RESISTIVE WIRE VELOCITY PROBE

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DEVELOPMENT DIVISION

MASTER

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ABSTRACT

The resistive wire technique used for measuring detonation velocity is discussed and a few results presented to report the progress.

To implement the technique a thorough investigation was performed to reveal any areas which might introduce errors in the results. Tests with lead sheathed PETN/MDF and RDX/ALSC reveal irregularities in the detonation burn. They appear as rising and falling values in velocity with respect to time. Work has concentrated on reduction of electrical noise, identification of instrumentation errors and improvements in data reduction. Future work will apply this knowledge to the study of high explosive detonation velocities.

INTRODUCTION

The resistive wire technique is desirable for velocity measurements since it yields a continuous velocity history whereas other established techniques yield incremental times and thus average velocities. The technique is described in a report(1) on instrumented card-gap tests. The card-gap test is used to evaluate the detonation sensitivity of explosives and hazardous chemicals. Work has led to test modifications and reassessment of some of the criteria used to establish the shock sensitivity of liquid explosives. Different probe arrangements are discussed which differentiate between the nonreactive donor shock and reactive pressure waves in liquid systems undergoing both high and low velocity detonations. Since early probe sensitivity was inadequate when used with liquid systems undergoing low and high velocity detonations, more sensitive probes were developed. The most recent improvement was made possible when the Molecu-Wire Corporation made available a resistive wire that was partially insulated by a skip-wound nylon thread. One advantage is its capability to respond to both weak inert shocks and low and high velocity detonation.

This resistive wire has an additional feature of resistive linearity well within the tolerances required. A four-terminal resistance measuring system has revealed values with less than 0.1% deviations. Any irregularities in the wire have a direct relationship to calculated velocities and must be kept at a minimum.

Work has revealed very important factors on application of this technique.

1. The wire must be located on the surface to be measured in such a way to avoid gaps (Fig. 1 illustrates the consequences of a badly located wire). A constant gap theoretically would result in accurate data but would be difficult to control. In practice therefore, a surface-to-surface contact was maintained for these studies.

(1) John Ribovich, R. W. Watson, and F. C. Gibson, "Instrumented Card-Gap Test," *AIAA Journal* 6, (?) 1260 (1968).

2. The thickness of the insulation is only 0.0127 mm and of such quality that it has not introduced any measured errors. It has the ability to break down physically with very low shock velocities. This characteristic relies on information in the report by John Ribovich.
3. The detonator can create a co-axial line ring with a duration of possibly the length of the streak record. This effect has been reduced by two methods.
 - a. Locating the grounded side of the resistive wire at least 50 mm from the detonator.
 - b. Introduction of a wooden detonator holder has reduced the detonator noise by at least 50% as compared to one made of plastic material.
4. A properly sized capacitor placed at the input to the recording oscilloscope was used successfully to shunt the signal.

In practice a constant current is held on the resistive wire. A shock wave traveling along the wire shorts the wire to ground in a manner analogous to a sliding switch. The voltage and current are both recorded immediately prior to a shot to establish a resistance/unit length value at environmental conditions present at the test site. Detonation velocity as a function of time is obtained from the following equation:

$$u = \frac{dV/dt}{I(dR/d\ell)}, \text{ where}$$

u = velocity

V = voltage

t = time

I = current

dR/dℓ = resistance/unit length

It can be seen that the velocity depends on the slope of the trace and that a constant slope equates to a constant velocity. The basic flow of data is shown in Fig. 2. The resistive wire voltage streak is recorded on Polaroid film with calibration voltage levels and time markers on this same film. The data are then digitized with the aid of a comparator capable of reading both X and Y values to very fine increments. Any reading error is reduced by use of computer program filters. This program has made it possible to rapidly compute and produce results. The program first compensates for scope non-linearities, then filters the raw data to minimize film reading error and finally the computer plots the velocity with respect to time.

Work is still in progress to improve accuracy and especially to establish repeatable results. One very recent study was made to investigate the final computed results or deviations versus the number of significant digits in the original data. The basic equation was a plot of $x = y^2$

whereas the derivative is plotted based on increments of 0.1 mm for this test. Plots of simulated accuracies from one decimal place to five were made. As was suspected, the one-decimal data contained excessive error in the derivative plot with each added digit improving the results. A close comparison of all the plots indicated that a three-decimal system would supply acceptable data.

DISCUSSION

This discussion will not attempt to explain those varying velocities which are characteristic of the MDF and ALSC used in the studies. At this time it is more important to present the technique and show a few typical test results for the purpose of illustrating the complete program.

Fig. 3 illustrates a typical MDF test unit. The MDF is manufactured by Ensign-Bickford (0.21 g/m with lead sheath). The side view shows the manner of attachment of the MDF to the holding fixture. An electrically conductive glue (volume resistivity of 2×10^{-4} ohm-cm) made by Emergon and Cuming, Inc., is used to bond the resistive wire to the aluminum block as shown. This appears to give a cleaner looking trace at the beginning of the break as compared to mechanically pinning the wire to the block. Although the breakdown quality of wire insulation is desirable in producing a continuous voltage streak it presents problems in installation. Much care has been exercised to avoid unwanted shorting of the wire to the block during assembly and prior to testing.

The Moleculoy wire resistive linearity is included in Table I. A four terminal system to measure resistance/unit length was required since the tolerances must be better than 0.1% by demand. Other methods to measure the linearity failed to give better than 1% results. Two razor blades firmly spaced on a block allowed consistent increments to be measured along the wire.

Four MDF shots of the 0.21 g/m loading are illustrated in Figs. 4 through 13 to show velocity plots after the raw data are filtered and linearized by the computer. This linearization means that, immediately prior to a shot, calibration voltages and time markers are put on the same film as the shot streak. These calibration points are then incorporated as part of the shot data computer input to create a set of defined blocks of linearity. This linearity may be as fine, proportionally, as the number of calibration points.

Shot No. 1876-02-06-01 used a current supplied from a bank of batteries to investigate the possibility of a transistorized constant current contributing to the rising and falling velocity. The velocity pattern is observed on this shot as well as those using the transistor circuit. Table II compares the results using these two different systems. These early shots did not compensate for scope non-linearity. At that time it did not appear necessary to correct for non-linearities. Also a discrepancy in the beginning of the trace invariably appears as a bump due to the sudden change in slope. There has been no attempt to understand the total cause of this bump but it is probably an artifact of the

data treatment method. More recently, the first datum point was read past the sudden change in slope as illustrated in the RDX/ALSC (0.53 g/m) Figs. 14 through 19. All velocities agree quite closely as compared to the MDF shots. Some improvement was attributed to the use of the voltage and time calibrations.

COMMENTS

Further efforts in this project will measure absolute detonation velocities and attempt to explain the irregular detonations as well as evaluate the attenuation of shock waves. It appears that the measured changing velocities are not associated with instrumentation but are a characteristic of the MDF. The investigation of the current source noise level by substituting batteries and limiting resistor further substantiated this postulation.

Investigation of the software in the computer program has revealed the need for sufficient decimal places in the raw data. The trial run of a known curve with varying decimal place accuracy has established a guide of 3-decimal or better for best results. Figs. 20 and 21 illustrate the results of a 3-decimal system.

Future efforts will also investigate the current source frequency response and resolve specifications on an acceptable source.

Fig. 1. Results of a Resistive Wire Improperly Placed Along MDF Column. (There was approximately 1.5 mm gap from lead sheath to wire)

- (1) Voltage Versus Time
- (2) Velocity Versus Time

Fig. 2. Resistive Wire Technique Schematic Diagram

Fig. 3. Typical Arrangement for Measuring MDF Linear Detonation Velocity

Table I. Moleculoy Wire Calibration
(4-Terminal Setup)

<u>Position</u>	<u>Voltage (mV)</u>	<u>Current (ma)</u>	<u>Calculated Resistance (ohms)</u>
1	14.45	1.94	7.448
2	14.46		7.454
3	14.46		7.454
4	14.48		7.461
5	14.47		7.459
6	14.46		7.454
7	14.47		7.459
8	14.47		7.459
9	14.46		7.454
10	14.47		7.459
11	14.46		7.454
12	14.45		7.448
13	14.45		7.448
14	14.45		7.448
15	14.45		7.448
16	14.47		7.459
17	14.47		7.459
18	14.46		7.454
19	14.46		7.454

$R_{avg} = 7.454 \Omega$, Deviation: $+ 0.09\%$, $- 0.08\%$.

Table II

<u>Shot No.</u>	<u>Average Velocity (km/s)</u>	<u>Peak Fluctuations (+/- %)</u>	<u>Correct Supply</u>
1876-02-06-1	7.25	9.7/12.8	Battery
1075-12-10-2	7.13	10.2/11.6	Constant Current
1075-12-10-1	6.97	13.2/9.6	Constant Current
1075-12-11-2	6.86	22.0/15.0	Constant Current
1075-12-11-4	6.77	14.2/30.0	Constant Current

Fig. 4. Straight HNS ALSC - Ambient Shot (I3AST-1)

Fig. 5. Shot No. 1876-02-06-1 Detonation Velocity PETN MDF (battery current supply)

Fig. 6. Batch No. 1075-12-10-2 Voltage History PETN MDF

Fig. 7. Shot No. 1075-12-10-2 Detonation Velocity PETN MDF

Fig. 8. Shot No. 1075-12-10-1 Voltage History PETN MDF

Fig. 9. Shot No. 1075-12-10-1 Detonation Velocity PETN MDF

Fig. 10. Shot No. 1075-12-11-2 Voltage History PETN MDF

Fig. 11. Shot No. 1075-12-11-2 Detonation Velocity PETN MDF

Fig. 12. Shot No. 1075-12-11-4 Voltage History PETN MDF.

Fig. 13. Shot No. 1075-12-11-4 Detonation Velocity PETN MDF

Fig. 14. Shot No. 1076-01-09-1A Voltage History RDX ALSC (Groove)

Fig. 15. Shot No. 1076-01-09-1A Detonation Velocity RDX ALSC (Groove)

Fig. 16. Shot No. 1076-01-09-2A Voltage History RDX ALSC (Groove)

Fig. 17. Shot No. 1076-01-09-2A Detonation Velocity RDX ALSC (Groove)

Fig. 18. Shot No. 1076-01-09-3A Voltage History RDX ALSC (Groove)

Fig. 19. Shot No. 1076-01-09-3A Detonation Velocity RDX ALSC (Groove)

Fig. 20. $Y = \text{SQRT}(X)$ With Decimal Accuracy 3

Fig. 21. $Y = \text{SQRT}(X)$ With Decimal Accuracy 3