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AN IMPROVED PIEZOELECTRIC CERAMIC TRANSDUCER FOR ULTRASONIC APPLICATIONS IN AIR

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The design considerations of a new type of piezoelectric ceramic transducer for transmitting and receiving ultrasonic waves in air have been reported. This transducer contains a bilaminar assembly consisting of a piezoelectric ceramic disc and a metallic plate which oscillates in flexural mode. This bilaminar assembly mounted at its nodal circle can be designed to operate at a fixed frequency in the range of 25 to 50 kHz.

The constructional details and the working of the transducer have also been given. The resonant frequencies $f_{\exp}$ observed experimentally for transducers having good transmitting and receiving sensitivities are found to be in good agreement with the values f_{cal} derived from theoretical considerations.

This closed-type transducer is rugged and compact and can be employed with advantage in several indoor as well as outdoor uses in automation, sensing and remote control applications.

1. Introduction

Ultrasonic transducers [1-4] for use in air have been of much interest in recent times for a number of automation, sensing and remote control applications [5-7], since ultrasonic waves have some definite inherent advantages over the other known conventional techniques.

This paper describes an improved type of ultrasonic transducer [8] developed at the National Physical Laboratory, New Delhi. The design of the transducer is so modified that the vibrating element oscillates freely without having any clamping effect and is completely sealed to avoid the adverse effect of environmental conditions in open fields. The design considerations and the performance of the transducer have also been discussed.

2. Design considerations

The ultrasonic transducer under report comprises a bilaminar assembly of a piezoelectric ceramic disk of lead zirconate titanate (NPLZT-5) [9] developed at the laboratory and a suitably designed metallic circular plate. The oscillation frequency f_r [kHz] of the bilaminar assembly of a nodal diameter d[cm] shown in Fig. 1 is given by the relation [10]

$$f_r = [kh_2/d^2][1+(3/2)A+(3/4)A^2]^{1/2},$$

where

$$A = [(E_1/E_2)(h_1/h_2)^2-1]/[(E_1/E_2)(h_1/h_2)+1],$$

E_1, E_2 are the Young's moduli [N/m²] and h_1, h_2 are the thicknesses [cm] of the piezoelectric ceramic and aluminium discs respectively. For this bilaminar assembly, k is equal approximately to 434 for the oscillation frequency under consideration.

In an earlier work [3] the oscillating bilaminar assembly was held in position by being supported on the outer periphery between the cork washer and foam. As the amplitude of vibration is minimum at the nodal plane in any oscillating element, it is considered proper that instead of keeping the element in its peripherial area, it may be mounted at the nodal circle.

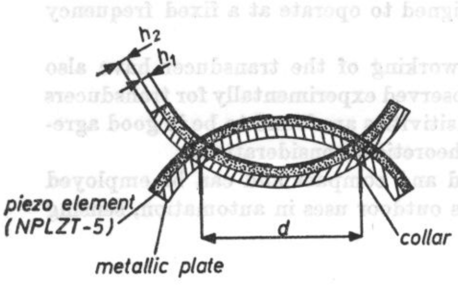

Fig. 1. Sectional view of the oscillation mode of the bilaminar disc at resonant frequency

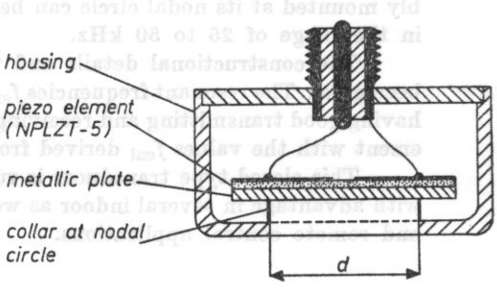

Fig. 2. Schematic diagram of the improved transducer

In view of this, a modification is incorporated in the metallic disc of the bilaminar assembly by providing a thin metallic collar at its nodal circle, as shown in Fig. 1. The calculation of the nodal diameter [13] has been done on the basis of known relations for thin plates. The ceramic disc has two semicircular electrodes on one face and a single electrode on the other. This bilaminar assembly is found to be oscillating freely in flexural mode on excitation by an *a.c.* signal of desired frequency. It is enclosed firmly and rigidly in a metallic housing, making a closed type transducer as shown in Fig. 2. The photograph of the transducer is shown in Fig. 3.

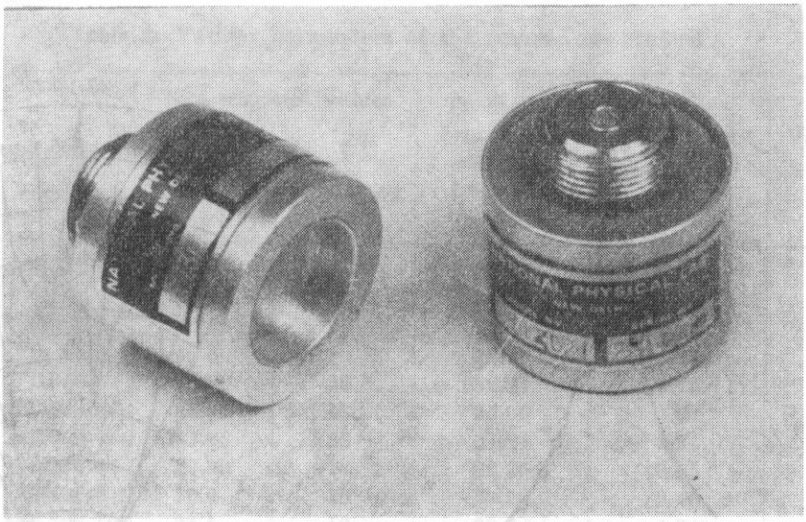

Fig. 3. A pair of improved piezoelectric transducers for ultrasonic applications in air

3. Performance

A series of ultrasonic transducers were made for checking the performance. Typical curves showing the transmitting response and pressure distribution, measured at a distance of 30 cm from the transducer are shown in Figs. 4 and 5, respectively. It is seen from the transmitting response that the transducer produces a sound pressure level of 110 dB and has a narrow 3 dB band width of 0.4 kHz at a resonant frequency of 33.8 kHz, with a Q of about 80. The measured pressure distribution as a function of angular orientation for a typical transducer shows an angular width of $\pm 30°$ for the main lobe.

The results measured experimentally and calculated theoretically are summarised in Tables 1 and 2. It can be seen that the measured resonant frequency f_{exp} of the transducers which have high sensitivity are in good agreement with the results calculated theoretically f_{cal}. The difference $f_{\text{exp}}-f_{\text{cal}}$ for these transducers is much less than 3.75% of the measured resonant frequency f_{exp}. On the other hand, the transducers for which the difference $f_{\text{exp}}-f_{\text{cal}}$ of the values observed and calculated of the oscillation frequency is large, varying from more than 5.86 % to as high as 13.78% are also weak in transmitting and receiving sensitivities.

Care was taken so as to avoid either an uneven epoxy layer or any air bubbles entrapped between the two constituents of the bilaminar assembly during fabrication, which could cause poor response of the transducer. It is observed that inspite of taking all the precautions during fabrication of transducers, some of the transducers show poor performance as transmitters and receivers. Moreover, any deviation of the physical constants of the constituents

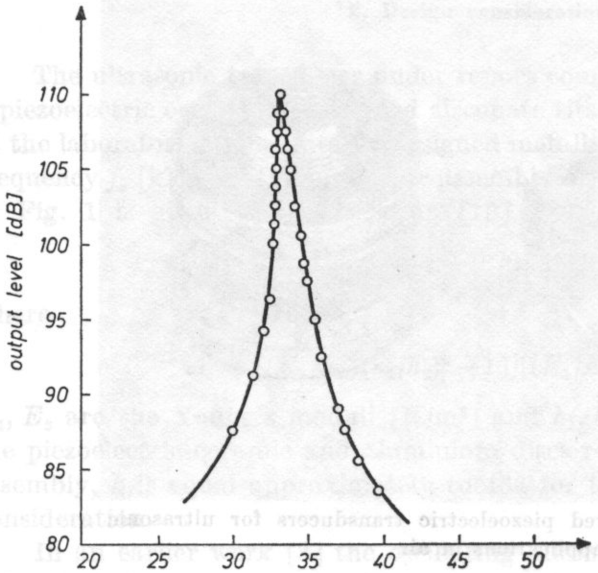

Fig. 4. Transmitting response of a typical transducer

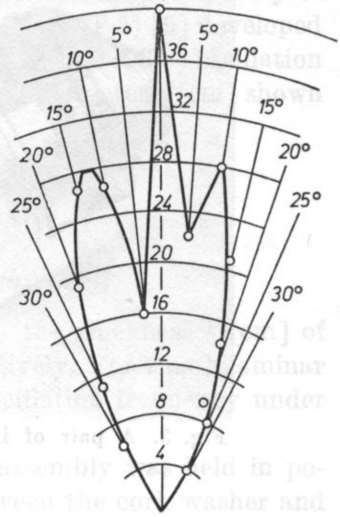

Fig. 5. Measured pressure distribution as a function of angular orientation for a typical transducer

of the bilaminar assembly from one sample to another is also likely to cause differences between the observed and calculated values of the resonant frequencies. It is, therefore, suggested that the desired resonant frequency of the transducer should be adjusted by decreasing either the thickness or the diameter of the metallic plate.

Table 1. Various (dimensional) parameters of the ultrasonic transducers studied

Sample no.	Transducer	Piezoelectric ceramic discs (NPLZT-5) thickness [mm]	diameter [mm]	Aluminium disc thickness [mm]	diameter [mm]	Nodal diameter d [mm]
1	UT-302-1	1.10	22.1	1.10	24.0	17.50
2	UT-302-2	1.10	22.0	1.10	22.8	17.40
3	UT-302-3	1.05	22.2	1.35	24.5	17.05
4	UT-302-4	1.10	22.1	1.50	25.0	17.05
5	UT-302-5	1.15	22.5	1.45	22.5	16.80
6	UT-302-6	1.18	23.0	1.50	22.5	16.50
7	UT-302-7	1.25	22.2	1.35	22.0	16.80
8	UT-302-8	1.05	22.0	1.20	23.0	17.50
9	UT-302-9	1.15	22.1	1.20	24.0	17.60
10	UT-302-10	1.15	22.0	1.30	23.0	17.60

Table 2. Various parameters of the transducers studied

Sample no.	Transducer	Experimental values		Theoretical value of oscillation frequency f_{cal} [kHz]	Difference $(f_{exp} - f_{cal})$	Variation [%]
		resonant frequency f_{exp} [kHz]	sensitivity [μA]			
1	UT-302-1	26.57	35	25.81	0.76	2.85
2	UT-302-2	27.60	25	26.25	0.35	1.26
3	UT-302-3	30.40	25	29.39	1.01	3.32
4	UT-302-4	32.30	40	32.66	0.36	1.11
5	UT-302-5	32.92	30	32.77	0.15	0.455
6	UT-302-6	33.08	18	35.02	1.94	5.86
7	UT-302-7	33.05	22	31.81	1.24	3.75
8	UT-302-8	29.90	15	26.25	3.65	12.20
9	UT-302-9	30.6	10	27.20	3.40	11.10
10	UT-302-10	34.5	10	29.7	4.74	13.73

The modification in the design of the transducer has resulted in improving its transmitting and receiving sensitivities by 8 to 10% compared with the performance of the transducer reported on earlier.

4. Conclusion

The new ultrasonic transducer developed at NPL is a compact, rugged and inexpensive source of ultrasonic waves in air. It is also an excellent receiver of these waves and is capable of detecting fairly weak ultrasonic signals generally needed in a number of automation, sensing and remote control systems. Apart from these applications, the transducer is suitable in various university experiments such as the verification of Bragg's law of diffraction [11, 12] for ultrasound, the demonstration of the constructive and destructive interference of ultrasonic waves and the determination of ultrasonic velocity in air.

The study shows that the accurate positioning of the nodal circle of the oscillating bilaminar assembly and its mounting there are very critical for its proper transmitting and receiving sensitivities. Care should, therefore, also be taken in the selection of the nodal circle in the proper position. The lead wire for taking connections should be fixed at the nodal circle with a minimum amount of solder to avoid any undesirable loading effect. The transducer, being closed-type and completely sealed, is suitable for both indoor and out door uses.

The technical know-how for the manufacture of the ultrasonic transducer is available through the National Research and Development Corporation of India, New Delhi. The process has already been transferred to two industrial organisations for commercial exploitation. Further work on the development of some other types of ultrasonic transducer for use in air is also in progress.

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