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Detonation Velocity Measurements from a Digital High-speed Rotating-mirror Framing Camera

by Matthew M. Biss and Kimberly Y. Spangler

ARL-TN-0502 **September 2012**

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Matthew M. Biss and Kimberly Y. Spangler
Weapons and Materials Research Directorate, ARL

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14. ABSTRACT
Rate-stick experiments were performed and digital high-speed framing-camera images were captured to determine energetic material detonation wave velocities. Rate-stick experiments consisting of 20-mm-diameter pressed pellets having a length-to-diameter (L/D) ratio of 1, with the total charge having a L/D of 10, were conducted. Digital high-speed images were recorded at rates upwards of 2.5 million frames/s using a Cordin model 570 rotating-mirror framing camera. Individual images were analyzed to determine the pixel position at which the reaction products break out from the energetic material-air interface. Position-time records were constructed and best-fit lines applied to the data to determine detonation velocities. The results of three different energetic materials are presented. Detonation velocities were found to be in good agreement with piezo-pin velocity measurements concurrently taken.

15. SUBJECT TERMS
Optical detonation velocity, Rate stick, Framing camera, High-speed

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1. Introduction

Energetic-material detonation-wave-velocity measurements have long been performed using ionization- or piezoelectric-type velocity probes. Though varying in operating principles, both probes act as time of arrival detectors upon encountering a propagating detonation wave. Thus, when positioned at known inter-pin distances, a detonation velocity can be determined.

The intense light emission produced throughout the energetic material detonation process, however, suggests the alternative use of optical measurement techniques (*1*). Optical visualization of the detonation process began with rotating-drum, rotating-mirror-framing, and rotating-mirror-streak film-based cameras. By sweeping an image of the detonation event onto the film, perpendicular to its propagation direction, a position-time image results. Data points are recorded from the image, and through the analysis of the resulting profile, a detonation velocity can be determined at any position (*2–4*).

When combined with digital high-speed cameras, the utility provided by optical visualization techniques is quite comprehensive. Digitally based records may be analyzed using advanced image processing software (as compared to optical comparators used for film-based records) allowing physical characteristics to be more easily tracked and providing a streamlined approach for replicate data sets. Additionally, numerical treatment of the data is expanded yet simplified, allowing a more in-depth analysis to be performed.

2. Objective

An analysis was conducted to demonstrate the utility of the Cordin Model 570 digital high-speed rotating-mirror framing camera for measuring energetic materials detonation velocities. Rate-stick experiments were conducted using several new U.S. Army Research Laboratory (ARL) energetic formulations to determine their detonation velocity as a performance metric. Additionally, standard piezo-pin data were collected to compare with the detonation velocities measured by the high-speed images.

3. Experimental Design, Results, and Discussion

Rate-stick experiments were conducted using 20-mm-diameter, pressed energetic-material pellets having a length-to-diameter (L/D) ratio of 1. Individual pellets were pressed to a specified density (based upon the energetic material of interest) on a half-ton hydraulic press. Individual explosive trains consisted of 10 pressed pellets placed end to end, a 20-mm-diameter PBXN-5 booster pellet (L/D=1) positioned at the initiation end, and a RP-80 detonator (Teledyne-RISI, Inc.) positioned concentrically within a poly(methyl methacrylate) (PMMA) holder and adjacent to the booster. The explosive train was positioned in a wooden fixture having a 20-mm-diameter half-cylinder bed to accommodate the pellets (figure 1).

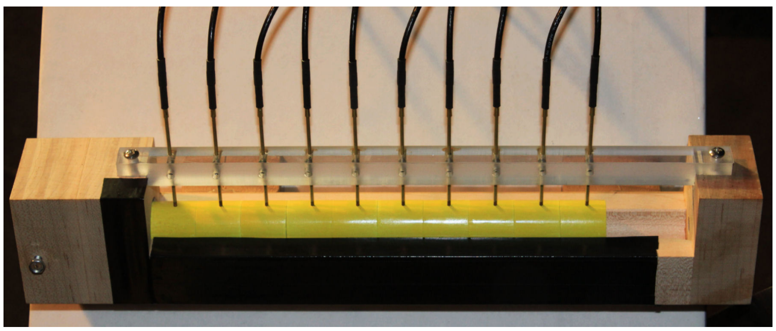

Figure 1. Explosive train assembly and piezo pins positioned in fixture.

The detonation velocity for three different energetic materials was investigated. Their respective shot numbers were 10306-1, 10306-2, and 12137-1. Energetic material detonation velocity was calculated using two separate measurement techniques: piezo pins and digital high-speed framing-camera images. Piezo pins were centrally positioned along the cylindrical axis and on the surface of the pellets using a PMMA holder with an interpin distance of 20 mm, figure 1. Pins were connected to a LeCroy 6030 series oscilloscope via BNC cable and sampled at 2.5 GHz. Detonation wave velocities were determined using the interpin distances and measured detonation wave arrival times observed on the oscilloscope record. A best-fit line was applied to the data to determine the average detonation wave velocity $D_{V_{piezo}}$ observed. Results are presented in figures 2–4 and table 1. Experimental error is represented by the physical size of the data point for all figures.

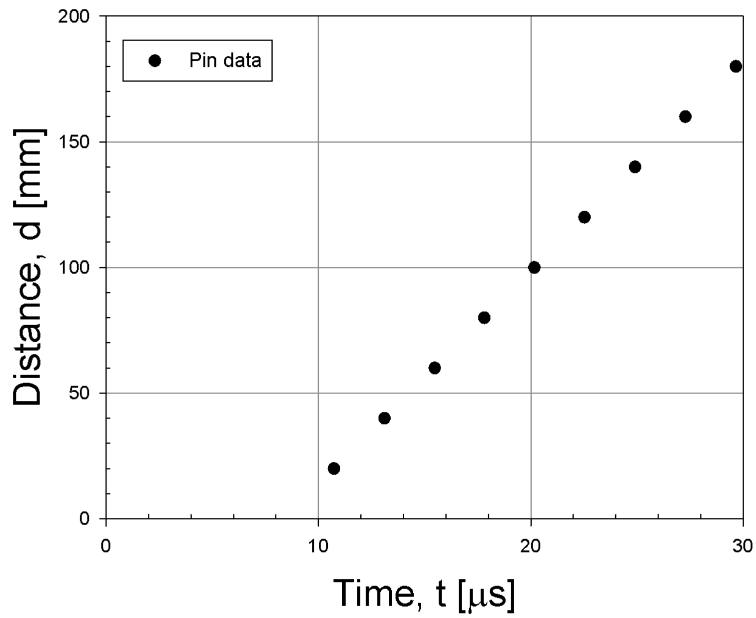

Figure 2. Piezo-pin detonation wave position-time data for shot 10306-1.

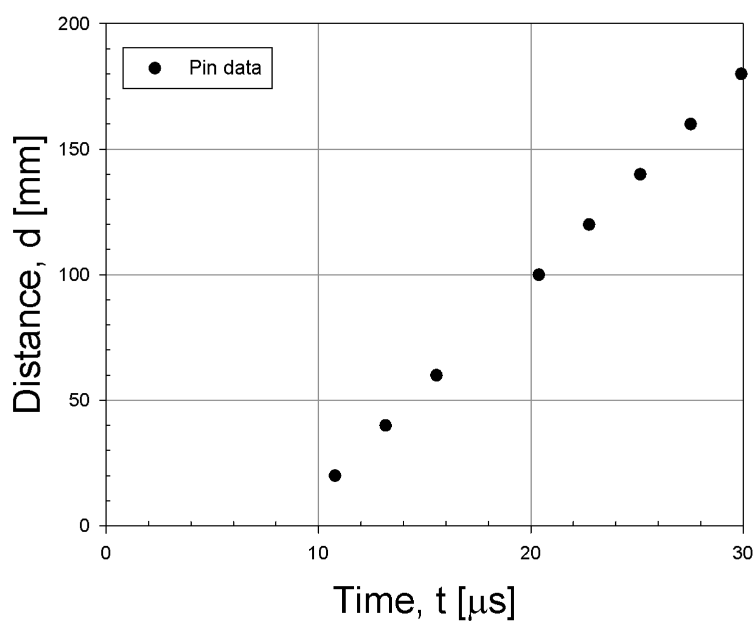

Figure 3. Piezo-pin detonation wave position-time data for shot 10306-2.

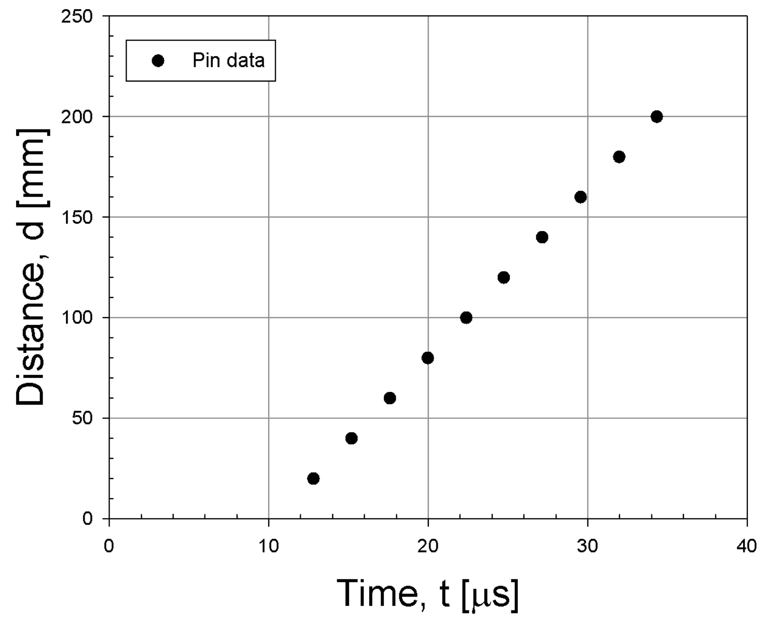

Figure 4. Piezo-pin detonation wave position-time data for shot 12137-1.

Table 1. Measured detonation wave velocities.

Shot #	**Frame rate** (frames/s)	**D**$_{V_{piezo}}$ (mm/μs)	**D**$_{V_{images}}$ (mm/μs)	**% Difference** (%)
10306-1	1,990,080	8.46	8.66	2.36
10306-2	2,515,680	8.36	8.50	1.67
12137-1	2,099,760	8.36	8.44	1.20

A Cordin Model 570 digital high-speed rotating-mirror framing camera was used to image the detonation event. Capable of up to 2.5 million frames/s recording speed, the Model 570 captures 74 independent frames at 4 Mpixels (2000 x 2000 pixels) resolution with dependent exposure times (figure 5). Experimental images were analyzed in PFV software (Photron USA, Inc.) to track the spatial shock wave position as a function of time. Due to the nature of the rotating-mirror arrangement, inter-frame image shifting results. Thus, the detonation wave position was measured with respect to the explosive train end (right-hand edge, figure 1). As previously stated, the detonation wave position was typically measured as a result of its light emission. Here, however, it was taken as the reaction products expansion position at the energetic material-air interface. While this was not the exact front of the detonation wave, its position does propagate at the same velocity as the steady-state detonation wave due to the constant pressure differential between the ambient air and detonation pressure. An artificial spatial "shift" was determined from the initial Cordin image and pin data measurements for each data set. This spatial adjustment was applied to all images in each data set. The implied shift resulted from the inability to measure the location of the detonation wave reaction products with respect to the beginning of the charge. Thus, it was imposed to simply illustrate/contrast the velocities measured by both methods. Image position-time data were plotted onto the previous pin data for comparison (figures 6–8). Experimental error is represented by the physical size of the data point for all figures. As shown, the high-speed image data are in excellent agreement with the piezo-pin data for all three data sets. Measured detonation velocities for both techniques may be found in table 1 for the three formulations tested. The percent difference between measurement techniques was determined using equation 1.

$$\%\ difference = \frac{|D_{V_{piezo}} - D_{V_{images}}|}{D_{V_{piezo}}} * 100 \qquad (1)$$

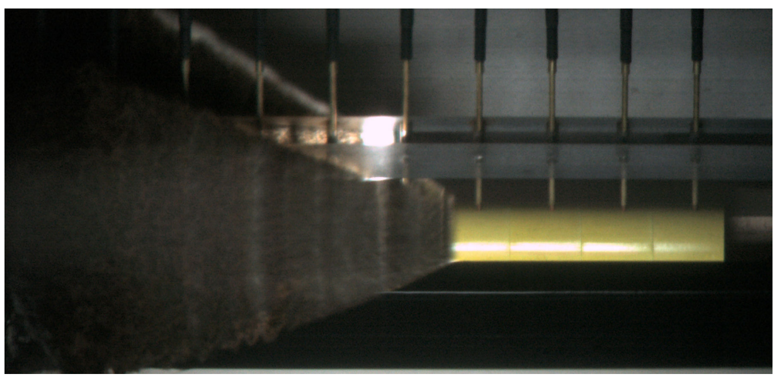

Figure 5. High-speed image of the detonation taken by the Cordin Model 570.

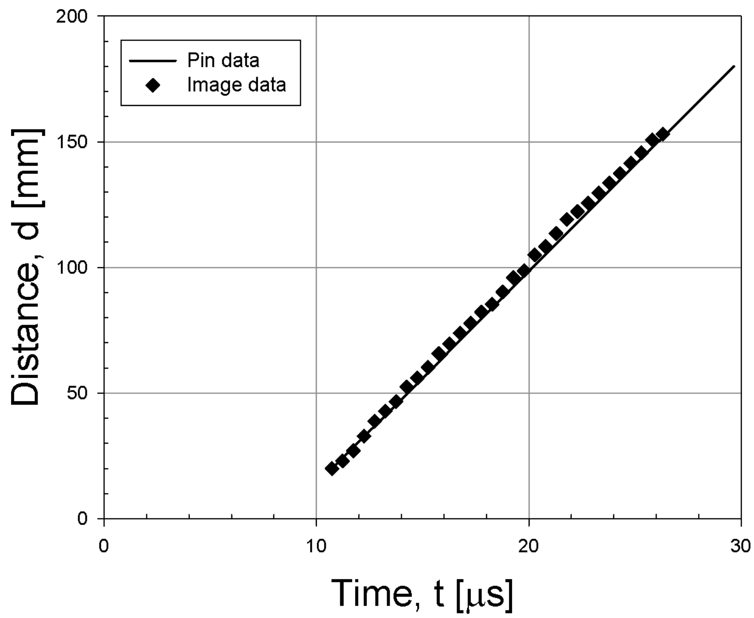

Figure 6. Cordin image detonation wave position-time data plotted against piezo-pin data for shot 10306-1.

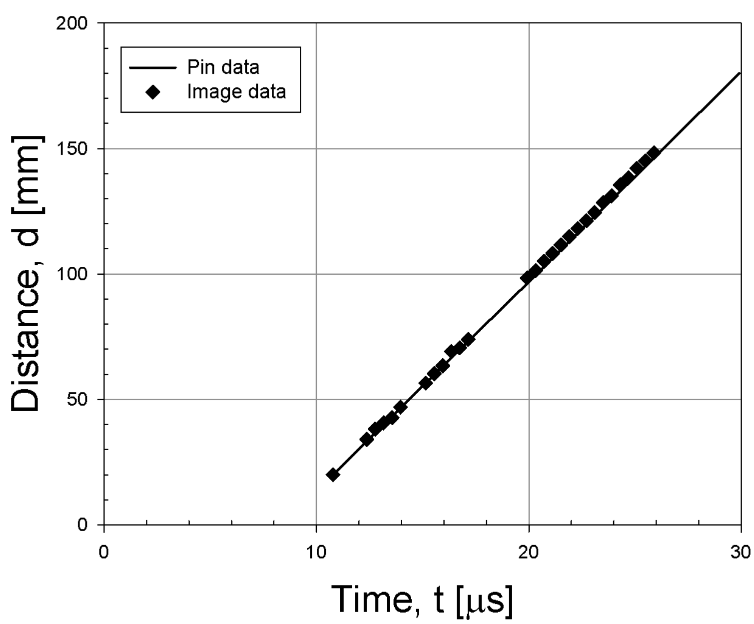

Figure 7. Cordin image detonation wave position-time data plotted against piezo-pin data for shot 10306-2.

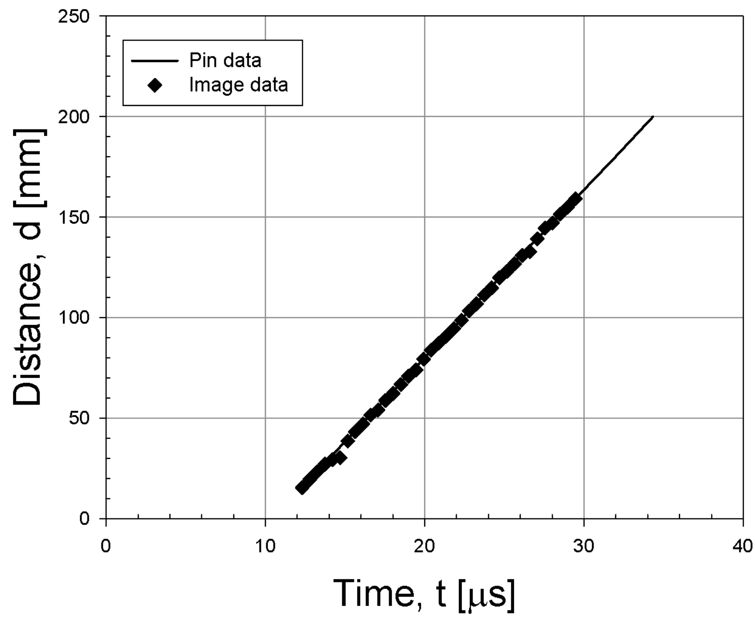

Figure 8. Cordin image detonation wave position-time data plotted against piezo-pin data for shot 12137-1.

4. Conclusions

Energetic material detonation velocities measured using digital high-speed images from a Cordin Model 570 rotating-mirror framing camera were found to correlate well with standard piezo-pin data. Using post-processing software, the temporal shock wave position was determined from the individual frames. Results were plotted against standard piezo-pin measured data and shown to be in good agreement for three different energetic materials of interest, thereby demonstrating the quantitative utility of the camera. Future rate-stick experiments will be conducted using this dual detonation velocity measurement technique, thus providing a secondary measurement for correlation purposes.

5. References

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