# CALIBRATION OF THE DYNAMIC PRESSURE TRANSDUCERS

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## ABSTRACT

A review of the methods used in the calibration of dynamic pressure transducers is presented. A new method is suggested using the acoustic waves generated due to air bubbles formation. Yieger's method was used to generate the bubbles, due to it's simplicity, and the stress generated during bubbles formation is measured using a resonant piezo-electric transducer. Calculation of the stress and the attenuation coefficient gave to a sensitivity of 2.36 mV/Pascal of the used transducer.

## INTRODUCTION

In the last four decades acoustic emission (AE) is known and has many applications in materials research, materials characterization and evaluation, non-destructive testing and structural integrity. Yet AE is used as a qualitative rather than quantitative tool due to the lack of absolute calibration and the complexity of the acoustic signals due to the reflections from the grain boundaries and material surface, specimen transducer coupling, and inside the transducer itself.

Hatano and Mori [1] developed the reciprocity technique and used it for the calibration of AE transducers. A totally different technique has been developed by Speake [2] which made use of laser interferometer to measure the vibration of transducer surface. Although this is very accurate method to calibrate the transducer in air, however it does not consider the conditions under which the AE transducer would normally operate. Bell [3] has described a calibration method using spark impact bar but the signals generated had very low frequency. Bridge and Hutchison [4] have used a helium gas jet as a broad-band source. This method is doubtful because it uses an uncalibrated "flat response" transducer. Grabec and Esmail [5] calibrated the AE transducer by breaking a 0.1 mm diameter capillary tube in the middle of the transducer surface. A step-like change of the force was obtained which gave a sensitivity of 0.62 V/N.

In the present work the acoustic signals due to air bubbles generated under water are taken as the source of calibration. Generation of bubbles is made in the laboratory by different means such as electric spark discharge method [6], exploding wire method [7] and laser light focussing technique [8]. The noise resulting during the generation of bubbles in these methods is very high so that the acoustic signals during formation of bubbles will be masked.

Yieger's method for measuring the surface tension of liquids is well known. In the present work it is used to generate air bubbles through water since the only sound generated is due to the bubbles formation. The rate of bubbles is controlled to isolate the acoustic signals due to each bubble then the sound is detected and the stress is calculated to make the desired calibration.

## EXPERIMENTAL TECHNIQUE:

The instrument used for bubbles generation is shown in Figure (1). Water flows from reservoir A to B through valve V1 increasing the pressure in B. When valve V2 is opened, air flows rising the pressure under water in C. If the pressure is high enough air bubbles are formed, the rate of bubbles can be controlled by means of V2. The diameter of bubbles is determined by the hole at the center of the thin disc D. To change the bubbles diameter the disc is replaced by another one.

The transducer to be calibrated is fixed via vacuum grease to a very thin copper plate fixed against a hole (5 cm diameter) in the side of water tank W. The acoustic waves generated are transmitted through water and the copper disk to the transducer. Water head above the orifice is changed and the pressure of air is measured by the manometer M.

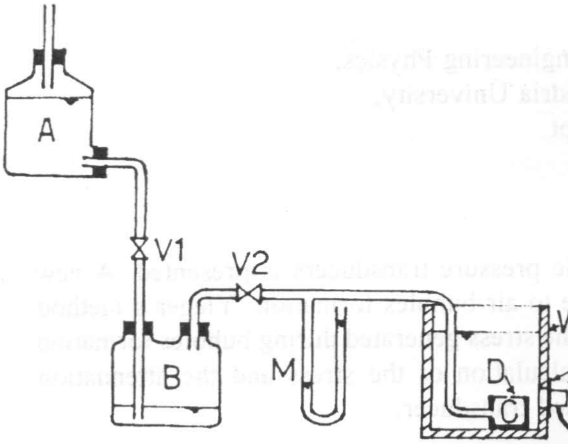

**Figure (1).** The arrangement used for bubbles generation.

A block diagram of the measuring instruments is given in Figure (2). The pressure waves sensed by the transducer (resonant 5 KHz quartz) is transformed to emf, amplified by the pre-amplifier and amplifier (1000 times) then it can be seen on the oscilloscope and/or the peak value of which is measured using a peak detector. The peak value can be recorded on the Y channel of a T-Y chart recorder.

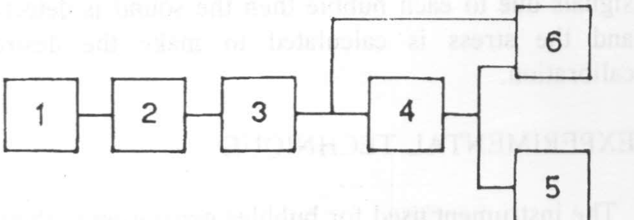

**Figure (2).** Block diagram of the measuring instruments

1 - Transducer 2 - Pre-amplifier
3 - Band-pass filter and amplifier
4 - Peak detector 5 - TY recorder
6 - Oscilloscope

## RESULTS AND DISCUSSION

Figure (3) is a typical form of the amplified acoustic signal due to a single air bubble. It has the shape of exponentially decaying sinusoidal wave with the same frequency of the transducer. Figure (4) is the record of the peak values (maximum amplitudes) of the signals for an orifice diameter of 1mm for different heads. The figure shows excellent consistency of the results at the same head for a bubbles rate 10 per minute. A plot of the peak value VS the water head is given in Figure (5) for the same orifice while Table 1 presents the values of the air pressure (oil head in the manometer), the water head above the orifice and the maximum amplitude of the acoustic signals (A for the same case.

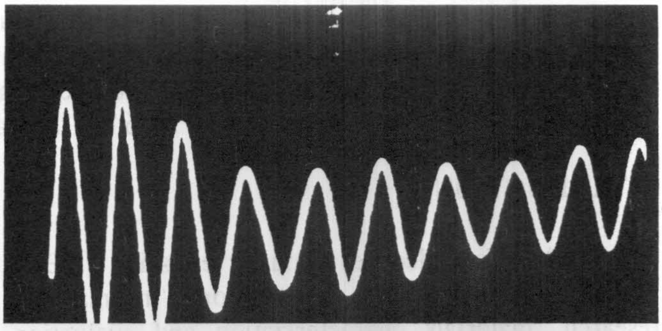

**Figure (3).** Typical acoustic signal due to single bubble: horizontal scale 0.2 ms/dev-vertical scale 0.5 v/dev.

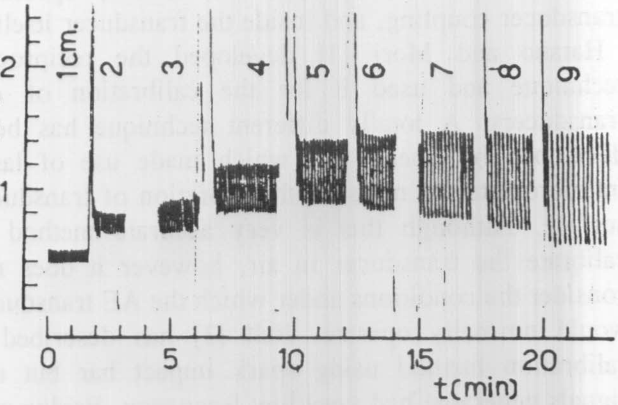

**Figure (4).** Record of the peak voltage against time form orifice of diameter 1 mm at different water heads.

**Table 1.**

| Water head $h_w$ (cm) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Oil head $h_o$ (cm) | 4.8 | 5.9 | 7.1 | 8.3 | 9.5 | 10.7 | 11.8 | 13.0 |
| max. amplitude A(V) | 0.5 | 0.8 | 0.95 | 1.2 | 1.4 | 1.45 | 1.5 | 1.5 |

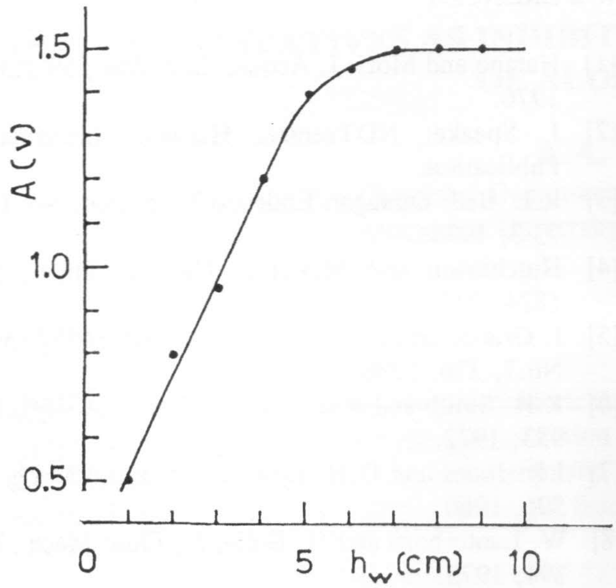

**Figure 5.** Plot of the peak voltage vs water head for an orifice of diameter 1 mm.

The radius of the air bubbles is calculated from the equation

$$r = \frac{2T}{(h_o\rho_o - h_\omega \rho_w)g}$$

where $\rho_o$ and $\rho_w$ are the densities of oil and water respectively.

Substituting $\rho_o$ by 850 Kg/m$^3$, $\rho_\omega = 1000$ kg/m$^3$ and T is the coefficient of surface tension of water = 0.075 N/m we get r = 0.5 mm which is the same value as measured by an optical microscope. Also from the same Table it is seen that the maximum amplitude increases with the water head to a maximum constant value (Am) at certain head ($h_m$). Increasing the water head more than $h_m$ has no effect on the maximum amplitude (for the same orifice). Table 2 gives the maximum values of the amplitude (Am) and the corresponding water head $h_m$ for different orifice diameters.

**Table 2.**

| | | | | |
|---|---|---|---|---|
| maximum amplitude $A_m$(V) | 1.5 | 1.8 | 2.3 | 2.7 |
| water head $h_m$ (cm) | 7 | 8 | 10 | 12 |
| orifice diameter D (mm) | 1.0 | 1.3 | 1.6 | 2.0 |

At equilibrium the pressure of air under the diaphragm is higher than due to the water head by the value (2T)/r. A very slight increase of the air pressure causes a break down of the diaphragm leaving the air to rush out the orifice making an impulsive pressure on the water column above it. The main property of the impulse is it's high value and short duration so that it should result in a sudden change of the velocity of the mass acted on without appreciable change in its displacement [9]. This is not realized for small water head since its mass is very small, but the head is partially pushed up and a part of the impulse is consumed in pushing the water head while the rest causes the water head to vibrate as a mass-spring system. Increasing the water head increases the mass and decreases the upward motion thus increases the amplitude of vibration. At certain head ($h_m$) equilibrium is achieved between the impulsive and static pressure, the result is only acoustic wave with it's maximum amplitude. In this case the impulsive pressure equals the static water pressure $h_m \rho_\omega g$. Increasing the water head more than $h_m$ will not affect the value of the impulsive pressure and the result is the constant value of the maximum amplitude.

The values of the maximum impulsive pressures calculated from the previous equation and the corresponding values of the peak voltage, together with the attenuated pressure calculated at the transducer surface, 2cm apart from the air bubbles, are given in Table 3.

**Table 3.**

| | | | | |
|---|---|---|---|---|
| maximum peak value $A_m$(V) | 1.5 | 1.8 | 2.3 | 2.7 |
| maximum impulsive pressure $P_m$ (Pa) | 686 | 833 | 1029 | 1176 |
| attenuated pressure $P_{att.}$ (Pa) | 619 | 751 | 928 | 1060 |

Since the pressure waves (acoustic waves) are generated and calculated at a point far from the transducer surface they are attenuated before being detected by the transducer. To account for the attenuation the orifice is moved in steps away from the transducer. Each step the distance from the transducer surface (X) and the peak value (A) are measured under the same head for the same orifice, the results are given in Table (4).

**Table 4.**

| the distance from transducer X(cm) | 2 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|
| the peak voltage A (V) | 2.3 | 1.8 | 1.5 | 1.2 | 1.0 | 0.8 |

The attenuation coefficient ($\mu$) is calculated from the equation

$$A = A_o e^{-\mu x}$$

where $A_o$ is the amplitude at zero distance, i.e at the transducer surface. From Table 4, we can write the last relation in the form $A = A_o e^{-0.103x}$ .

$$A = A_o e^{-0.103x}$$

the attenuation coefficient is 0.103 $cm^{-1}$. The values of the attenuated impulsive pressure are calculated from the same relation and given in Table 3. Figure (6) is the plot of the attenuated pressure against the maximum peak values for the four orifices used. The slope of the straight line relation is 423 Pa/volt at 1000 times amplification. The sensitivity ($2.36 \times 10^{-3}$volt/Pa) is divided by 1000 to exclude the system amplification, multiplied by the atmospheric pressure to give the absolute calibration of 0.236 volt/bar.

Figure (6). Attenuated pressure vs the maximum peak voltage for the four orifices used.

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