PYROSHOCK EXPLAINED

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This Tech Note provides an introduction to the mechanical environment of pyroshock. Specifically, it (1) defines pyroshock, (2) identifies those situations where pyroshock can induce equipment failure, (3) explains the response of structural systems to pyroshock, and (4) discusses uniqueness in the shock spectra (see PCB® Tech Note 19) associated with pyroshock. Since the importance of pyroshock became recognized in the late 1960s, many articles[1,2] have been written about it and some test standards[3] generated.

Pyroshock is the decaying, oscillatory response of a structure to high-amplitude and high frequency mechanical excitation. The frequencies that comprise this oscillatory response can extend to thousands of Hertz and beyond. They are a subset of the resonant frequencies of the structure.

The aerospace industry was the first to recognize the potentially destructive effect of pyroshock. The firing of explosive bolts, nuts, pins, cutters, and other similar devices initiated this pyroshock. Subsequently, it was recognized that other environments (e.g., the sudden release of strain energy and metal-to-metal impact), although not initiated by explosive devices, produced effects similar to pyroshock.

Originally, the high frequencies associated with pyroshock were believed to be benign; i.e., they did not have the potential to cause damage. For example, a rocket guidance system typically contains an inertial measuring unit (gyros and precision accelerometers) mounted with elastomeric materials to mechanically isolate it from pyroshock. Similarly, massive structures have low resonant frequencies, which effectively isolate them from pyroshock. However, over the years, electrical and optical components have become increasingly more miniature. Because of this miniaturization, the mechanical resonant frequencies of these components have increased, making them susceptible to damage by pyroshock.

Pyroshock is categorized in the literature as near-field and far-field. This categorization is really a division of thought process and can be explained by the following example[4]. Consider the center of a 1-centimeter thick aluminum plate (Figure 1), which is explosively loaded. One-dimensional strain will be achieved in this center portion until relief waves propagate from the edge of the plate into this region. We will initially focus just on this central region.

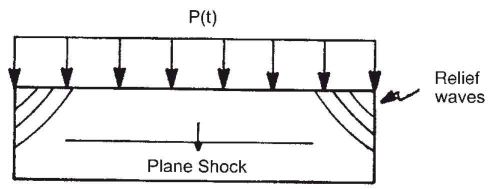

Figure 1: Plane wave propagating through material

Figure 2 describes the interaction between the explosive and the plate. It shows the left going pressure-particle velocity curve for the explosion products of TNT, along with the pressure-particle velocity relationship for aluminum. State (2) represents the pressure and particle velocity initially imparted to the loaded surface of the plate. State (3) occurs after a shock wave has traversed the plate thickness and arrived at its front surface. At state (4), a rarefaction has traversed back to the loaded surface and again interacted with the detonation products, similar to states (6), (8), etc. These reflections occur until the plate is traveling with zero internal pressure and uniform particle velocity.

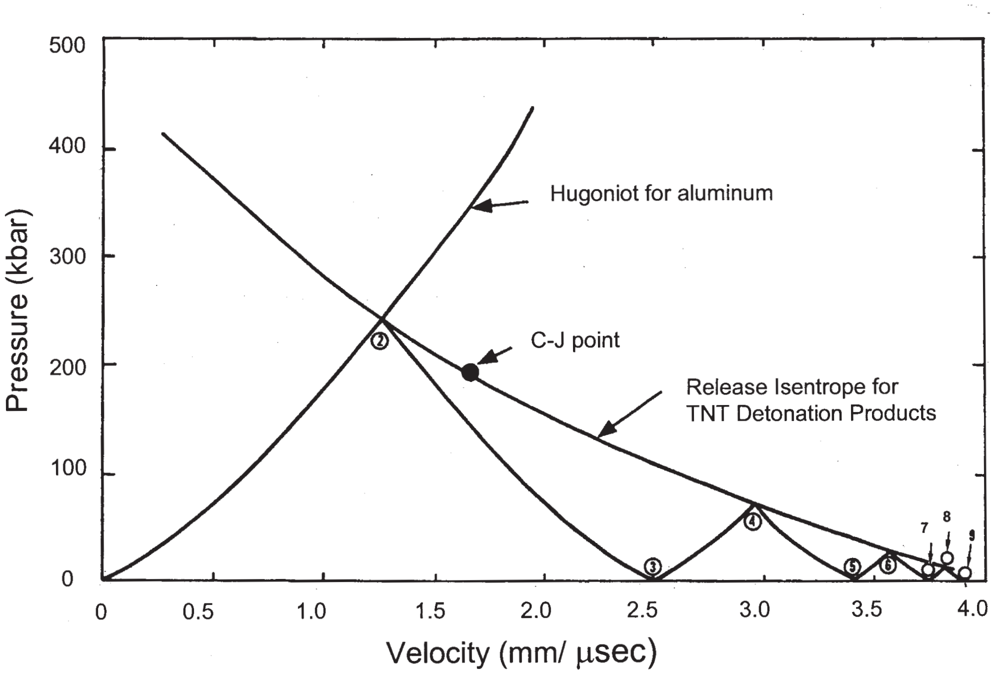

Figure 2:
Pressure versus particle velocity for explosively loaded aluminum plate

Figure 3 illustrates this same process but in the context of a position-time plot. At state (2), the loaded surface begins to move, and at state (3) the unloaded front surface begins to move. At state (4), the loaded surface attains a new velocity, and so on. Figure 4 shows the velocity-time response of the loaded surface, which is the time derivative of Figure 3. Similarly, Figure 5 shows the acceleration-time response of the loaded surface, which is the time derivative of Figure 4.

Note that these time-response determinations have all been for the loaded surface of the plate. This is the surface that directly interacts with the explosive. The front surface of the plate, the unloaded surface, will have a very similar response, only time-delayed about 1 µs. For this example, the just described complex response of the central region of the plate ends after about 12 µs and can be considered near-field pyroshock.

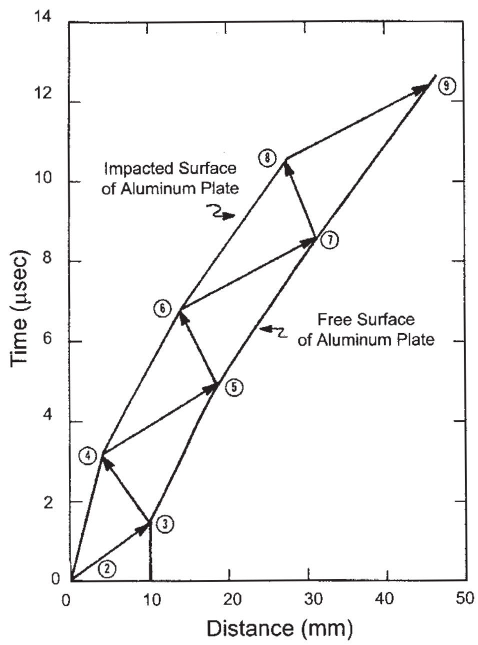

Figure 3: Time versus position for explosively loaded aluminum plate

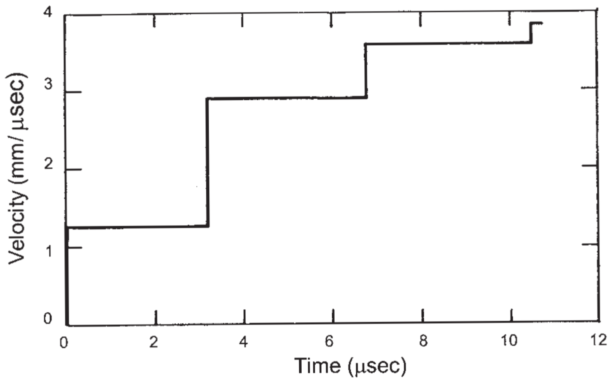

Figure 4: Velocity versus time of loaded surface of aluminum plate

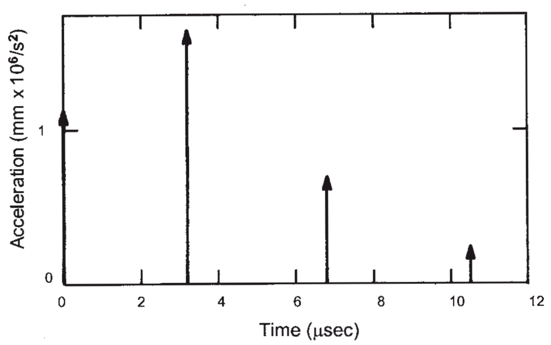

Figure 5: Acceleration versus time of loaded surface of aluminum plate

Other than briefly at the center of the plate, one-dimensional strain is not achieved. The motion of the plate extremities is governed by three-dimensional strain. In addition, practical engineering structures have joints and interfaces. Complex geometries and various materials, along with these joints and interfaces, initiate multiple wave reflections. Material properties can also be rate sensitive. The motion in the extremities of an explosively loaded structure lasts for a much longer time period than it takes the waves traversing back and forth in the central portion of the plate to settle down. This longer time motion is modeled by treating the system as an assembly of discrete springs and masses. The motion in these extremities describes far-field pyroshock.

The damage potential associated with a specific pyroshock event can be replicated to a test item in the laboratory by developing an acceleration-time stimulus whose shock spectra envelops that which the item encounters in service. Carefully tuned bars, beams, plates, and more complex structures are used to achieve this simulation. They are excited by mechanical impact or even explosive loading[3].

Ideally the shock spectra associated with pyroshock has a low frequency slope of between 6 and 12 dB/octave. Reference 5 provides the mathematical basis for this observation. It is not uncommon for a lesser slope to be observed in processed data. When this occurs, typically the measuring accelerometer is blamed. While a very small zero shift originating in the accelerometer can produce this error, it can also be attributed to an improperly defined signal zero reference level[5], truncation of the signal during recording[5], or even aliasing[6] of the signal due to an inadequate sampling rate.

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3. IEST-RP-DTE032.1: PYROSHOCK TESTING TECHNIQUES, Design, Test, and Evaluation Division, Institute of Environmental Sciences and Technology, 20 pages, Document No. D032, 2002.
4. Walter, Patrick L., Lessons Learned in Applying Accelerometers to Nuclear Effects Testing, Proceedings 74th Shock and Vibration Symposium, San Diego, CA, October 2003.
5. Smallwood, David O., Shock Response Spectrum at Low Frequencies, The Shock and Vibration Bulletin, SAVIAC, Volume 1, 279-288, 1986.
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