VISAR Measurements of Velocities in Explosive Valves

R. Ng

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VISAR MEASUREMENTS OF VELOCITIES IN EXPLOSIVE VALVES

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ABSTRACT

A Velocity Interferometer System for Any Reflector (VISAR) was used to measure the velocity histories of plungers in explosively actuated valves. These experiments proved the capability of measuring valve interactions by means of a VISAR and provided empirical information and data for analytical studies.
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VISAR MEASUREMENTS OF VELOCITIES IN EXPLOSIVE VALVES

Introduction

In the past, explosively actuated valves have been designed on an empirical basis because the interactions and forces involved in a valve operation were not fully understood. However, this design approach was satisfactory in that the size and design of the valves permitted a more than adequate amount of explosive to be used to ensure proper operation of the valves. That is, the driving force available from the extra explosive provided a "design cushion" that helped compensate for variations in the unknown parameters.

Eventually, however, systems were proposed which required valves of smaller size and different design that could not tolerate excessive amounts of explosives. Also, due mainly to the smaller size, any variation became more critical. Therefore, it became necessary to understand the interaction and forces present in the operation of an explosive valve.

The first analytical effort was MAVIS, a computer program which modelled all the interactions present in a valve and calculated the forces and velocities involved. Comparison of the MAVIS calculations with available experimental data has demonstrated the usefulness of this computer program for analytical studies.

The data used to confirm MAVIS were some preliminary data acquired in 1968 on a valve design of that era. A part of those experiments had been performed on actual valve hardware. However, modifications were required on those valves in order to record the data. These modifications were such that they also affected the actual operation of the valves. Therefore, even though data were available for comparison with MAVIS, they were (1) related to the earlier, larger valves, and (2) obtained from modified hardware. No data were available on the present "mini-valves" in their actual hardware configuration. Data were therefore needed which would supply both basic information on the operation of the mini-valve as well as the needed data for correlation with MAVIS.
This report describes a technique based upon the Velocity Interferometer System for Any Reflector (VISAR) with which the plunger velocities were measured in actual unperturbed hardware. The monitoring of the plunger velocity would give a direct indication of the forces involved at each valve interaction since the forces influence the velocity of the plunger. The velocity results of these experiments at various configurations of the mini-valve are also presented.

Experimental Techniques

VISAR, which is commonly used to measure the velocity histories of shock waves in materials, detects any motion of a given surface by means of a laser beam and converts the detected motion into velocity measurements. The advantages of a VISAR over other measuring techniques are (1) only a small target area is required, and (2) there is minimal perturbation to the actual hardware. Both of these characteristics are critical to the measurement of plunger velocities.

As shown in Figure 1, the laser beam of the VISAR is reflected (diffusely) from the surface of the specimen, collected, and passed through a polarizer. Any surface motion causes a Doppler shift in the frequency of this light. The beam is then split, with part of it going into the beam intensity monitor (BIM) that records the light intensity for use in normalizing the data signals. The remaining light goes into beam splitter #2 (BS2). At this point the data beam is again split into two parts. One part goes to a mirror M2 and back again. The other portion first goes to an optical delay leg composed of (in this case) two lenses and mirrors and then rejoins the first leg. (Most other laser systems use etalon rods for their delay leg rather than the two lenses. The two lenses, as well as long rods of etalon, result in the sensitive system needed to detect the lower-than-shock-wave velocities experienced in the valves.) The recombined beam is sent through a polarized beam splitter (BS3) which splits the beam into two signals, one into each of two photomultiplier (PM) tubes which record the data fringes. A data reduction computer program converts these fringes into velocity histories.

The feasibility of using a VISAR to measure the plunger velocities of mini-valves was demonstrated with a system located at Sandia Laboratories Albuquerque (Division 2513). The experiments documented in this report were performed using a VISAR located at Lawrence Livermore Laboratory. Actual valves were used for both phases of the experimentation. As shown in Figure 2, a typical valve consists of an explosive actuator, disc, plunger, tube(s), and the housing. As the explosive burns a pressure builds up in the actuator chamber until it is sufficiently large to shear the
Figure 1. Schematic of a VISAR

disc. The pressure then accelerates the plunger down the bore of the housing and shears the tube(s). The plunger is finally stopped as it wedges itself into a tapered section of the valve housing. This sequence is shown pictorially in Figure 3.

For the laser beam to be incident upon the face of the plunger, a hole was drilled through the housing into the end of the bore. This hole was the only modification made to the valves and did not perturb or influence the operation of the valves in any manner.

Experimental Results

A description of the 20 valves tested (in the order tested) and the results of the tests are listed in Table I. The "Housing S/N" is the serial number associated with the housing used. The next three columns describe the combination of actuator, disc, and tubes in each valve. The "SBASI" actuator is a modified version which contains 160 mg of Zr-KClO₄ powder. The "3004" powder is 100 mg of TiH₂-KClO₄, which at that time was the pyrotechnic to be used on the MC3004 actuator. The "Results" column lists a measured stroke as well as a VISAR integrated velocity stroke value.
Figure 2. Typical Valve Design
Figure 3. Explosive Valve Operational Sequence
**TABLE 1**
DESCRIPTION OF TEST VALVES

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Housing S/N</th>
<th>Actuator*</th>
<th>Disc Thickness (mm)</th>
<th>No. of Tubes</th>
<th>Measured Stroke (mm)</th>
<th>VISAR Stroke (mm)</th>
<th>Comments</th>
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<tr>
<td>1</td>
<td>1</td>
<td>SBASI</td>
<td></td>
<td></td>
<td>8.38</td>
<td>(8.14 plus)</td>
<td>Still moving</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>SBASI</td>
<td></td>
<td></td>
<td>14.48</td>
<td>(13.18 plus)</td>
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<tr>
<td>3</td>
<td>30</td>
<td>SBASI</td>
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<td></td>
<td>12.62</td>
<td>No Data</td>
<td>Premature trigger</td>
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<tr>
<td>4</td>
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<td></td>
<td>13.84</td>
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<td>No trigger signal</td>
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<td>5</td>
<td>42</td>
<td>SBASI</td>
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<td>9.20</td>
<td>9.06</td>
<td></td>
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<tr>
<td>6</td>
<td>38</td>
<td>3004</td>
<td></td>
<td></td>
<td>11.50</td>
<td>No Data</td>
<td>Premature trigger</td>
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<tr>
<td>7</td>
<td>21</td>
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<td>8</td>
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<td>3004</td>
<td>0.356</td>
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<td>10.80</td>
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<tr>
<td>10</td>
<td>49</td>
<td>SBASI</td>
<td></td>
<td></td>
<td>13.30</td>
<td>(11.72 plus)</td>
<td>Still moving</td>
</tr>
<tr>
<td>11</td>
<td>35</td>
<td>3004</td>
<td></td>
<td>1</td>
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<td>12</td>
<td>45</td>
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<tr>
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<tr>
<td>14</td>
<td>26</td>
<td>3004</td>
<td></td>
<td>2</td>
<td>6.12</td>
<td>(4.72 plus)</td>
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<tr>
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<td>No Data</td>
<td>Premature trigger</td>
</tr>
<tr>
<td>16</td>
<td>47</td>
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<td>2</td>
<td>5.30</td>
<td>No Data</td>
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<td>17</td>
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<td>7.32</td>
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<tr>
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<td>2</td>
<td>6.37</td>
<td>(3.63 plus)</td>
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<tr>
<td>19</td>
<td>32</td>
<td>SBASI</td>
<td>0.127</td>
<td>2</td>
<td>6.07</td>
<td>6.20</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>29</td>
<td>SBASI</td>
<td>0.356</td>
<td>2</td>
<td>6.12</td>
<td>6.03</td>
<td></td>
</tr>
</tbody>
</table>

\*SBASI = 160 mg Zr \cdot KClO$_4$
3004 = 100 mg TH$_2$ \cdot KClO$_4$
Comparison of the measured strokes with the VISAR strokes (for the cases in which the plunger has stopped) would indirectly confirm the accuracy of the VISAR measurements.

As shown, of the 20 valves functioned in this test series, 14 yielded data. Four of the six yielded no data due to problems with a triggering circuit used for the oscilloscopes. (This electronics problem was solved during the testing.) One set of data was lost due to a misalignment of the laser beam, and the other "no data" test was due to the misplacement of the oscilloscope traces after the data had been recorded.

Two oscilloscopes of different sweep rates were monitoring each of the two data PM tubes. The signal from the beam intensity monitor went into one channel of these dual-beam oscilloscopes. Time marks and baselines are automatically placed on each picture. Figure 4 shows the two data traces from the PM tubes measured at the same sweep rate. The sensitivity of this particular set-up is 0.0573 mm/μsec per fringe. From top to bottom, each picture contains (1) the time marks, (2) a baseline, (3) the data fringes, and (4) the beam intensity. The curves were digitized and used in the data reduction computer program which calculates a velocity history. The derived velocity histories for the 14 tests are shown as Figures 5 to 18. Also plotted on each figure is the displacement history of the plunger, derived by an integration of the velocity curve.

Figures 5 to 18 are not in the order of testing. Instead, they have been grouped into similar categories for ease of comparison. For example, Figures 5 to 12 are the data for the SBASI actuators, while Figures 13 to 17 are those for the MC3004. Within each actuator grouping are first the data for no tubes and then for 1 and 2 tubes. The data plots indicate that (1) the plunger's velocity history can definitely be measured, and (2) the VISAR data is accurate and consistent.

Observations on Valve Operation

The following observations are made based upon this series of velocity data. The comments are not in any order of importance.

a. The plungers can crack if stressed too highly. Referring to Figures 5, 6, and 7, note that at a displacement of approximately 8 mm the velocity curves of Figures 6 and 7 level out rather than decrease uniformly as in Figure 5. This leveling out indicates that the drag force was no longer present. Disassembly of the valves confirmed the absence of the drag force, as the plunger was discovered to have cracked. These cracked

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plungers would in no way be present in an actual valve operation because the presence of tubes (absent in these cases) would prevent the plunger from traveling that far into the taper.

b. The SBASI-driven plungers have a higher acceleration than those driven by the 3004 powder. This conclusion was expected, since the SBASI powder burns faster than the 3004.

c. The SBASI-driven plunger has a higher peak velocity due mainly to the faster burning powder. A greater peak pressure would also produce the same result.

d. The presence of a disc may affect the operation of a valve. This observation cannot be confirmed by the 14 plots, as the change in disc thickness did not create any noticeable difference in the velocity traces.

However, a review of the measured strokes listed in Table I tends to reveal that an optimum disc thickness exists for maximum stroke. For example, (for all other conditions being the same) shots 7, 8, and 17 have disc thicknesses of 0.127, 0.254, and 0.762 mm respectively. The measured strokes were 7.47, 8.66, and 7.20 mm. Similarly, shots 19, 18, 12, and 20 with disc thicknesses of 0.127, 0.254, 0.254, and 0.356 mm had strokes of 6.07, 6.37, 6.50, and 6.12 mm respectively. Although these results are not conclusive, the trend indicated is as expected.

e. In the present design, the plunger impacts the tube(s) at velocities between 75 and 100 m/s. With one tube present the plunger continues to accelerate after impact (Figure 16); with two tubes, the plunger decelerates as it cuts them (e.g., Figure 12). The velocity at the time of impact into the tapered region is about 75 m/s (Figure 12).

Conclusions

It is now known that a VISAR can be used to accurately measure the velocities of plungers in explosive valves. This technique can be used on the actual valves without perturbing or influencing any part of the functional operation. Thus, VISAR data can provide the empirical information necessary for future design and analytical studies.
Figure 4. VISAR Fringe Data (Shot No. 17)
Figure 5. Shot No. 1
Figure 6. Shot No. 2
Figure 7. Shot No. 10
Figure 8. Shot No. 5
Figure 9. Shot No. 19
Figure 10. Shot No. 12
Figure 11. Shot No. 18
Figure 12. Shot No. 20
Figure 13. Shot No. 7
Figure 14. Shot No. 8
Figure 15. Shot No. 17
Figure 16. Shot No. 11
Figure 17. Shot No. 14
Figure 18. Shot No. 13
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