PCB PIEZOTRONICS
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INTRODUCTION TO AIR BLAST MEASUREMENTS - PART I

Written By
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An explosion in air is a process by which a rapid release of energy generates a pressure wave of finite amplitude. The energy source can be anything that generates a violent reaction when initiated. This includes: chemical or nuclear materials, gases (high pressure gas-storage vessels, steam boilers), or electricity (spark gap, rapid vaporization of a metal). The properties of air will cause the front of this pressure wave to "shock up", or steepen, as the front moves. The result is a shock front moving supersonically, i.e., faster than the sound speed of the air ahead of it, with discontinuities in pressure, density, and particle velocity across the front.

Free Air Blast **Directed Air Blast (Shocktube)**

Contained Air Blast

Figure 1: Examples of Freely Expanding, Directed, and Contained Air Blasts

Unlike acoustic waves that move at sonic velocity, produce no finite change in particle velocity, and don't "shock up," air blast is a nonlinear process involving nonlinear equations of motion. Air blast can be encountered in freely expanding shocks in air or, if obstacles enclose the energy source, in directed shocks and contained shocks. Examples of all three are shown in Figure 1.

A near-ideal explosion that is generated by a spherically symmetric source, and that occurs in a still, homogeneous atmosphere, would result in a pressure-time history similar to the one illustrated in Figure 2. The pressure is at ambient until the air blast arrives. At this time it instantaneously rises to its peak side-on overpressure, decays back to ambient, drops to a partial vacuum, and eventually returns to ambient.

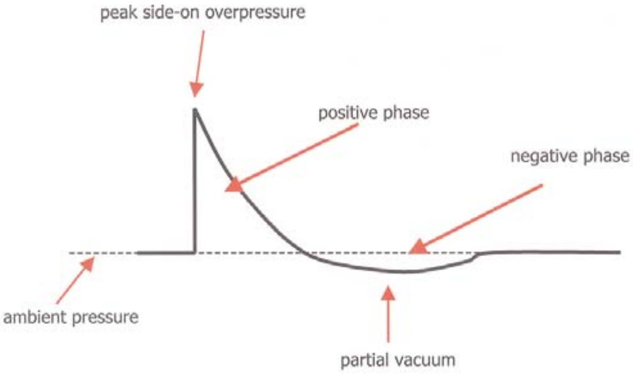

Figure 2: Ideal Side-on Pressure Record Attributable to a Spherical Symmetric Source in a Homogeneous Medium

Deviations from this ideal waveform are to be expected. Rarefaction waves occur at the contact surface between the explosion products and air; these waves result in modification of the positive shock phase.

For caged explosives, any fragment that is generated may have an associated momentum adequate for it to outrun the blast-wave velocity and produce disturbances before the wave's arrival. Ground effects due to dust or heat-reflecting surfaces may form a precursor wave.

Additionally, if the blast wave has low specific energy, it may travel a significant distance before "shocking up." The interaction of blast waves with a solid object can result in reflections from the object or cause the waves to reflect from, as well as diffract around the object.

Figure 3 shows the reflection of strong shock waves from a reflective surface. I_1, I_2, and I_3 represent the expanding shock wave, while the "R" contours represent the respective reflections from the surface. When I_1 just touches the surface S, a reflection occurs that is more than two times I_1. As the shock wave continues to move outward, the intersection of each I and its corresponding R lies on the dashed line. The incident and reflected shocks coalesce to form a Mach stem. As the shock expands, the Mach stem grows, eventually encompassing the 2-shock system above it.

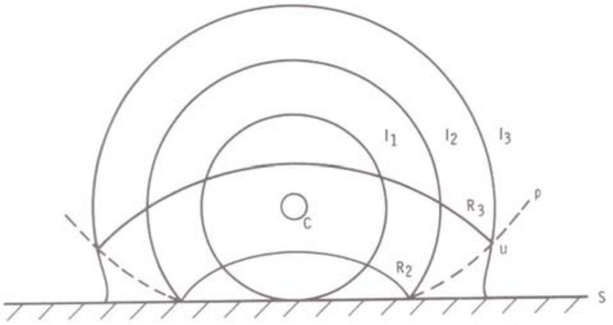

Figure 3: Strong Shock Wave Interaction with a Reflective Surface

As the blast wave propagates to greater distances from its source, its magnitude lessens and it decreases in velocity until it propagates at the speed of sound. Theoretically, acoustical laws could then apply, but meteorological conditions tend to control its properties at long distances.

The development of predictive codes and analytical techniques for the strength and directional characteristics of blast-waves is highly dependent on experimental measurements. Robust blast-pressure transducers were not always available to make these measurements; they had to be developed.

Much of the early development of these blast-pressure transducers occurred at government laboratories such as the Ballistic Research Laboratory (BRL - United States) and Royal Armament Research and Development Establishment (RARDE - United Kingdom) in the 1950s and 1960s. Among the early commercial pressure transducer developers were Atlantic Research Corporation, Kaman Nuclear Corporation, Kistler Instrument Corporation (where some of its founders subsequently formed PCB Piezotronics), and Shaevitz-Bytrex Corporation.

To characterize the time signature of a blast-pressure event, transducers are required for two types of measurements. Side-on transducers (incident) are those that record free field pressure at varying distances from the blast source. Their design must minimize interference with the flow behind the shock front. Reflected-pressure transducers are used for measuring pressures reflected at normal or oblique incidence from a rigid surface. Flow and diffraction effects are no longer important. This type of transducer must be mounted so that its sensing surface is flush with the reflecting surface for the shock front.

One of the notable pioneers in this field was Mr. Ben Granath who originally worked at BRL and subsequently founded Susquehanna Instruments, a development company for blast transducers. This company is now part of PCB Piezotronics. Photographs of two transducers, which resulted from Mr. Granath's work, are provided as Figure 4.

PCB Series 137 Pencil Probe **PCB Series 134 Blast Probe**

Figure 4: PCB Blast Pressure Transducers

In Figure 4, the transducer on the left, the pencil probe, is obviously intended for side-on pressures. Its quartz acceleration compensated piezoelectric sensing element is built into the housing. The geometry of the contained piezoelectric element, as well as the velocity of the shock front of the blast wave passing over it, control its rise time of < 1-4 μsec. This transducer covers a pressure range extending to 1000 psi. The transducer in the right portion of this figure works on the principle of a pressure bar. Its sensing element is tourmaline, which is interfaced to an internal bar. The bar is acoustically impedance-matched to the tourmaline, resulting in a 1.5-MHz resonant frequency for the transducer. This model transducer is used for reflected pressure measurements to 20,000 psi.

A limitation of the early piezoelectric transducers developed by government labs and/or industry was the influence of the cable on their signal. In hazardous tests, such as those involving explosives, cable lengths of 100s to 1,000s of feet are typical. When these cable lengths were employed with charge-sensing circuits, a variety of deleterious effects would result; the principal problems were:

- noise generated within the cable due to triboelectric effects,
- the high cost of special noise-treated cables to eliminate

the above effects, and

- a charge sensing amplifier's noise level, which increases in proportion to cable capacitance, i.e., cable length.

All of the aforementioned problems have subsequently been solved with integral-electronics piezoelectric (IEPE) transducers. PCB Piezotronics equivalent registered trademark, which predates the IEPE designator, is "ICP®." The IEPE configuration converts the transducer's output to low impedance, thus eliminating triboelectric effects, and it also permits the use of a variety of inexpensive 2-wire cable systems, none of which require noise treatment. In addition, if a typical 20-milliamp current is used to power the transducer, the high-frequency response of the transducer is maintained over very long cable runs. Figure 5 shows a cross-sectional view of an acceleration compensated pressure transducer in an IEPE or ICP® configuration.

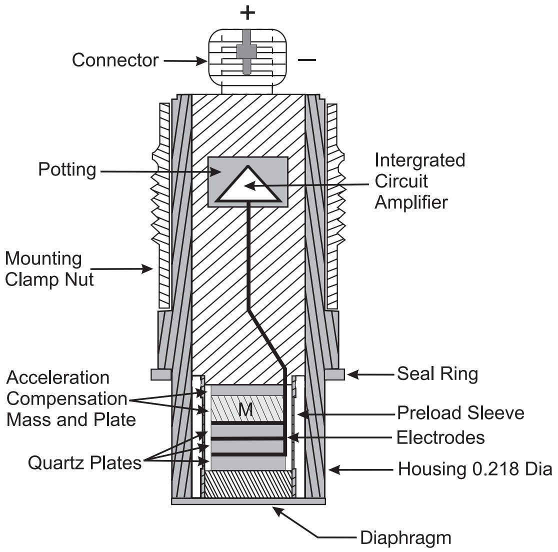

Figure 5: ICP® Acceleration Compensated Pressure Transducer

Author's note: This article introduced the topic of blast pressure measurement and provided background on it. Subsequent articles will deal with other unique challenges associated with this discipline.

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