Pramāṇa, Vol. 22, No. 5, May 1984, pp. 447–451. © Printed in India.

Dynamic calibration of shock overpressure transducers

J HARVEY, J NANDAKUMAR and L V KRISHNAN
Safety Research Laboratory, Reactor Research Centre, Kalpakkam 603 102, India

MS received 7 May 1983; revised 9 February 1984

Abstract. Piezoelectric transducers for dynamic overpressure measurements are commonly calibrated with static or quasistatic loads and the calibration is extrapolated to frequencies up to 30% of the resonant frequency of the piezoelectric crystal. Sinusoidal pressure generators are also used for dynamic calibration up to 500 Hz in the range of 3 MPa. This paper describes a method for dynamic calibration using transient overpressures, with rise time of 2 μsec and width 40 μsec, generated by exploding wires in air. The calibration is done in the range of 600 kPa.

Keywords. Exploding wire; piezoelectric transducer; calibration; shock overpressure; shock velocity.

1. Introduction

Piezoelectric transducers with μsec response time are used to measure shock overpressures. These are often calibrated with static or quasistatic pressures. The calibration is expected to be valid for the measurement of dynamic pressures, assuming that the transducer response is flat up to one third of the resonant frequency of the crystal. In the literature there are many methods available to calibrate a pressure sensitive transducer. Dead weight tester method (Holman 1971) permits calibration of gauges up to the maximum pressure level but not at high frequencies, since loading-unloading is slow. Experiments with sinusoidal pressure pulses, applying reciprocity technique (Swift *et al* 1982) have also limitations on frequencies and pressures. Much depends upon the choice of the reversible transducers used, namely the loudspeakers of which frequency response is not better than 1 kHz. In the projectile method (Vantine *et al* 1980) manganin gauges are calibrated with pressures obtained from the measured projectile velocities using shock-Hugoniot relations for the projectile and the target material. In this method pressures as high as 40 GPa are reached, but extension to piezogauges is rendered complex because of the finite thickness of the housing material. For transducers with short time constants, where static calibrations are considered inapplicable, manufacturers recommend (Endevco TP-268) sinusoidal calibrators and comparison with a standard, in the pressure range of 4 MPa and frequency 500 Hz. This paper describes a method for dynamic calibration of transducers without the need for a standard. The technique is based on the determination of shock overpressures from the measured shock velocities in air. Shock overpressures in the range of 600 kPa with 2 μsec risetime are generated by the exploding wire techniques, obviating the need for the relatively expensive shock-tube arrangement.

2. Experimental set up

A schematic diagram of the experimental set-up is given in figure 1. A condenser bank 190 μF, 10 kV is used for exploding the wires. The condenser discharge is electrically damped to produce a single shock pulse and avoid ringing. The discharge is triggered using a two-electrode spark gap with 100 nsec switching time. The experiments are done in air using copper wires of 5 mm length and 0·18 mm diameter. Two quartz pressure transducers on a common mounting and separated by a fixed distance between them are used to sense the arrival of the shock wave. The transducers have a response time of 1 μsec. The shock overpressure signals from the transducers are recorded on a digital waveform recorder. The time of travel of the shock wave between the two sensors is recorded by a digital time interval meter having 100 nsec resolution. The signal from the first and second transducers respectively start and stop the timer.

3. Results and discussion

From liquid dynamic consideration (Zel' dovich and Reizer 1966) the relation between shock overpressure and shock velocity in air is given by

$$P + P_0 = P_0\left[1 + \frac{2\gamma}{(\gamma+1)}\left(\frac{U_s^2}{C^2} - 1\right)\right], \tag{1}$$

where P is the shock overpressure (kPa); P_0, the atmospheric pressure (kPa); γ, the ratio of specific heats; U_s, the shock velocity (m/sec); and C the sonic velocity in air (m/sec).

Substituting the measured value of $\gamma = 1{\cdot}401$ (Washburn 1929).

$$P/P_0 = 1{\cdot}166\left[\frac{U_s^2}{C^2} - 1\right], \tag{2}$$

where $U_s = \Delta x/\Delta t$, Δx being the separation distance between the two sensors and Δt the measured time interval.

By varying the capacitor voltage or the distance of the sensors from the exploding wire, different shock strengths of unknown intensity were obtained. The average of the electrical charge generated by the two transducers in each case is plotted against the corresponding time interval measured (figure 2).

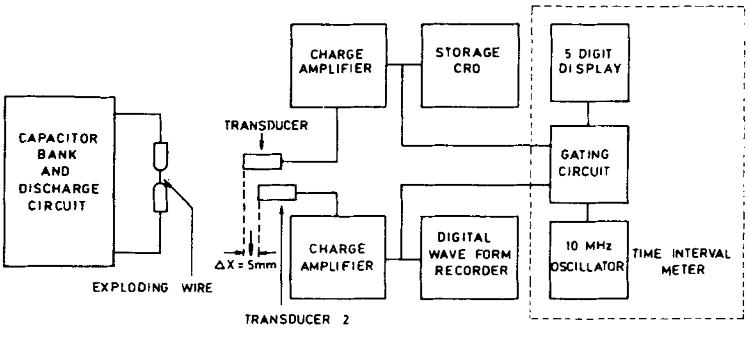

Figure 1. Experimental set up.

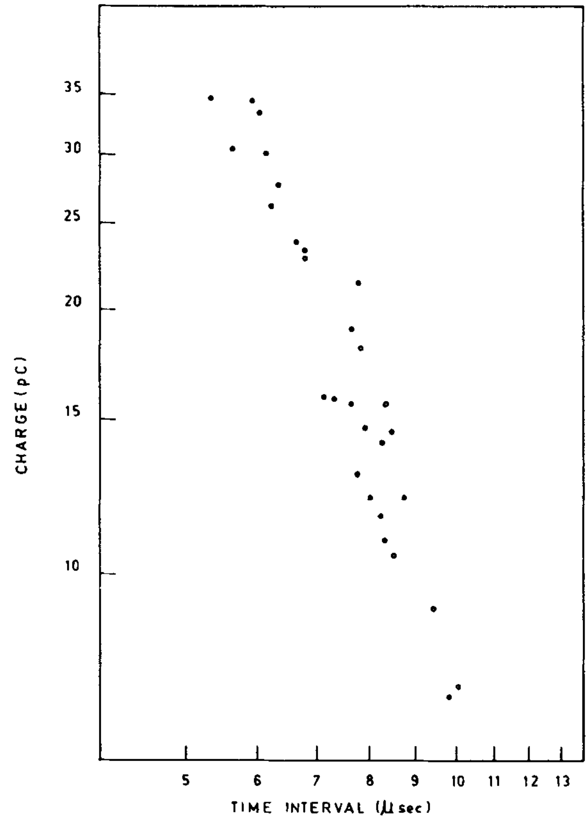

Figure 2. Measured charge *vs* time interval.

The uncertainty in the starting and stopping of the timer is approximately 200 nsec. This combined with the 100 nsec uncertainty in the time interval measurement itself leads to a total error of about 3 %. This reflects effectively as a 6 % error in the measured charge. The error in reading of the charge was limited to 1 % by use of a digital wave form recorder having 8 bit resolution. A larger contribution to the error resulted from the fact that the transducers employed were of 100 MPa range. Consequently, to measure the charge in the pressure range of 1 MPa the charge amplifier had to be operated in the most sensitive range where it is reported to have an accuracy of only 5 %. The source of error would be in the range of 1 % for transducers of a lower pressure range.

Since the measurement involved an error in both the variables, Q and Δt the following technique was used for curve fitting (Donald 1960). The measured time intervals (Δt) were arranged in an increasing order and divided into three roughly equal groups. For the two extreme groups the logarithmic averages

$$X_1 = \langle \log \Delta t_i \rangle_1, Y_1 = \langle \log Q_i \rangle_1;\ X_3 = \langle \log \Delta t_i \rangle_3, Y_3 = \langle \log Q_i \rangle_3$$

were determined and the slope b of the straight line connecting (X_1, Y_1) and (X_3, Y_3) was also determined. With grand average $\bar{X} = \langle \log \Delta t_i \rangle, \bar{Y} = \langle \log Q_i \rangle$ for the entire

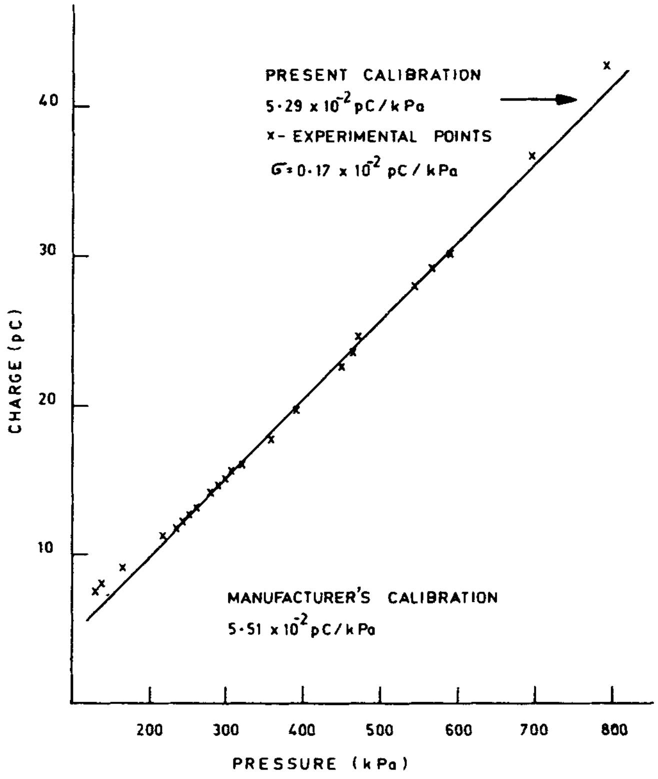

Figure 3. Calibration curve for pressure transducer.

experimental data set, the intercept a of the straightline on the Y axis was determined as $a = \bar{Y} - b\bar{X}$ yielding a fitting expression given by

$$\log Q = b \log \Delta t - a. \tag{3}$$

For a particular measured time interval Δt, the charge was obtained from (3) and plotted (figure 3) against the corresponding shock overpressure from (2). The charge sensitivity of the transducer derived from this dynamic method of calibration is $5{\cdot}29 \times 10^{-2}$ pC/kPa.

4. Conclusion

In applications where accurate shock overpressure measurements are required, it becomes necessary to redetermine periodically, the charge sensitivity of the transducer. The method described above enables this to be done with a simple, inexpensive capacitor bank arrangement, without the need for a shock tube.

References

Compendium on Endevco, Endevco Tech. Paper TP-268 (M/s Endevco, USA)
Holman J P 1971 *Experimental methods for engineers* (Kogakusha: McGraw Hill) 2nd edn
Menzel D H (ed.) 1960 *Fundamental formulas of physics* (New York: Dover) Vol. 1
Swift G W, Migliory A, Carret S R and Whealtey J C 1982 *Rev. Sci. Instrum.* **53**
Vantine H C, Enickson L M and Johnson J A 1980 *J. Appl. Phys.* **51** 1957
Washburn E W (ed.) 1929 *International critical tables* (New York: McGraw Hill) Vol. 5, p. 81
Zel'dovich Ya B and Raizer Yu P (eds) 1966 *Physics of shock waves and high temperature hydrodynamic phenomena* (New York: Academic Press)