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FREE-FIELD MICROWAVE INTERFEROMETRY FOR DETONATION FRONT TRACKING AND RUN-TO-DETONATION MEASUREMENTS

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Abstract. A quadrature interferometer used in a free-field measurement mode has, with the aid of a high directivity horn antenna, been successfully used to measure the detonation front of PBX-9501 within a dielectric can. Using the known length of explosive, a relative dielectric permittivity of 3.84 has been calculated for the 34 GHz frequency used. Using this value, the displacement vs. time of the detonation front can be found and hence the velocity of detonation may be calculated. This technique shows good promise as a method of measuring the run-to-detonation distance in explosives using a totally non-contacting technique.

Keywords: Microwave Interferometry, Detonation, Run-To-Detonation

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INTRODUCTION

Microwave interferometry has been widely used to study the reaction front locations in explosives and propellants [1-10]. However, in most cases (reference [1] being a notable exception) the explosive has either been packed into a confining waveguide or a diagnostic probe has been inserted into the material under study. Data with a low signal-to-noise is easily obtained in the case of waveguide confinement owing to the low losses, but the penalty is the limited sample diameter/area that may be studied for a given microwave wavelength. This is because allowing multiple modes to propagate within a waveguide [11] greatly increases the difficulty of analysis of the returned signal. Typically, the phase of a reflected microwave signal is unwrapped to give displacement vs. time information. If the phase error associated with such a measurement is fixed (for example $\approx 10^\circ$) then decreasing the microwave frequency increases the waveguide size that may be used, but consequently lowers the effective spatial accuracy of the technique.

Therefore, this paper focuses on the attempt to make free-field measurements of reacting explo-

sives in a dielectric can. In this way, a totally non-contacting measurement technique is employed allowing large charges to be studied with relatively high spatial resolution using a 34GHz quadrature microwave interferometer. The key development is the design of a high directivity, disposable, horn antenna for use with inexpensive and disposable circular waveguide. This allows adequate reflected signal to be captured despite the free-field nature of the geometry.

EXPERIMENTAL

A low power 34 GHz quadrature interferometer manufactured by Millitech was used. The output WR-28 rectangular waveguide had a short section of PTFE filled waveguide fixed to act as a backup block to detonation products entering the interferometer. Ahead of that, a Millitech rectangular to circular waveguide adaptor was attached. A suitable single mode circular waveguide inside diameter at 34 GHz is 6.35 mm (0.25 inches). This corresponded with readily available soft copper tubing that was used as a disposable

FIGURE 1. The horn antenna for the circular waveguide and corresponding directivity plot in dB.

waveguide with the addition of brass end fittings soldered in place.

The key aspect to making free-field measurements is a highly directional antenna. The design shown in figure 1 can be seen to have almost 19 dB of forward directivity with correspondingly low side lobe levels. The carefully shaped PTFE insert acts both to improve the directionality and as a primary blockage to detonation products entering the waveguide.

The setup used is shown in figure 2 with only a short length of waveguide leading to the horn. The dielectric can containing the explosive and timing pins can be seen to the left.

Two geometries have been tested (shown in figure 3) both using 1 inch (25.4 mm) diameter PBX 9501 pellets pressed to a density of 1.1815 g/cc. In shot A, an initial booster pellet was separated from two acceptor pellets by a very thin Al layer. The layer acted as an initial reflector to align the interferometer but ensured prompt detonation from the booster. The length of explosive in the acceptor was known

FIGURE 2. The antenna and explosive setup.

FIGURE 3. Diagrams of the two different geometries used.

allowing the relative dielectric constant to be calculated later. This value was required to convert the interferometer's output phase to displacement.

In shot B an attenuator was added so that detonation breakout was less prompt, however the run-to-detonation was still < 2 mm. In both shots, a 1/4 wave matched PTFE cover plate was added to provide a distinct signal upon shock breakout at the end of the explosive. The 1/4 wave matching minimized back reflection from the PTFE/air interface.

The quadrature signals from the interferometer were collected on an oscilloscope at 5 G samples second^{-1} and transferred to a phase unwrapping algorithm written in the IGOR analysis package. Little filtering of these data was required, except to center and circularize the Lissajous figures prior to unwrapping [12]. After converting phase to displacement,

FIGURE 4. The recorded quadrature signals from shot A.

extensive filtering would be required to differentiate the data to velocity, however, owing to the linear detonation velocity of the ideal explosive used, a least squares straight line was fit to the displacement vs. time plot to obtain the velocity of detonation (VOD).

RESULTS

A plot of the recorded data from shot A is shown in figure 4. It may be observed that the returned microwave signal had a high signal-to-noise ratio.

Using the distinctive detonation start and stop jumps in the waveforms and the known length of the explosive run, the relative dielectric permittivity was calculated as 3.84. Comparison with the sparse literature of such values reveals a measured value of 3.52 at 24 GHz for PBX 9404, a similar HMX based material [13]. Given the difficulty of these type of measurements, our value is in reasonable agreement with the literature.

The displacement vs. time plots for both shots A & B are shown in figure 5. Using a least squares fit, the VOD was calculated to be $8.68 \pm 0.01 \text{ km s}^{-1}$. This is in good agreement with a CHEETAH 6.0 estimate for the PBX 9501 VOD of $8.71 \pm 0.01 \text{ km s}^{-1}$ at the pressed density. The VOD data from the piezo timing pins was found to be unreliable in shot A for unknown reasons.

FIGURE 5. The displacement vs. time plots for shot A (top) and shot B (bottom).

DISCUSSION

Close examination of the breakout of steady detonation in Shot B reveals an inflexion (figure 5, bottom, inset plot). It is believed that the cause of this can be readily explained by considering the short run-to-detonation imposed by the attenuator. Specifically, we believe that this inflexion is caused by the mixing of reflected microwave signal from the aluminum surface and pockets of reflectivity as thermal explosion begins behind the shock front prior to a steady detonation front being formed. Figure 6 illustrates the chain of events.

In region 1 the shock has not yet reached the front of the Al attenuator. In region 2 particle velocity in the Al is measured together with a weak reflection from the impedance change in the explosive from a currently unreacting shock front. In region 3 the onset of thermal explosion has begun increasing the reflection from just behind the shock front. This moves the apparent reflection point rapidly forward resulting in the increased gradient. In region 4 a steady detonation has been created resulting in a steady reflection of microwave signal.

The free-field interferometry technique has been shown to work well for detonating PBX 9501 with a reasonably planar shock breakout front. The measured VOD agreed well with calculations and signals with a high signal-to-noise ratio were obtained. Further experiments are required to investigate the effect of highly divergent detonation fronts and possible retonations back into previously shocked explosive. However, this technique appears to be a promising non-contact method of measuring run-to-detonation in explosives.

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FIGURE 6. An explanation for the observed inflexion of the curve at detonation breakout in shot B.