THE ELECTRO-ACOUSTIC EFFICIENCY OF A MAGNETOSTRICTIVE TRANSDUCER

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ABSTRACT

A vane type radiometer has been constructed in the laboratory for measuring the radiation pressure due to acoustic waves from a magnetostrictive transducer. A method based on the use of this radiometer is described for calibrating underwater applications.

Introduction

In the course of our investigations on acoustic cavitation in liquids, it was felt necessary to develop a method for calibrating the magnetostrictive transducer in terms of its acoustic pressure output. For this purpose a vane type radiometer was fabricated to measure the radiation pressure due to the acoustic waves from the transducer and to calculate the acoustic intensity. Measurements on the electro-acoustic efficiency carried out on a window-type magnetostrictive transducer which was driven by a Mullard Ultrasonic Generator are reported in this paper. Some results on the onset of acoustic cavitation in water and on the resulting spectrum of noise due to the cavitation bubbles are also discussed.

Theory

A considerable amount of literature [1,2] exists on the theory of radiation pressure and its use in measuring acoustic intensity. A window-type magnetostrictive transducer can be treated as a square piston-like vibrator, the radiation from the rear face of which is rendered negligible by suitable absorbing pads. The magnitude of the acoustic pressure p_x at a point on the axis of the sound beam is given by [3]

$$p_x = \frac{2Ca^2v_o\, p}{\lambda D} \qquad (1)$$

where

a=the length of the side of the transducer

v_o =the particle velocity amplitude at the transducer surface

λ=wavelength of sound

D=distance of the point x from the transducer surface

C=velocity of sound in medium

p=density of the medium

The acoustic intensity is related to the peak acoustic pressure p by the equation

$$I = p^2/2\rho c \qquad (2)$$

From equation (1) and (2) one can obtain an expression for the acoustic intensity I_x at a point on the axis of the beam in terms of v_o . Since the intensity I_o at the source is given by

$$I_o = \tfrac{1}{2}\rho c v_o^2 \qquad (3)$$

one obtains, I_o in terms of I_x by combining equations (1), (2) and (3). Thus

$$I_o = \tfrac{1}{4}\,\frac{C^2 D^2}{a^4 \nu^2} I_x \qquad (4)$$

where ν is the frequency of the sound wave.

Now the intensity I_x at different points on the axis of the sound beam can be calculated from measurements of the radiation pressure p exerted on a perfectly reflecting plate which is numerically equal to twice the mean energy density in the medium. All the quantities on the right hand side of equation (4) can be measured; one thus obtains the acoustic power output from the transducer.

Measurements

Biquard's method[4] of measuring radiation pressure was adopted in our experiments. The apparatus is essentially a kind of a torsion balance carrying on one side a vane on which the sound beam is incident and on the other a small balancing weight. The vane is made up of two parallel thin circular metal foils enclosing an air gap between them. The air gap makes the vane a perfect reflector to the sound beam. The vane is suspended from a torsion head, by a fine nichrome wire which also carries a reflecting mirror. It is shielded from air currents by a glass tube. A thin mica window, interposed in front of the vane, protects it from being disturbed by the hydrodynamic flow of the liquid caused by the vibrating source. The rotation of the vane is measured by the usual lamp and scale arrangement.

The magnetostrictive transducer supplied by Mullard is of the window-type and has a resonant frequency of 27·5 kc/s. It was driven by a Mullard RF generator capable of delivering 250 watts of electrical output. The transducer was placed in a large tank of water in which the radiometer was set up at a known distance with its vane on the axis of the sound beam. The deflection of the spot of light from the mirror attached to the vane was noted for different gain settings of the RF generator. The experiment was repeated by altering the distance between the vane and the transducer. The RF current through the transducer and the RF voltage across it were also measured.

In order to reduce the observed data in terms of pressure, a second experiment[5] was performed to determine the constant of suspension K, which is defined as the acoustic intensity required to produce unit deflection on the scale, placed at a known distance from the suspension mirror. For each position of the vane, the acoustic intensity was thus determined for various gain settings of the ultrasonic generator and the acoustic power output was calculated. At 27·5 kc/s, which is the resonant frequency of the transducer, the equivalent circuit consists of an inductance L in parallel with resistance R both of which can be obtained from impedance measurements. The phase factor in such a circuit works out to 0·995. Therefore, the electrical input to the transducer was given by the product of the RF current and the transducer voltage. The electro-acoustic conversion efficiency was then computed for the different gain settings of the ultrasonic generator.

Discussion

Table I gives the electrical input, the acoustic output and conversion efficiency of the transducer for different gain settings of the RF generator and for different positions of the transducer. Figure I shows the acoustical output plotted against the gain settings of the generator. The vertical lines in the curve denote the dispersion of values of the acoustic output from the mean. This scatter of values is partly due to the fluctuations in the electrical input (which are similar), and partly due to the fact that the vane does not come to a steady position but merely oscillates over a small range. Moreover, the radiometer is very sensitive even to the slight variations in voltage. These variations give rise to a similar scatter in the values of the conversion efficiency of the transducer, which was found to be 58$\pm$8%. The efficiency is independent of the gain setting of the RF generator within limits of experimental error. The transducer was never driven to the extent of producing cavitation, which would have resulted in a lower value of the acoustic intensity at the point of measurement due to the scattering by the cavitating bubbles. The criterion for the onset of cavitation used was the appearance of the cavitation noise.

The validity of the equation (4) in the present calculations can be ascertained from constancy of the quantity $D^2\theta$; for in equation (4), I_x is equal to the constant of the suspension K multiplied by the deflection θ and all the other quantities in that equation are constant. In our experiments the deviation never exceeded 25%.

Measurements on Cavitation Threshold and Noise

If the gain setting of the ultrasonic generator is increased to an extent that the acoustic output from the transducer exceeds a certain threshold value, cavitation sets in. Till recently observations of visible bubbles had been taken as the criterion for the onset of cavitation. However, a more sensitive method to detect the onset of cavitation is by the noise of the bubbles produced at the time of their collapse. The wide band spectrum of the noise which depends on the acoustic pressure in the liquids is mainly produced by the pressure impulses which are generated during the collapse of the bubbles. Since the spectrum extends into the audible range also, aural detection of the cavitation noise has been used to determine the cavitation threshold in the present series of experiments. From Fig. 1 it can be inferred that the cavitation sets in tap water

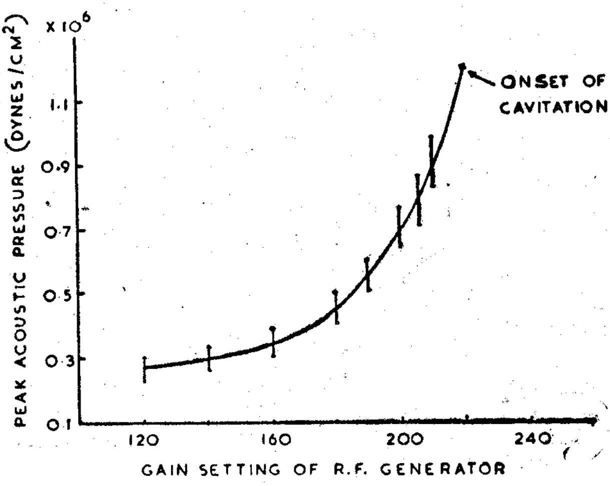

FIG. 1—Graph showing the relation between peak acoustic pressure at the Transducer face and the gain setting of R. F. Generator.

that has been left undisturbed in the tank for a number of days, when the peak acoustic pressure reaches a value of 1·12 atmospheres. Iyengar and Richardson[6] have found an empirical relation between the pressure threshold for cavitation expressed in dynes/sq. cm and radius of the bubble in cms to be,

$$p_c = \frac{4450}{a} + 0\cdot5\times10^6 \tag{5}$$

From this equation the radius of the cavitating bubble corresponding to a threshold acoustic pressure of 1·12 atm is found to be 7×10^{-3} cm. A bubble of a given radius can pulsate in an ultrasonic beam at a frequency which is characteristic of its size. If a and s are respectively the radius and surface area of the gas bubble in water, it will pulsate under the action of the vibrating mass of the medium pas and its compliance $a/3P\gamma s$ where p is the density of the medium, P is the ambient pressure and y is the ratio of the specific heats of the gas in the bubble. The resonant frequency f_o of the bubble is given by

$$f_o = \frac{0\cdot328}{a} \text{ kcs/cm.} \tag{6}$$

From this equation we find that the natural frequency of the bubble of radius 7×10^{-3} cm is about 47 kc/sec. One should therefore expect the cavitatoin noise to consist of the fundamental frequency with all its harmonics and a continuous spectrum due to the shock wave generated by the collapse of the bubbles. The noise can be picked up by a hydrophone and its spectrum analysed. A typical spectrum of the noise in tap water when the acoustic intensity exceeds the cavitation threshold value is shown in Fig. 2; it, however, gives only

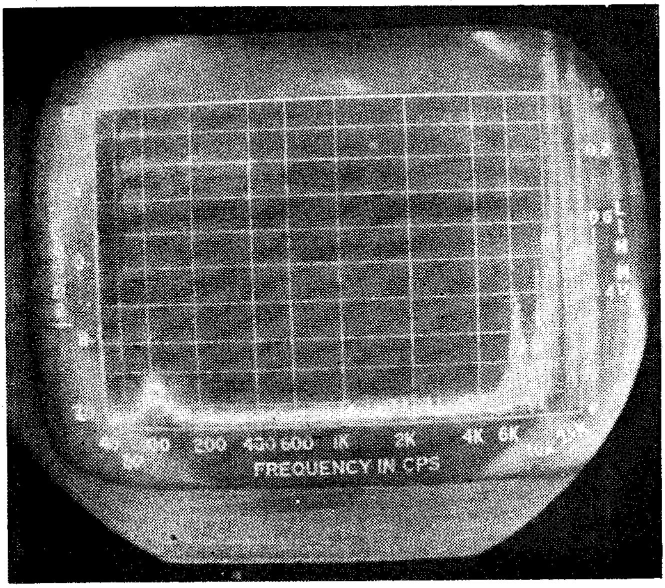

FIG. 2—Photograph of Cavitation Noise Spectrum as Displayed on Panoramic Analyser.

qualitative idea of the spectral distribution of the cavitation noise. A detailed paper on the study of this cavitation noise will be presented in a separate communication.

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TABLE I

Variation of Acoustic Output for Different Gain Settings of the Generator

Gain setting of RF Generator	D=18 cms			D=22·5cms			D=25·5cms			D=27 cms		
	Electric input (watts)	Acoustic output (watts)	Efficiency %	Electric input (watts)	Acoustic output (watts)	Efficiency %	Electric input (watts)	Acoustic output (watts)	Efficiency %	Electric input (watts)	Acoustic output (watts)	Efficiency %
120	0·427	0·22	51·5	..	..	..	0·307	0·21	64·5	0·264	0·22	58·0
140	0·555	0·28	50·8	0·481	0·26	54·4	0·481	0·30	62·6	0·555	0·32	58·2
160	0·738	0·36	50·2	0·600	0·30	50·2	0·616	0·36	58·6	0·695	0·42	0·6
180	1·08	0·56	52·2	0·727	0·40	60·8	0·846	0·56	66·6	0·918	0·58	63·6
190	1·27	0·98	56·6	..	..	..	..	..	..	1·27	0·74	58·2
200	2·75	1·56	57·0	1·75	1·20	68·6	2·08	1·42	68·6	2·16	0·96	44·6
205	3·41	2·26	66·6	2·82	1·56	55·6	..	..	..	3·42	1·96	57·8
210	..	..	..	4·05	2·02	50·2	..	..	..	4·12	2·80	68·0
220	..	..	..	8·25	3·66	44·6	8·99	4·96	55·4	9·10	4·68	51·6

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