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Novel Uses Of Detonator Diagnostics

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Abstract. A novel combination of diagnostics is being used to research the physics of detonator initiation. The explosive PETN (Pentaerythritol tetranitrate) commonly used in detonators, is also a piezo-electric material that, when sufficiently shocked, emits an electromagnetic field in the radio frequency (RF) range, along crystal fracture planes. In an effort to capture this RF signal, a new diagnostic was created. A copper foil, used as an RF antenna, was wrapped around a foam fixture encompassing a PETN pellet. Rogowski coils were used to obtain the change in current with respect to time (di/dt) the detonator circuit, in and polyvinylidene difluoride (PVDF) stress sensors were used to capture shockwave arrival time. The goal of these experiments is to use these diagnostics to study the reaction response of a PETN pellet of known particle size to shock loading with various diagnostics including an antenna to capture RF emissions. Our hypothesis is that RF feedback may signify the rate of deflagration to detonation transition (DDT) or lack thereof. The new diagnostics and methods will be used to determine the timing of start of current, bridge burst, detonator breakout timing and RF generated from detonation. These data will be compared to those of currently used diagnostics in order to validate the accuracy of these new methods. Future experiments will incorporate other methods of validation including dynamic radiography, optical initiation and use of magnetic field sensors.

INTRODUCTION

Historically PETN has been known to emit RF electrical noise when shock-loaded. The RF emissions are thought to be piezoelectric in origin, created by crushing of the crystals and the subsequent electrical discharges along fracture surfaces. The goal here was to correlate the RF signature with the explosives state of reaction. For these experiments a simple copper foil antenna was used to measure the RF signal. Other diagnostics included a Rogowski coil, a PVDF gauge, and a current viewing resistor (CVR). The Rogowski coil is a passive current gauge included in the ground return of a circuit [1]. The PVDF sensor is a common piezoelectric transducer foil that generates an electrical signal when impacted by a shockwave. The CVR is a small resistor that monitors the current in the firing circuit.

EXPERIMENTAL

Assuming that the RF emissions are piezoelectric in origin, high porosity PETN pellets were chosen to facilitate shock induced fracture. In these experiments PETN powder of 79 micron mean particle size was pressed to a density of 1.3 g/cc into pellets measuring 12.7 mm x 12.7 mm. At this density the porosity was ~27%. The RF antenna was fixed at a sufficient standoff radius (50 mm) surrounding the PETN to ensure only field changes were observed rather than physical impact of shockwave or fragmentation. The Rogowski coil was embedded into a custom firing cable for the highest accuracy. The Rogowski has the ability to detect start of current, bridge burst of the detonator and electrical ringing. A Polyvinyl Chloride (PVC) shim stock stack-up was used to attenuate the shockwave leaving the detonator. By varying the attenuator thickness from experiment to experiment, the degree of reaction induced in the PETN could be controlled. The degree of reaction was determined using a steel witness plate and the PVDF shock sensor, Figure 1..
The RF signatures were then correlated with the degree of reaction where possible.

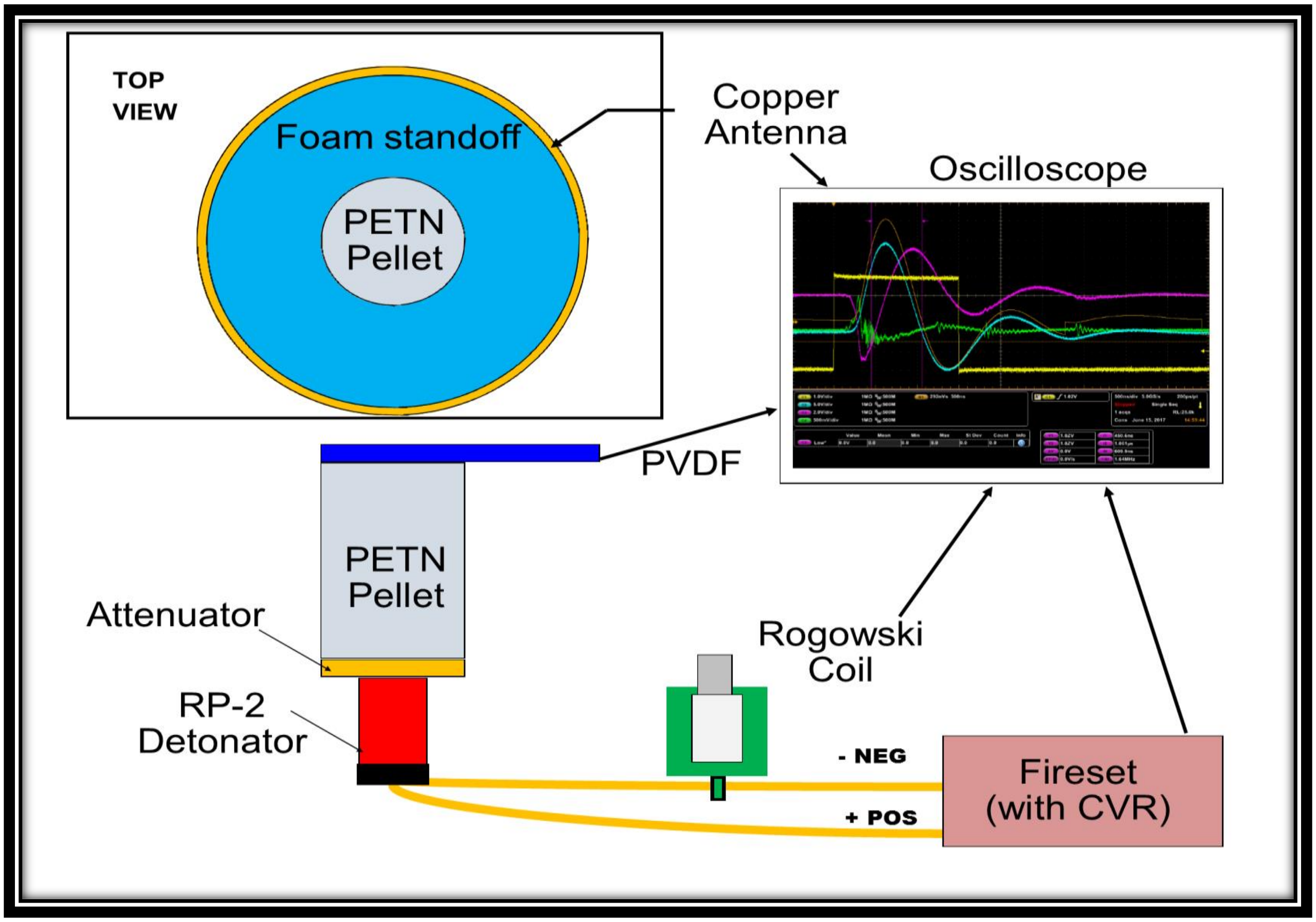

Figure 1. A full diagram of shot setup with diagnostics.

RESULTS

RF noise perturbs all electrical measurements made in explosives experiments, but with these new data the origins of RF are better understood. Additionally the antennas ability to distinctly identify a full detonation versus a failure (NO-GO) creates tremendous potential for novel diagnostics that can be used to characterize detonator performance. The antenna clearly shows features in the frequency domain in a full detonation that are nonexistent in a NO-GO. This capacity of the antenna is vital as it provides the experimenter a potential safety diagnostic and can verify the explosives status post fire. The RF signature in the antenna also shows such features as start of current and bridge burst. These features are validated by the CVR and Rogowski data. The PVDF functioned flawlessly and captured arrival time even in NO-GO shots where only the detonator produced a shockwave. This allowed for a consistent point of reference in each shot.

Spectral resonance as evidence of detonation

From the original RF temporal data, it was difficult to discern any influence of the reaction on the RF data. However, when the data were converted to the spectral domain significant differences emerged, see Figure 2. Certain features were clearly visible in the NO-GO shots that disappeared in the GO shots. The data suggest that the antenna is picking up signal when compaction (and potentially deflagration) occurs but when the threshold is crossed into detonation these signals are lost. It is hypothesized that the electrical conduction zone associated with detonation [2] suppressed these signals.

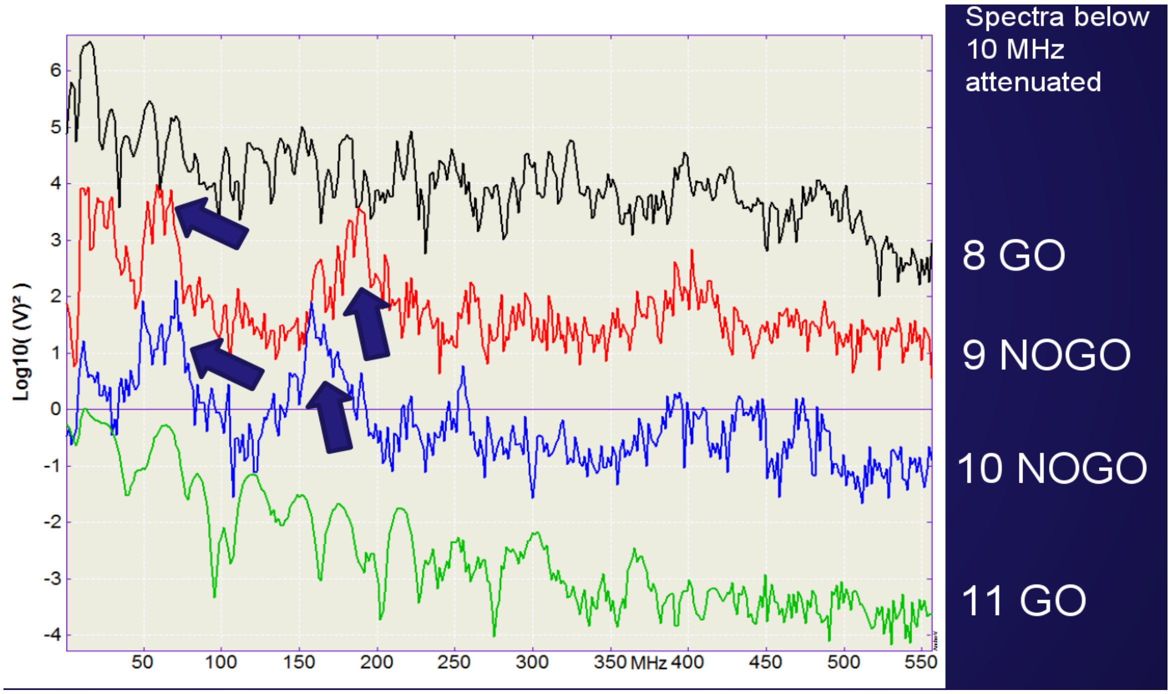

Figure 2. Spectra from four experiments observed close to the 50% attenuation point. The data are plotted as log (power) of the emissions vs. frequency. The arrows indicate differences in the spectra between the GOs and NO-GOs.

The features in the spectra suggest that the noise seen in the NO-GO shots exists from approximately 50 to 225 MHz. This is interesting to note as the initial Coulter performed on the PETN yielded a mean particle size of 80 um, Figure 3. Assuming particle velocities of the order of 2 to 4 km/s in the PETN and pores sizes of ~0.3 x the particle diameters, a mean frequency range of 50-250 MHz which correlates very well to the plot. This finding is encouraging in that the RF noise appears to be correlated to the particle size and porosity of the PETN.

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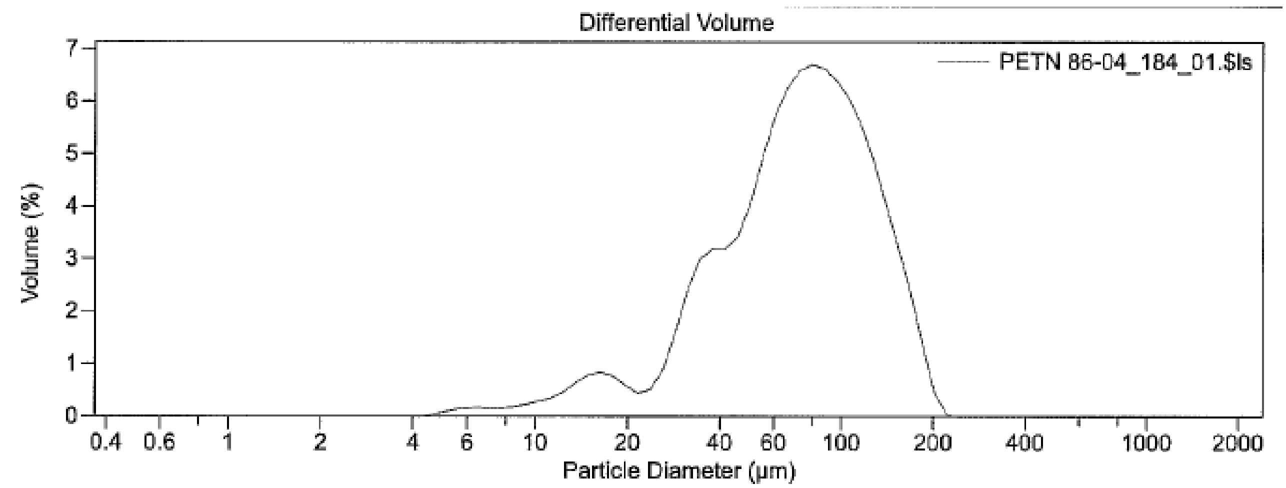

Figure 3. Coulter particle size analysis of PETN powder.

DISCUSSION

In future studies the antenna data could be further understood by using dynamic radiography (Advanced Photon Source (APS) facility at ANL) to show in-situ pore collapse within the PETN to validate the theory of the shockwave suppressing RF signal. Additionally, a magnetic antenna could be implemented to observe the field polarity and local magnetic field changes produced by the PETN at high resolution. All future studies will seek to further characterize the effects of RF on current diagnostics in addition to further studying the effectiveness of the antenna as an indicator of RF interference in detonator shots and as alternative diagnostic to current methods of tracking start of current and bridge burst. This may be achieved through testing different compositions of explosive at various particle sizes, porosity, surface area, grain structures and densities. In an effort to reduce timing variance, the next attenuators will be a machined fixture of a characterized polycarbonate reducing interfaces and air gaps.

The Rogowski coil will also be further isolated and fire cable redesigned to minimize inductance. The use of optical or gas-gun initiation systems will be considered in an effort to further reduce electrical noise. Finally, tests will be conducted to establish the antenna's ability to signify a GO or NO-GO response as an absolute indicator of either no response, detonation or deflagration (partial fire).

CONCLUSIONS

Preliminary experiments show that the RF spectra emitted by shock loaded porous PETN pellets can be used to determine the degree of reaction induced in them.

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