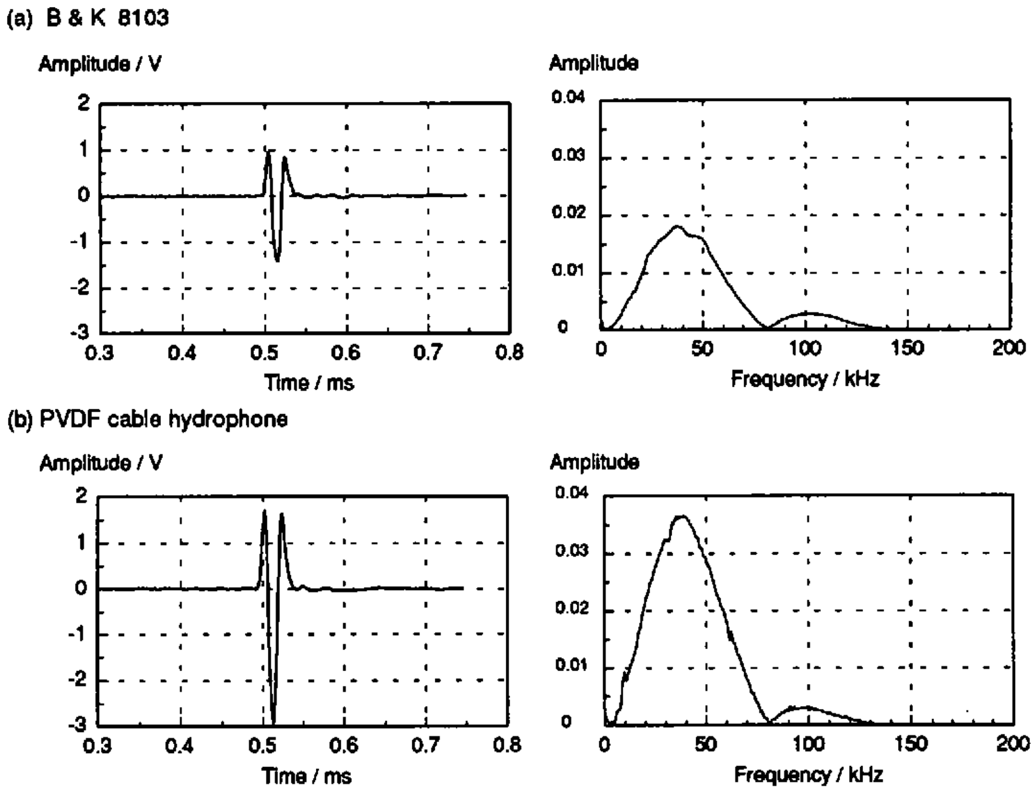

Figure 3. Comparison of waveforms (and their spectra) obtained with (a) Brüel and Kjær 8103 hydrophone and (b) 1 m PVDF cable coil hydrophone (not encapsulated).

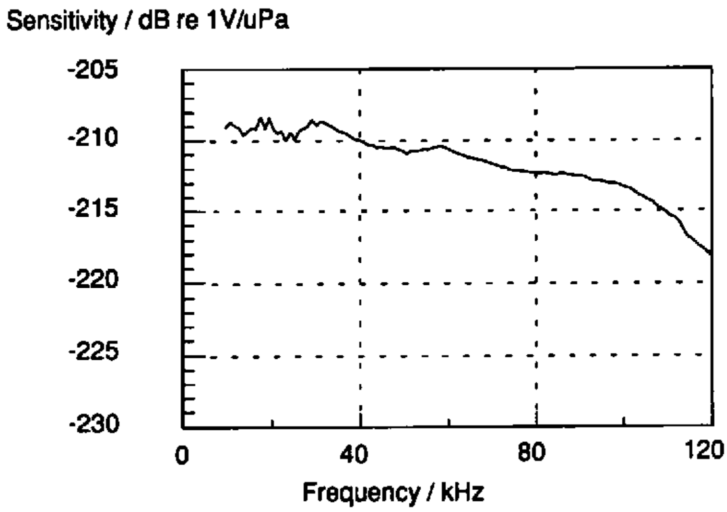

Figure 4. Sensitivity of 67 mm diameter coil hydrophone made from 1 m of PVDF cable as a function of frequency.

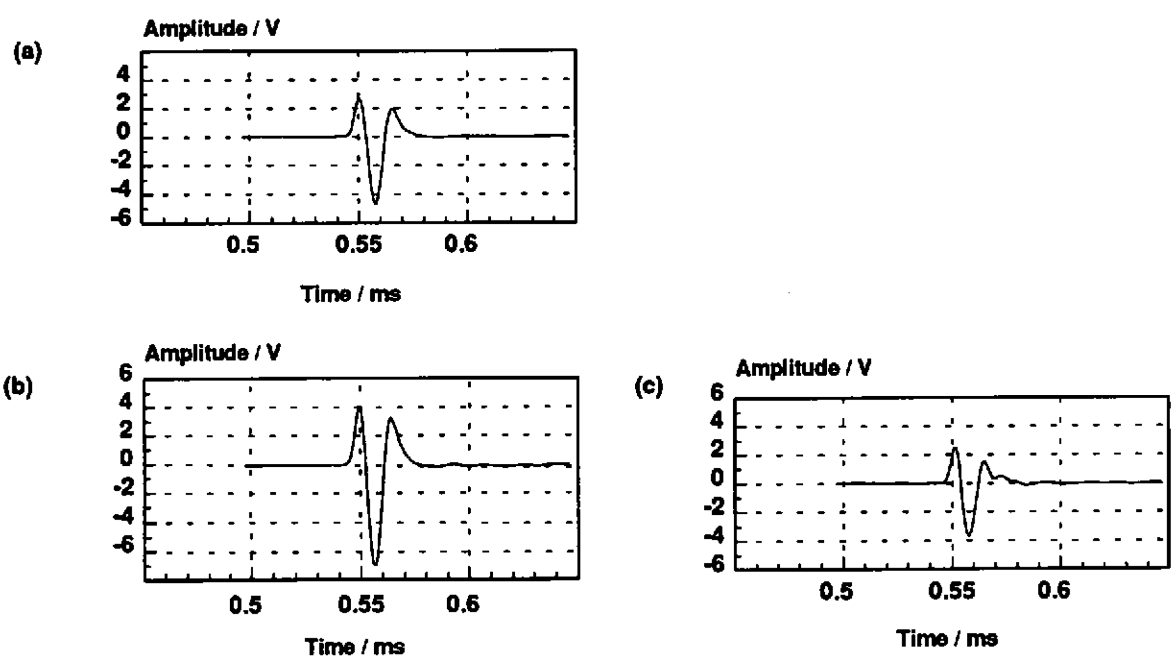

Figure 5. Comparison of waveforms obtained with (a) 67 mm diameter potted PVDF coil, (b) 180 mm diameter potted spiral and (c) Brüel and Kjær 8103 hydrophone.

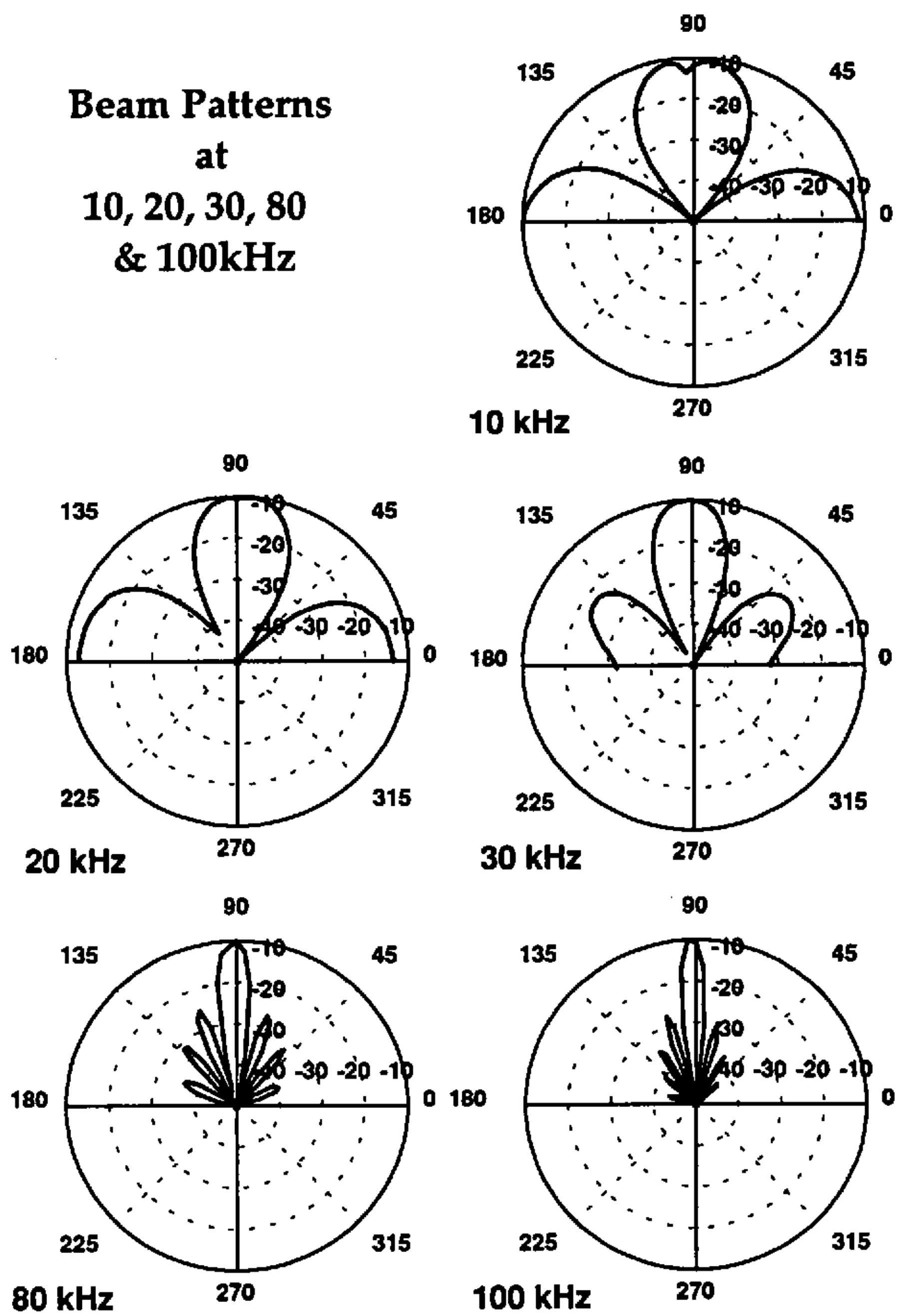

Figure 6. Directional response of an encapsulated 67 mm diameter PVDF cable coil hydrophone at 10, 20, 30, 80 and 100 kHz. Graphs are plotted on a dB scale with a 10 dB interval.

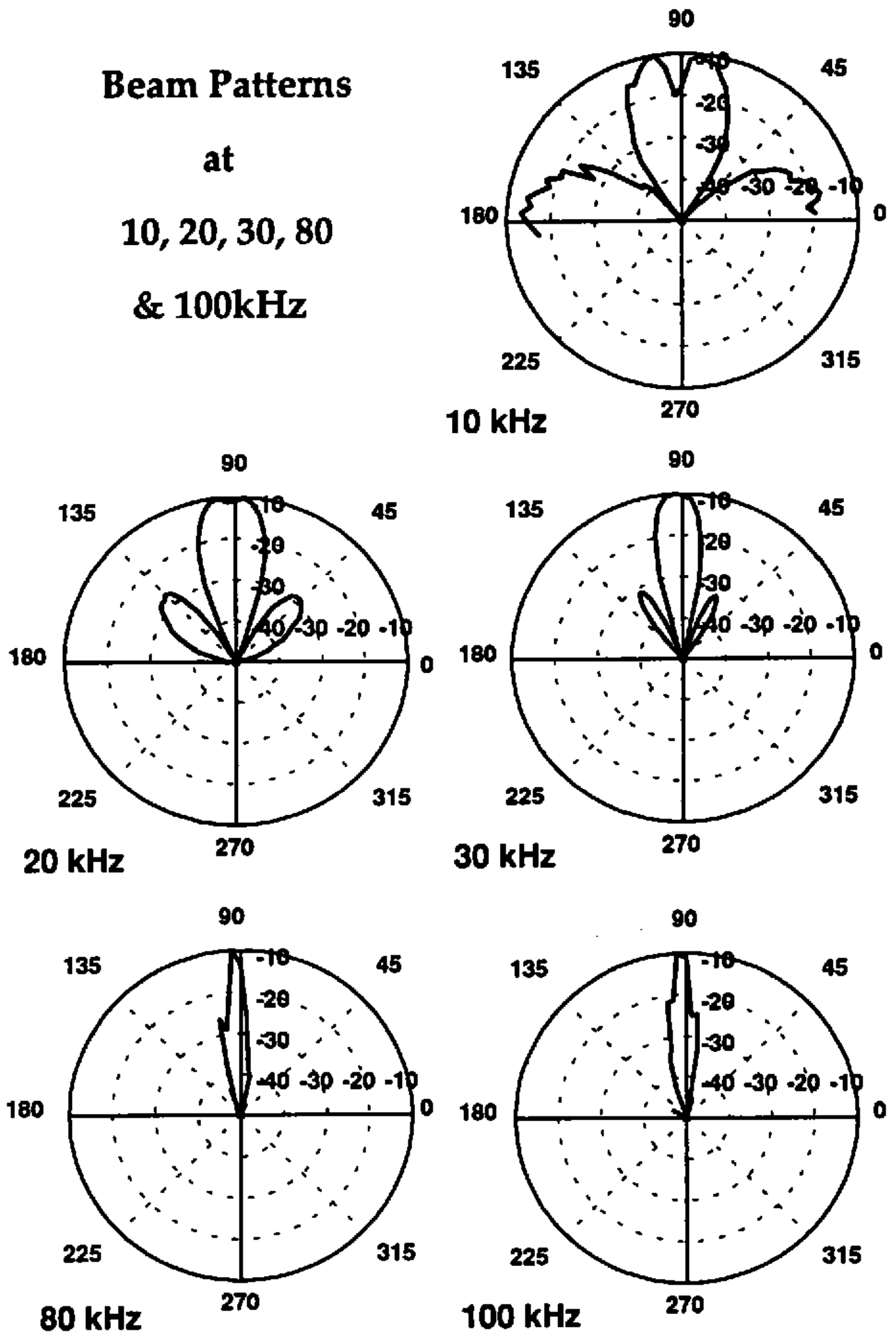

Figure 7. Directional response of an encapsulated 180 mm diameter PVDF cable spiral hydrophone at 10, 20, 30, 80 and 100 kHz. Graphs are plotted on a dB scale with a 10 dB interval.