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Introduction to Air Blast Measurements - Part II

Interfacing the Transducer

Written By
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Introduction to Air Blast Measurements - Part II: Interfacing the Transducer

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Part I of this series described the physics of air blast from both a theoretical and practical viewpoint. It also provided a brief, historical perspective of the development of transducers in government and industry laboratories to measure air blast phenomena. Part II, presented here, deals exclusively with appropriate methods of interfacing the blast pressure transducer to the measurand (the blast environment).

Figure 4 from Part I showed a Model 137A ICP® blast pressure transducer in a pencil probe configuration for side-on pressure measurements. In application, its axis must be aligned incident (perpendicular) to the incoming air blast wave. Its size should be small, relative to the highest frequency of interest in the shock front. For example, assume a shock front is moving at 3,300 feet per second. The wavelength (λ) corresponding to a spectral frequency (f) of 20,000 Hz in the front would be:

$$\lambda f = c = 3300\ (12) \text{ inches per second or}$$
$$\lambda = 1.98 \text{ inches.}$$

Looking at the dimensions of the pencil probe in Figure 6 relative to the preceding value of λ, it is clear that the probe has the potential to act as a reflecting body to high frequencies in the approaching shock front.

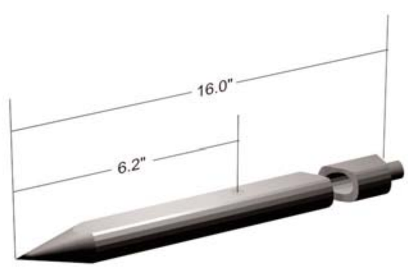

Figure 6: Outline Drawing of the Pencil Probe in Figure 4 (inches)

In order to minimize reflections, the probe is tapered over approximately its first two inches of length. It then transitions into a cylindrical body with a flat surface on one side. This flat surface eliminates discontinuities between an embedded, disc-shaped, radial facing, quartz sensing element and the transducer housing. Ideally, the velocity of the shock front and the spatial averaging of the disc as the front traverses across it will control the measured rise time. The averaging effect associated with any pressure transducer can be envisioned as the distortion that a sine wave would encounter as it passes at right angles to the axis of symmetry perpendicular to the plane of the circular diaphragm of the transducer. The diaphragm would cause distortion through spatial averaging of the wave, which results in its attenuation.

The analysis of the spatial averaging effect of the diaphragm of pressure transducers has been performed[1]. Results are shown in Figure 7. When using these results, the velocity (inches/second) of the gas passing over the transducer must be applied as a multiplier to the abscissa (x-axis) to convert its units to Hz. As an example of the application of Figure 7, at 1100 feet/second (13,200 inches/second) in dry air, a 0.3-inch diameter diaphragm would nominally produce a five-percent amplitude error at 9,200 Hz, and a 0.1-inch diameter diaphragm would produce the same error at 24,000 Hz.

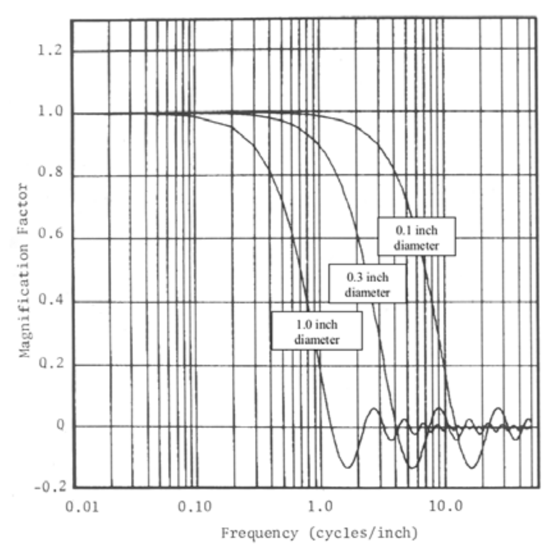

Figure 7: Frequency Response of Spatial Averaging Pressure Transducers

For reflected pressures at a stationary barrier, the averaging effects due to flow at normal incidence are not a consideration. However, the diaphragm of the transducer should be flush with the reflecting surface. If the diaphragm is flush, the structural properties of its sensing element control dynamic performance. However, in some instances, deviations from flush mounting may be required.

These deviations could be needed to isolate the transducer from high temperature or some other harsh environment. In this situation, the transducer could be coupled to the process by a length of tubing or other intermediate fitting. The resultant passageway could even be filled with a porous material of high specific heat capacity to further reduce the temperature of the gaseous explosion products, thus lessening their effect on transducer performance. However, this recess mounting of the transducer severely degrades its ability to measure the initial reflected blast pressures accurately. On occasion, this compromise may be justified in an attempt to quantify the total pressure impulse, which requires a longer measurement time, or, in the case of an enclosed explosive, the residual contained pressure in the enclosure after the blast occurs.

Acoustic theory, while not exact, provides us with guidance to estimate this degradation in transducer performance. In Figure 8, we see a transducer mounted with an associated volume in front of its sensing face. A long cavity or equivalent tube provides the interconnection to this volume. Based on the assumption that all dimensions are much less than the wavelength of sound at the frequency at which this system is designed to operate, an analysis of this cavity as a second-order-single-degree-of-freedom system can be performed. For a short tube, the Helmholtz resonator model[2] yields a natural frequency in Hz of:

$$f_n = [c/(4\pi)][\pi d^2/(V(L + 0.85d))]^{1/2}. \qquad (1)$$

In this equation, c is the velocity of sound of the gas being measured (≅1100 feet/second for room-temperature air), V is the volume of the lower cavity, L is the length of the entrance tube, and d is the diameter of this tube.

Figure 8: Pressure Transducer with Tubing and Associated Volume Interconnect

If the entrance tube in Figure 8 is lengthened to cause the lower volume V to become less significant, relative to the volume of the tube (Figure 9), and if the tube is sufficiently narrow that the displacement of the gas at any instant is the same at all points on its cross section, it can be modeled by the wave equation[2]. Results are:

$$f = [(2n-1)c]/4L \qquad (2)$$

where n = 1 corresponds to the first natural frequency; c and L have the same meaning as before. It's been suggested that the Helmholtz resonator model (equation #1) should transition to the wave equation model (equation # 2) when the volume of the tube is about one-half the volume of the chamber.

It is interesting to make a representative calculation using one of these equations. Assume that a pressure transducer with a resonant frequency of 100 kHz is mounted at the end of a standpipe of length 1.5 inches measuring reflected blast pressures at 500 degrees Fahrenheit (F). The sound velocity in air is proportional to the square root (√) of the absolute temperature. Therefore, 1100 feet/second at room temperature (70 °F or 530 °R (Rankine)) would scale to √960/√530 or about 1480 feet/second at 500 °F or 960 °R. Using equation (2), the effective resonance of the transducer/tube combination would be lowered from 100 kHz to 2,960 Hz! Equations (1) and (2) then enable calculation of an approximate value as to how much the dynamic response of a pressure transducer is reduced when coupled through a gas-filled cavity.

Figure 9: Pressure Transducer with Tubing Interconnect

When performing explosively driven blast pressure meas-urements, these equations may yield somewhat imprecise results because gas composition and temperature, and thus sound velocity, are often unknown. However, when compar-ing the speed of sound for gases such as methane, air, and carbon dioxide, it can be concluded that an acceptable starting point for most calculations is to assume air to be the gas in the cavity at a temperature of 500 degrees Fahrenheit.

1. Walter, P. L., Limitations and Corrections in Measuring Dynamic Characteristics of Structural Systems, Ph. D. Thesis, Arizona State University, pp. 140-141 and 205-208, Dec. 1978.
2. Morse, P. M., Vibration and Sound, McGraw Hill, NY, ch. 22, pp. 221-235, 1948.

Author's note: Part I of this series introduced the topic of blast pressure measurement and provided background. This part has discussed errors attributable to interfacing the transducer to the blast environment. The next part will deal with still other challenges in managing this interface.

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