LA-UR-96- 3875

CONF-9610245--1

TITLE: CHANGES TO THE LANL GAS-DRIVEN TWO -STAGE GUN: MAGNETIC GAUGE INSTRUMENTATION, ETC.

AUTHOR(S): Stephen A. Sheffield, Richard L. Gustavsen, and A. Richard Martinez, Robert R. Alcon
LANL, Los Alamos, NM 87545

SUBMITTED TO: 47th Aeroballistic Range Association Meeting

Changes to the LANL Gas-Driven Two-Stage Gun: Magnetic Gauge Instrumentation, etc.†

S. A. Sheffield, R. L. Gustavsen, A. R. Martinez and R. R. Alcon
Los Alamos National Laboratory
Group DX-1, MS P952
Los Alamos, NM 87545

Abstract

Our gas-driven two-stage gun was designed and built to do initiation studies on insensitive high explosives as well as other equation of state experiments on inert materials. Our preferred method of measuring initiation phenomena involves the use of magnetic particle velocity gauges. In order to accommodate this type of gauging in our two-stage gun, projectile velocity was sacrificed in favor of a larger experimental target area (obtained by using a 50 mm diameter launch tube). We have used magnetic gauging on our 72-mm bore diameter single-stage gun for over 15 years and it has proven a very effective technique to monitor reactive shock wave evolution. This technique has now been adapted to our gas-driven two-stage gun. We describe the method used, as well as some of the difficulties that arose while installing this technique. Several magnetic gauge experiments have been completed on plastic materials. Waveforms obtained in one experiment are given, along with the Hugoniot information that was obtained. This new technique is now working quite well, as is evidenced by the data. To our knowledge, this is the first time magnetic gauging has been used on a two-stage gun. We have also made changes to the burst diaphragm package in the transition section to ensure that the petals do not break off during the opening process and to increase the burst pressure. This will also be discussed briefly.

Introduction

The two-stage gun is a compressed-helium driven, two-stage light gas gun (based on a design from Ernst Mach Institute[1]) designed to perform shock initiation studies on insensitive high explosives (see Fig. 1). It has a 100-mm diameter by 7.6-m long pump tube and a 50-mm diameter by 7.6-m long launch tube. The relatively large launch tube diameter of 50 mm was chosen to provide an experimental area large enough to allow one-dimensional multiple magnetic gauge experiments to be done. A gas breech, capable of operating at 15,000 psi, is the driver for the pump piston. Three large hydraulic clamps are used to clamp the breech to the pump tube, the pump tube to the transition section, and the transition section to the launch tube. Helium is used as the driver gas for both the launch projectile and the pump piston. The target chamber (similar to that on our single-stage gun) provides the needed room for the electro-magnet which produces the magnetic

† Work performed under the auspices of the U. S. Department of Energy.

field. Projectile velocities in excess of 3 km/s have been achieved with the breech charged to only 8000 psi. This gun design and performance has been described previously.[2,3,4]

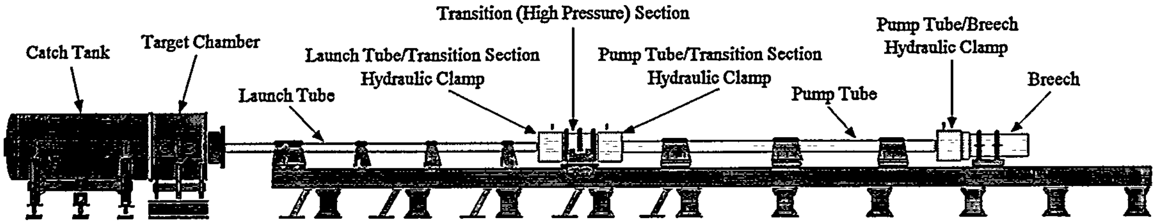

Figure 1. Schematic of the LANL gas-driven two-stage gun.

We have used magnetic particle velocity gauging for 15 years to measure the details of initiation in solid and liquid explosives initiated by projectile impact in a single-stage gun. This technique allows us to make up to 10 in-situ particle velocity measurements in a single experiment so that the shape of the reactive initiation shock can be monitored as it grows from the input shock to a detonation. With this type of experimental information available, functions can be developed to describe the global reaction process occurring. In this paper we will briefly describe this technique and how it is used. We will also describe how we have demonstrated this technique works on our two-stage gun. Although we have not yet done experiments on explosive materials, experiments on plastics have been completed that give us confidence it will work with explosives. Data from one experiment will be presented.

In the process of shooting the gun for the magnetic gauging experiments, we changed the burst diaphragm package design. Diaphragm petals had been tearing on some of the diaphragms and there was concern they might break off and go down the launch tube. In addition we had not been able to get as high diaphragm burst pressures as we desired so this was another reason for the change. Our experience with the new diaphragms and a description of the changes will be briefly discussed.

Magnetic Gauging Technique

Magnetic gauging was first described by Dremin and Pokhil[5] in 1960. They used a loop gauge to measure particle velocity in explosively driven shock experiments. Because of this a magnetic gauge has sometimes been called a *Dremin loop*. Although a number of others tried this technique, it did not see serious use until the technique was developed further and on gas guns at Physics International and Washington State University, largely under the direction of Fowles and coworkers[6,7] during the 1970's.

Principle of Operation -- The gauge functions based on some quite simple physics principles. When a conductor in a closed loop moves in a magnetic field, a voltage is induced in the circuit because part of the loop cuts magnetic field lines as it moves. Output voltage depends on the magnetic field strength, the length of the conductor which is cutting the field lines, and the velocity it is moving. This can be written as

$$E = Blv$$

where E is the voltage, B is the magnetic field strength, l is the length of the conductor cutting the field lines, and v is conductor velocity. In the experiments we measure B and l before the experiment and E as a function of time during the experiment. With this information we can obtain the conductor velocity v as a function of time. If one assumes that the conductor moves with the material it is embedded in, then v is the mass or particle velocity of the sample material at that particular Lagrangian position.

In solid samples we have found that the gauges accurately measure the particle velocity. In liquid samples, there are two-dimensional affects that develop as the shock interacts with the gauge membrane and errors up to 10 % in particle velocity can result depending on the impedance mismatch between the liquid and the gauge membrane. We are in the process of studying this effect in liquids as the present time.[8]

Gauge Design -- Magnetic gauge technique development work started at Los Alamos by Vorthman and Wackerle in about 1980. They began measuring the particle velocity waveforms during the shock-to-detonation transition in explosives.[9] The LANL technique involves the use of a thin gauge membrane that is embedded in the sample material so that in-situ particle velocity measurements are made. Vorthman developed the gauge package which is a sandwich of several materials. It is made using a 25 mm thick FEP Teflon base and gluing a 5 μm thick piece of aluminum foil to it. The foil is then photo-etched to obtain the rather intricate gauge pattern shown in Fig. 2. Finally, another piece of FEP Teflon 25 μm thick is glued over the top of the etched gauge and base FEP Teflon. The completed gauge membrane is approximately 60 μm thick, indicating that both glue bonds are very thin. The aluminum conductors on the gauge end of the pattern are 0.1 mm wide, so the gauges have resistances on the order of a few ohms. The details of two different gauge patterns are shown in Figs. 2 and 3.

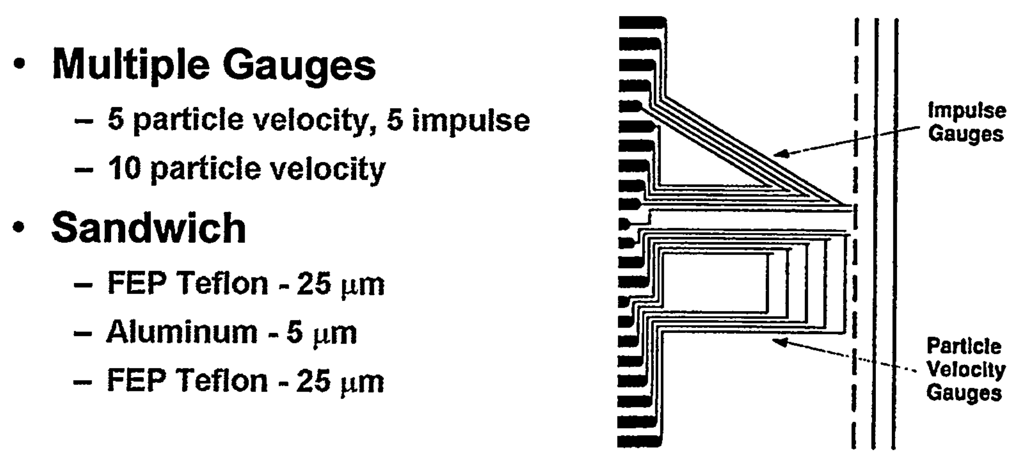

Figure 2. Magnetic particle velocity gauge with both impulse and particle velocity gauges, one of each gauge type at each position. Other gauge patterns are also used (see Fig. 3). Gauge patterns are made by photo-etching a 5 μm thick aluminum layer using precise masks to define the pattern.

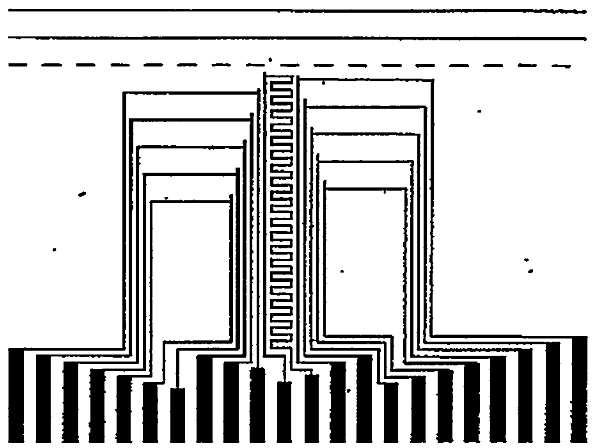

Figure 3. Details of the gauge pattern for a 10 gauge membrane with a shock tracker to track the shock velocity. Gauges are staggered so that 10 different positions can be measured in one experiment.

Target Design -- In solid targets the sample is machined with a bottom and top designed so the gauge membrane can be glued in at an angle as shown in Fig. 4. Generally the angle is 30 degrees so that when the gauges is in place, they are either 1/2 mm apart on the sample axis for a 10 staggered gauge membrane (as shown in Fig. 3) or 1 mm apart when there is 5 gauges (as shown in Fig. 2). When the membrane is installed in this fashion, the gauges do not shadow each other. Typically, in the single-stage gun experiments, the samples are 50 mm diameter by about 25 mm thick. Because the two-stage experimental area is smaller by about 20%, the sample size and gauge patterns have been reduced to about 80% the normal size.

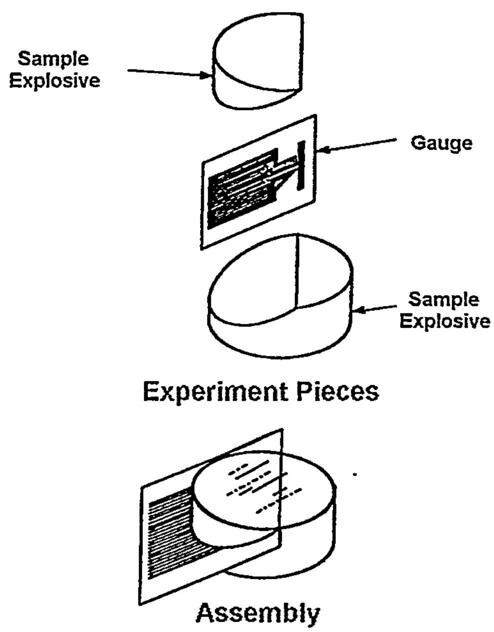

Figure 4. Schematic of the sample with the gauge. Angle is usually 30 degrees. The assembly top is lightly machined after the gluing operation to make sure the top is flat.

The target assembly is placed on a target plate with the gauge end positions carefully noted. The target plate is placed in the target chamber so that it is between the pole pieces of the electromagnet and the gauge ends are perpendicular to the field lines as shown in Fig. 5. When the gauge ends are perpendicular to the field lines, the gauge leads are automatically situated so they don't cut the field lines as they move. Otherwise the lead movement would add to the measured voltage signal, causing it to be in error.

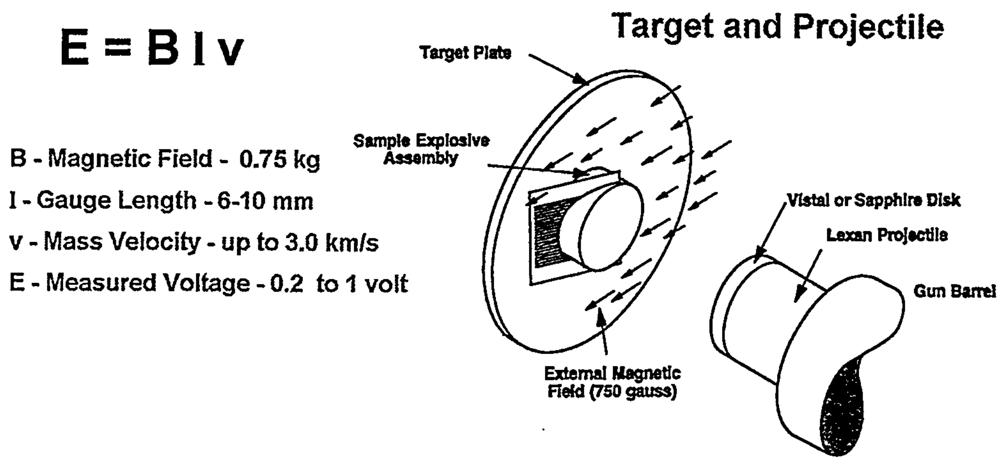

Figure 5. Schematic of the sample/target plate assembly in the magnetic field with the projectile that impacts it. The target plate is carefully positioned so that the gauge ends are perpendicular to the field lines and the gauge leads do not cut the lines as they move. Typical values for the magnetic field, gauge length, and voltage are shown.

Magnet -- The magnetic field is developed by a large electro-magnet that is turned on just before the experiment. The single-stage gun has an electro-magnet with large diameter coil wires so it can operate at high current. It is normally operated at about 290 amperes producing a field of about 750 gauss in the region of the gauges. The field is mapped before each experiment using a plate with 25 holes that the calibration probe will fit into. The holes are on 1.0 in centers in both the right and left and up and down directions with the center hole on the gun barrel axis. A reading is taken at each hole position and then the field for the experiment is determined from this mapping.

Figure 6 shows the field for +/- 0.6 inches above and below and on either side of the gun barrel axis for a typical experiment. In this region the field varies from about 752 to 759 gauss, about 1 percent. This is about as good as can be expected with this type of magnet with the pole pieces separated by more than 10 inches.

A 10-in diameter aluminum tube or shroud with a 1/2-in thick wall is centered between the magnet pole pieces and around the target. This is used to protect the magnet from the initiating explosive and the projectile/target fragments. It also directs the shot debris into the catch tank. When an explosive initiates inside the tube, the aluminum wall deforms somewhat and after several experiments it is discarded. It does a nice job of protecting the magnet.

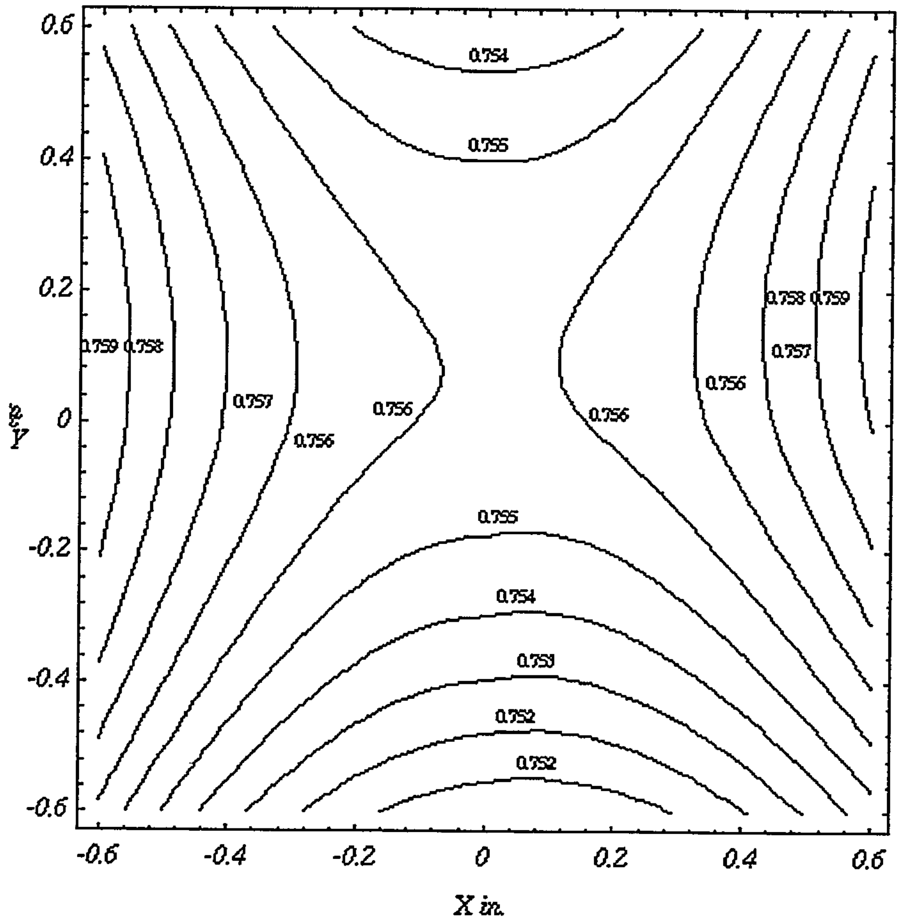

Figure 6. Contour plots of field calibration data from a typical single-stage magnetic gauge experiment. Only the region where the active gauge ends are located is shown in this plot. The field varies from 752 to 759 gauss in this region, indicating that this leads to errors of about one percent in the measured data.

Over the years this technique has proven extremely useful in monitoring the progress of shock-induced reactions, the shape of wave structures, and in determining Hugoniot data. Up to 11 gauges at different Lagrangian positions have been incorporated into a single experiment. With this number of gauge measurements, it is apparent that evolutionary processes can be tracked, leading to a more complete understanding of the shock processes occurring in a given experiment. An example of data obtained in an explosive experiment is shown in Fig. 7. This experiment had a gauge membrane with 10 different gauge elements. The wave growth both at the front and behind the front is clearly visible in the data. From these waveforms global reaction rate information can be developed for use in reactive wave code calculations.

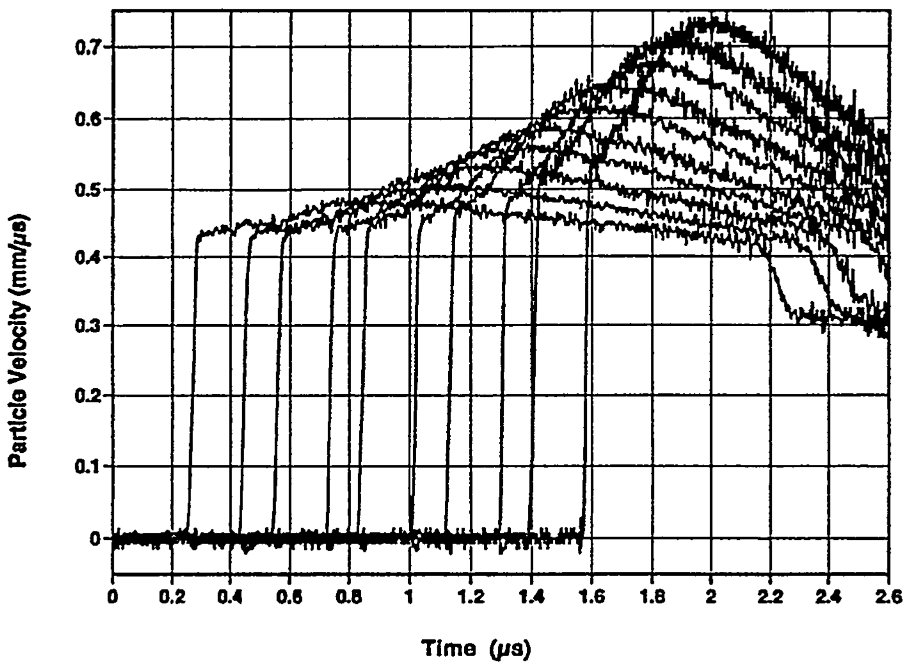

Figure 7. Particle velocity waveforms measured during an initiation experiment on the single-stage gun. There were 10 elements in the gauge package so there are measurements at 10 different Lagrangian positions in the plot. The reacting wave had traveled about 5 mm into the explosive by the time the last gauge started recording. The waveforms show growth at the front of the wave as well as considerable growth behind the wave in the form of a reactive hump.

Implementation of Magnetic Gauging on the Two-Stage Gun

Since the two-stage gun was built for the purpose of measuring the initiation properties of insensitive high explosives, it was desirable to implement a magnetic gauge capability. Rather than use the same magnet in both guns and risk the possibility of competing for the use of the system, we decided to build another magnet system from excess parts that were available. However, the basic design of the electro-magnet was quite different because of these parts. The single-stage gun electro-magnet is basically a high current, small number of coil turns magnet. The two-stage gun electro-magnet is a lower current, large number of coil turns magnet. The pole pieces are smaller diameter but the coils are larger in diameter. Also the power supply available for the two-stage electro-magnet would only put out about 50 amps. A picture of the target chamber with the magnet installed is shown in Fig. 8.

A magnetic field of over 2000 gauss can be developed by the two-stage electro-magnet in the area of the target if a high current (25 amps) is used. However, care must be taken to make sure the magnet does not heat up substantially while the current is on at this level. Also when a conductor moves through a field of 2000 gauss at a relatively high velocity, voltages of several volts can be developed in the gauge circuits and gauge-to-gauge interference becomes a concern. For these reasons the field is generally limited to about 1200 gauss or less in the shots.

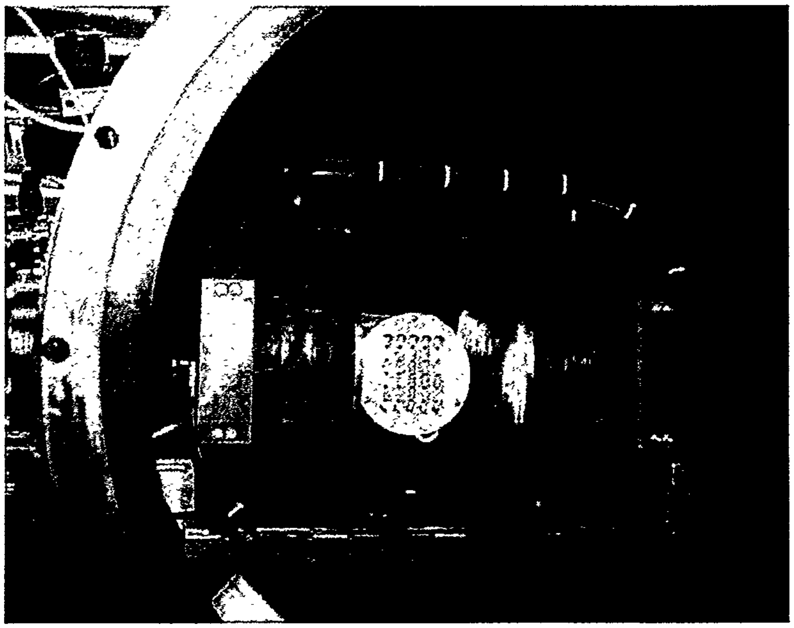

Figure 8. Picture of the target chamber with the electro-magnet system installed. There are three coils on each side of the magnet. In the center is the plate with 25 holes (and slots to orient the calibration probe) used for mapping the magnetic field. The center hole of the plate is on the axis of the gun barrel. The target chamber is about 1 m diameter.

The magnetic field was not as uniform in the two-stage gun as that in the single-stage gun because of several design differences. At the end of the single-stage gun barrel is a 3 ft section made from stainless steel rather than 4340 steel. This eliminates the distortion caused by having a magnetizable material in the magnetic field. On the two-stage gun the barrel is all 4340 steel so distortion of the field was expected. In addition, because the two-stage gun projectiles are smaller, the end of the barrel is several inches closer to the center of the magnet. There are also several differences in the design of the magnet pole pieces. To get some idea of the magnitude of this effect, we mapped the field as a function of distance from the center of the magnet and out toward the back. The maximum field occurred about 2 inches back from the center. Although this was not the best situation, the first shots were fired with the sample located at this position.

A mapping was made of the field at the 2-in off-center position for Shot 2s-11. The mapping on the two-stage gun is done in the same way as the single-stage gun except the probe holes are on 0.875 in centers rather than 1.0-in centers. A contour map for this shot is shown in Fig. 9. From the figure it is apparent that for this shot the field was constant to about 2 percent in the region of the gauges. This was considered to be quite good but we hoped that some changes might improve this to as good as the single-stage gun. It is also apparent that the magnet position was about 0.3 in to high with respect to the axis of the gun barrel. We made some design changes to try to correct the off-center position problem.

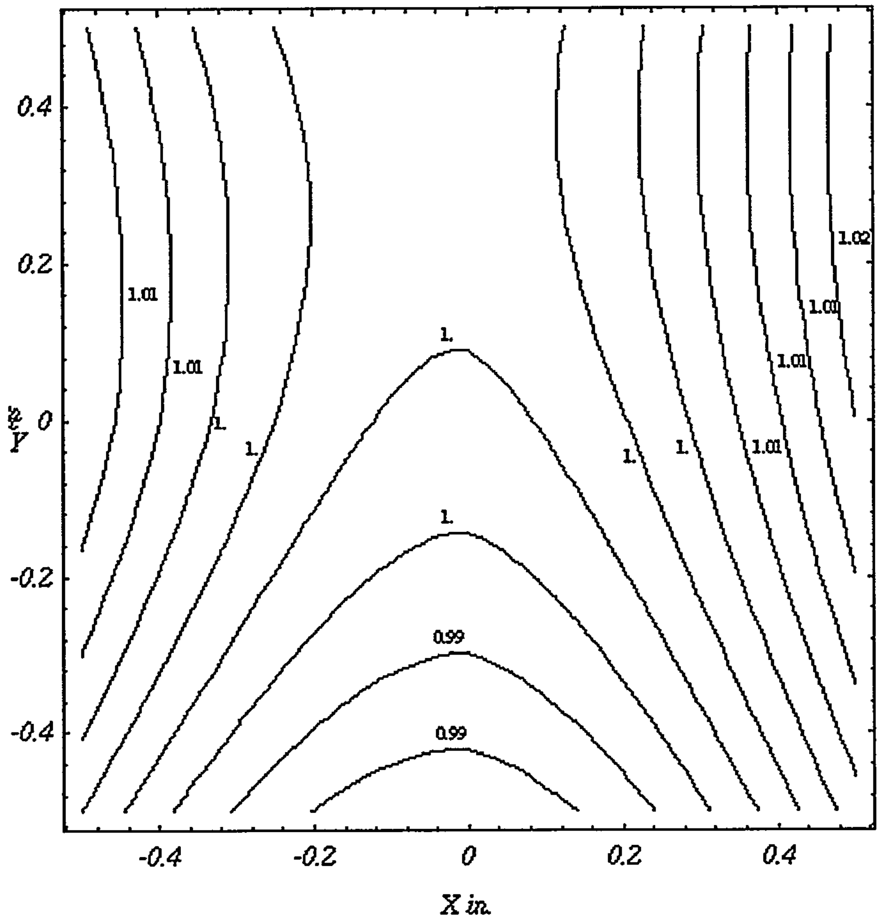

Figure 9. Contour plots of field calibration data from the two-stage gun Shot 2s-11. Only the region where the active gauge ends are located is shown in this plot. The field varies from 750 to 760 gauss in this region, indicating that this leads to errors of about one percent in the measured data.

A 4-in long stainless steel barrel extension was built and installed to eliminate the magnetizable material in the near region of the magnetic field. It was possible to attach this to the end of the barrel because there are several tapped holes in the barrel end face which are normally used to attach the projectile velocity measuring system to it. The barrel was repositioned to accommodate the extension. After this change a new mapping of the magnetic field was made and the resulting contours are shown in Fig. 10. This figure clearly shows that the uniformity of the field has been increased considerably and that the error due to the field nonuniformity is now less than one percent. This is as good as the single-stage gun system which was what we were hoping for. The magnet is still positioned about 0.2 in high but it does not appear that this will make a great deal of difference.

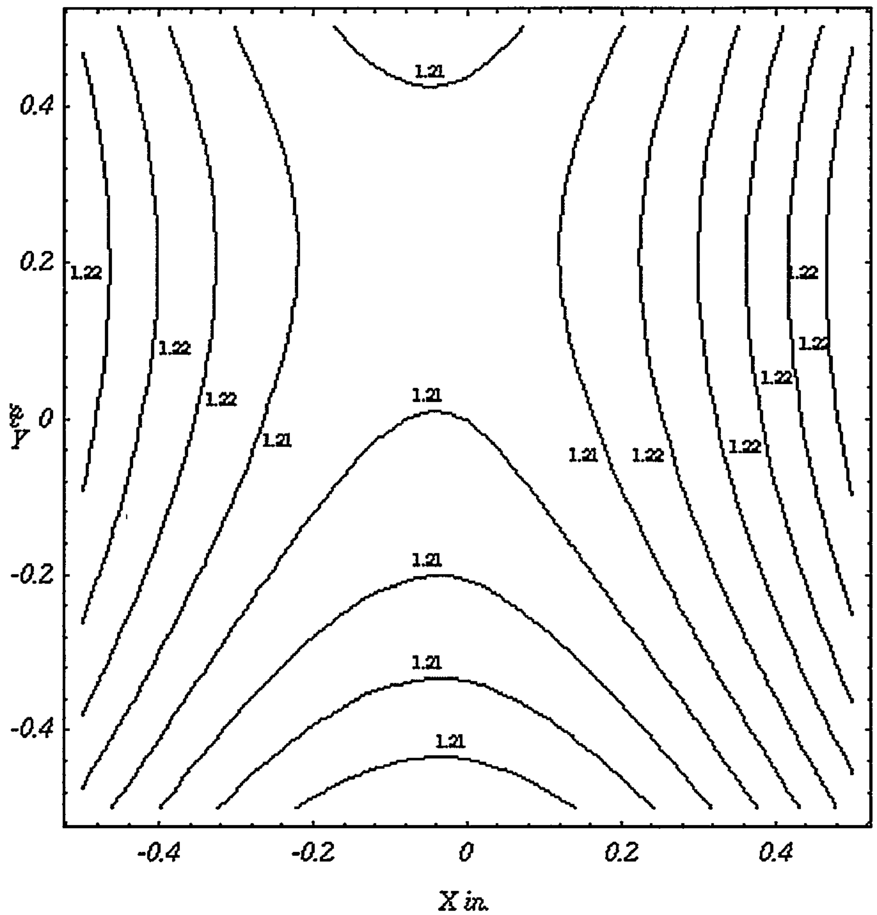

Figure 10. Contour plots of field calibration data from the two-stage gun after modifications to gun barrel. Measurements were taken on the centerline of the magnet. The field varies from 1210 to 1220 gauss, indicating that the errors due to the magnetic field measurement are less than 1 percent.

Because the launch tube on the two-stage gun is only 50 mm diameter (compared to 72 mm diameter for the single-stage gun), it was necessary to cut down the experimental area where magnetic gauging could be done. By carefully building the targets and impactors, we felt we could cut the size of everything down to 80 percent that of the single-stage gun. So the maximum length of the gauge ends was decreased from 10 mm to 8 mm and the sample size was decreased from 50 mm to 43 mm. Also the calibration plate hole spacing was decreased from 1.0 in to 0.875 in and the area shown in the contour plots of Figs. 9 and 10 was decreased from +/- 0.6 in to +/- 0.5 in.

Magnetic Gauge Experiments on the Two-Stage gun

Several multiple magnetic gauge experiments have been conducted on the two-stage gun with varying degrees of success because we were working the bugs out of the system. These experiments had either Kel-F or polymethyl methacrylate (PMMA) targets that were impacted by Lexan projectiles. The targets were as shown in Fig. 4 with 10 gauge elements as shown in Fig. 3 The finished target was a cylinder 43 mm diameter by 23 mm high.

Shot 2s-11 was a PMMA target impacted by a Lexan projectile at a velocity of 2.8 km/s. A gauge package with ten gauges was used but only nine were successfully recorded. The particle velocity data from the shot are shown in Fig. 11. The particle velocity measured was about 1.35 mm/µs. Data from the shock tracker gave a shock velocity of 4.76 mm/µs. This translates into a pressure in the PMMA of 7.6 GPa. This data point is plotted with other data for PMMA[10] on Fig. 12. It is slightly above the other data but fits quite nicely with it. We take this to mean that the magnetic gauging technique is working properly on the two-stage gun and will provide good data.

One set of 5 (4) waveforms was taken by one side of the gauge package and the other 5 by the other side. If the tilt had been very small (less than 0.1 mradian) the waveforms should have been equally spaced in time. The offset indicates that there was a few mradians of tilt in the experiment. This is being looked at at the present time. The waveforms have some rounding at the top which is evidence that there is still viscoelastic behavior even at 7.6 GPa.

Although several problems have been experienced, we are gratified that we can make in-situ magnetic particle velocity measurements on a two-stage gun. We still have some problems to overcome (such as decreasing the tilt to less than a mradian) but are looking forward to being able to study insensitive high explosives and homogeneous explosives in the near future.

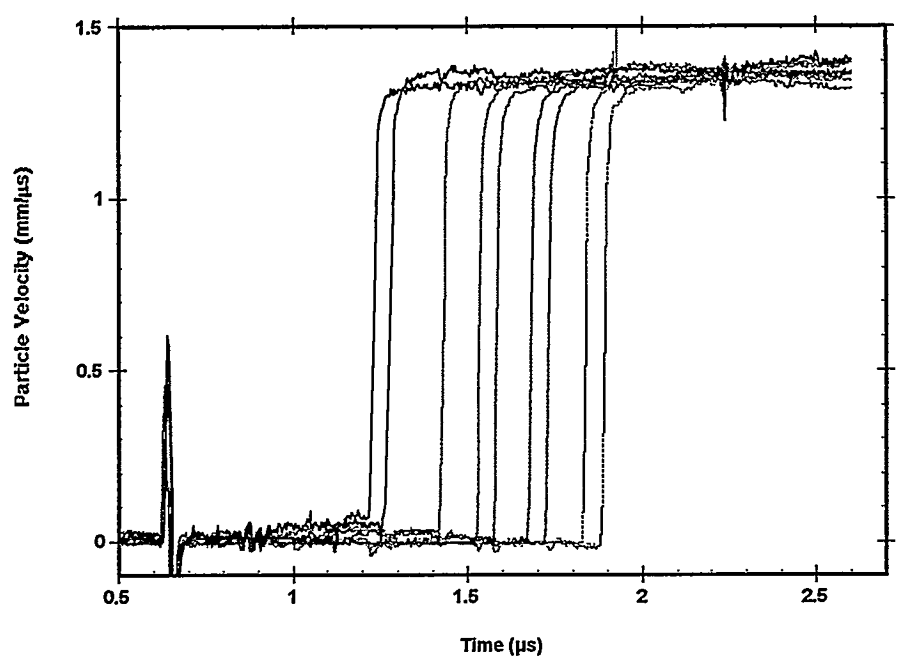

Figure 11. Particle velocity waveforms from Shot 2s-11. There are only 9 gauge measurements because 1 gauge was not recorded properly.

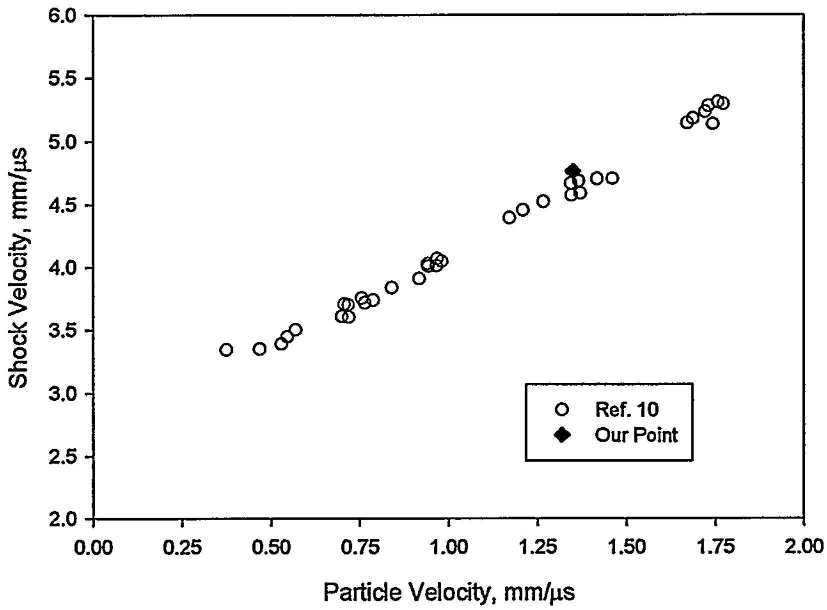

Figure 12. Hugoniot data plot for PMMA. Data from Ref. 10 were generated by explosively driven shots.

Burst Diaphragm Package Changes

The burst diaphragm package that was part of the original gun used stainless steel diaphragms with machined grooves so that six petals were developed when the diaphragm burst (see Fig. 13). After several shots on the gun, it became apparent that there was a possibility that some of the petals might break off and go down the launch tube. One of these diaphragms is shown in Fig. 13 with the petals nearly broken off. In addition, we desired to increase the diaphragm burst pressure from less than 10,000 psi to over 20,000 psi.

Our single-stage double-diaphragm breech insert uses nickel diaphragms that burst into a four petal pattern. The diaphragm package is designed so the petals can each bend around a radius that is large enough that they don't tear during the rapid opening process. This seemed an ideal design to use for the two-stage burst diaphragm to eliminate the petal tearing problem.

We redesigned the package to use the same nickel diaphragms as are used in the single-stage gun. The only thing that had to be done to make the diaphragms work was to drill 4 holes in each one. The redesigned package is shown in Fig. 14. It was necessary to put four bolts through the package to hold it to the transition section so the launch tube and transition section could be clamped in the proper position on each side. The left side mates to the launch tube and the right side to the transition section. A square hole 2.4 in on a side tapers down to a 2 in round hole. It was necessary to make the square hole larger than 2 in to provide room for the diaphragm petal without unduly restricting the flow. The edge the diaphragm petal bends around has a radius of about 0.25 in.

The nickel diaphragm is machined from a nickel 100 plate that is approximately 5 mm thick. On the single-stage gun with a larger square hole, the diaphragms burst at about 10,000 psi or less depending on the groove depth. When used on the two-stage gun with the smaller square hole, a burst pressure of near 20,000 psi is obtained. Pictures of the nickel diaphragms before and after bursting are shown in Fig. 15. The petals do not show any tendency to tear and they appear to be opening all the way. From the transition section pressure measurements we have made, it appears that these diaphragms are probably opening slower than the old stainless steel diaphragm because we don't see a double hump in the pressure profile. However, there have not been enough shots made to verify this for sure and we can not yet tell how much effect these new diaphragms have had on gun performance.

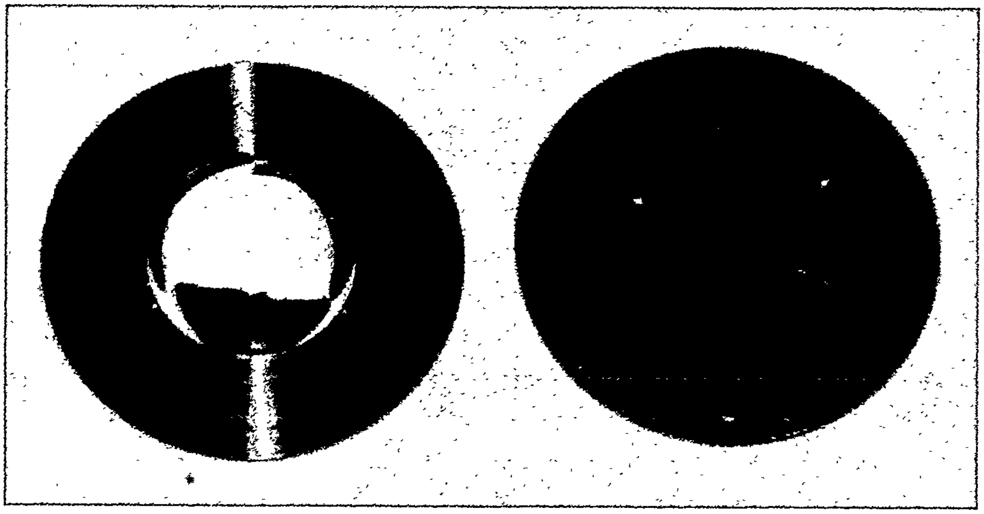

Figure 13. Picture of old stainless steel diaphragms showing the machined grooves. On the left is a diaphragm after bursting showing how the petals have nearly broken off.

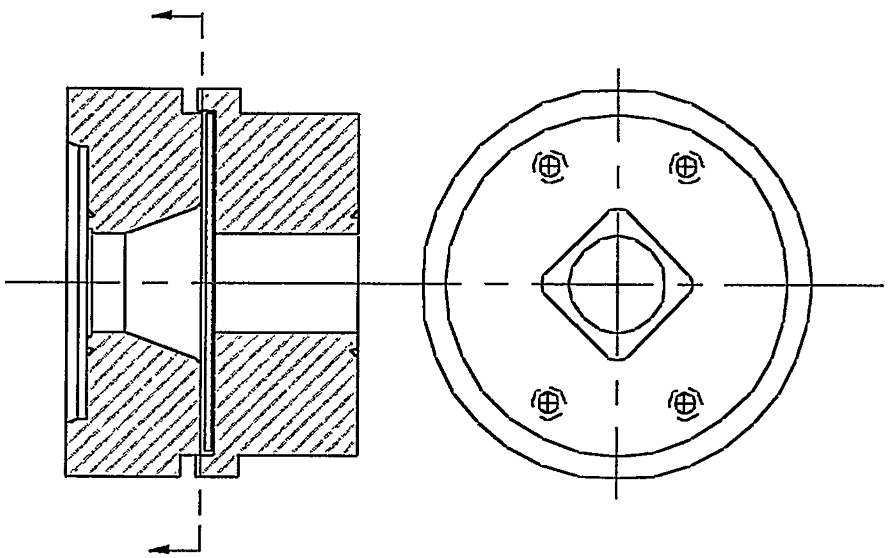

Figure 14. Schematic cross-section of the redesigned diaphragm package. The left side mates to the launch tube and the right side to the transition section. The right schematic shows a view looking into the

piece that mates to the launch tube. The 2.4 in on a side square hole is clearly shown in this view.

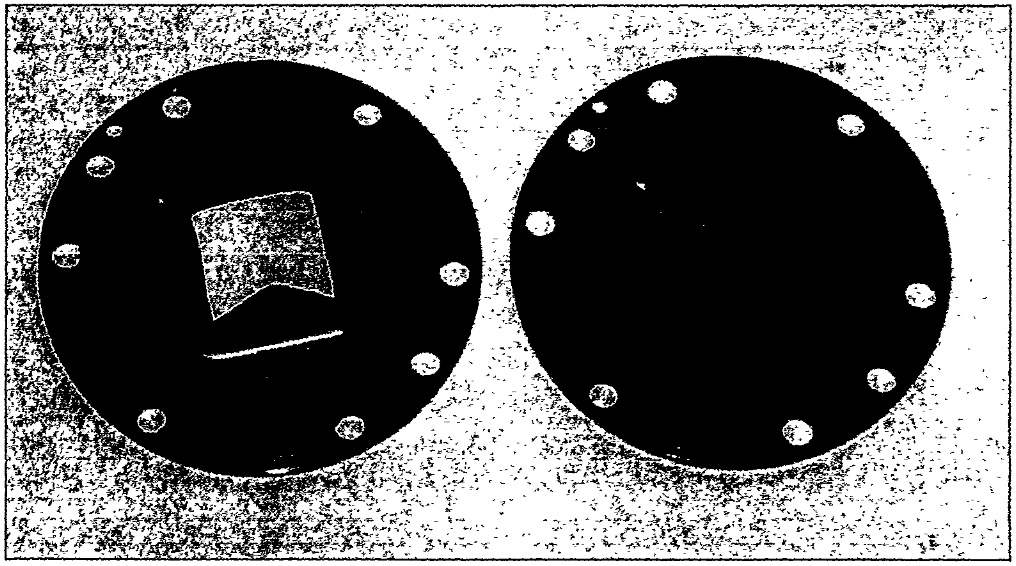

Figure 15. Picture of new nickel diaphragms showing the machined grooves. On the left is a diaphragm after bursting showing how the petals have opened.

Acknowledgments

Alois Stilp from Ernst Mach Institute has been very kind in helping us understand the design and operation of our gun. We thank him for this. Larry Hill helped us develop a Mathematica routine to do smoothing and contour plots for the magnetic field mapping.

References

1. A. J. Stilp, **The New EMI Terminal Ballistics and Hypervelocity Impact Range**, unpublished report, Ernst Mach Institut, Freiburg, Germany, August 1987.

2. A. R. Martinez, S. A. Sheffield, M. C. Whitehead, H. D. Olivas, and J. J. Dick, **New LANL Gas Driven Two-Stage Gun**, in High-Pressure Science and Technology -- 1993, Eds. S. C. Schmidt, J. W. Shaner, G. A. Samara, and M. Ross, AIP Conference Proceedings No. 309, American Institute of Physics, New York, 1994, p. 1643.

3. S. A. Sheffield and A. R. Martinez, **New LANL Group M-7 Two-Stage Gun: Double Diaphragm and Wrap-Around Gas Breech**, presented at the 43rd Aeroballistic Range Association (ARA) Meeting, Columbus, Ohio, September 28 - October 2, 1992.

4. S. A. Sheffield and A. R. Martinez, **Testing of New LANL Gas-Driven Two-Stage Gun**, presented at the 45th Aeroballistic Range Association (ARA) Meeting, Huntsville, Alabama, October 10-14, 1994.

5. A. N. Dremin and P. F. Pokhil ,Zh. Fiz. Chim., 34, p. 11 (1960).

6. L. R. Koller, **Generation and Measurement of Simultaneous Compression-Shear Waves in Arkansas Novaculite**, PhD. Thesis at Washington State University working under R. Fowles, 1978.

7. C. Young, R. Fowles, and R. P. Swift, in **Shock Waves and the Mechanical Properties of Solids**, Eds. J. J. Burke and V. Weiss, Syracuse University Press, 1971, p 203.

8. R. L. Gustavsen and S. A. Sheffield, **Response of Inclined Electromagnetic Particle Velocity Gauges in Shocked Liquids**, in High Pressure Science and Technology -- 1993, Eds. S. C. Schmidt, J. W. Shaner, G. A. Samara, and M. Ross, American Institute of Physics AIP Conference Proceedings 309, 1994, Part 2, p. 1703.

9. J. E. Vorthman, **Facilities for the Study of Shock Induced Decomposition of High Explosives**, in Shock Waves in Condensed Matter -- 1981, Eds. W. J. Nellis, L. Seaman, and R. A. Graham, AIP Conference Proceedings No. 78, American Institute of Physics, New York, 1982, p. 680; also J. E. Vorthman and Jerry Wackerle, **Multiple-Wave Effects on Explosive Decomposition Rates**, in Shock Waves in Condensed Matter -- 1983, Eds. J. R. Asay, R. A. Graham, G. K. Straub, Elsevier Science Publishers B. V., 1984, p. 613.

10. W. J. Carter and S. P. Marsh, **Hugoniot Equation of State of Polymers**, Los Alamos National Laboratory Report, LA-13006-MS, July 1995.