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TITLE: NEW LANL GROUP M-7 TWO-STAGE GUN: DOUBLE-DIAPHRAGM AND WRAP-AROUND GAS BREECH

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# NEW LANL GROUP M-7 TWO-STAGE GUN: DOUBLE-DIAPHRAGM AND WRAP-AROUND GAS BREECH†

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## Abstract

A new two-stage gun is being installed in a high explosive testing facility at Los Alamos National Laboratory for the purpose of subjecting insensitive high explosives to controlled projectile impacts so that shock-to-detonation transition can be studied in detail. This gun has been patterned after guns designed by Alois Stilp at Ernst Mach Institut (EMI) in Freiburg and Wintersweiler, Germany. Several changes were made to adapt the design to our needs. The gun has a 100-mm diameter pump tube and 33-mm and 50-mm diameter launch tubes; both pump and launch tubes are 7.[illegible] m long. We plan to use only helium as the reservoir gas. Large hydraulic clamps hold the gun together in three places during a shot; these are located on both sides of the transition section and at the breech. These clamps make gun conversions to different setups relatively simple, i.e., the two-stage gun can be converted into a single-stage gun. A gas breech has been designed which can be operated in either wrap-around or double-diaphragm mode with a maximum operating pressure of 15,000 psi. Two-stage gun calculations indicate that in the gas breech configuration, projectile velocities up to 4 km/s can be obtained using helium in both the breech and the reservoir. The gun has been fabricated and is being installed at the present time. Testing is expected to begin in early 1993 if the startup difficulties do not become excessive.

## Introduction

A new two-stage (TS) gas gun is being installed at the gas gun high explosive test facility located at DF-Site at the Los Alamos National Laboratory. The primary purpose for this gun facility is to perform research and characterization studies on the initiation and detonation of high explosive materials. An existing 72-mm bore single-stage (SS) gas gun capable of projectile velocities up to 1.5 km/s is routinely used as the driver system for high explosive experiments[1]. The most used diagnostic technique is a magnetic particle velocity system with which in-situ particle velocity histories are measured. Gauge packages are available that provide up to 10 measurements, each at a different Lagrangian position, in a single experiment. By analyzing these waveforms carefully, reaction rates during high explosive initiation can be estimated.

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The SS gun system has proven valuable in studying conventional high explosive materials over the past 20 years. However, it is not capable of producing the projectile velocities required to initiate insensitive high explosives (IHE) such as 1,3,5-triamino-2,4,6-trinitrobenzene (TATB) or homogeneous liquid explosives such as nitromethane. Because of this a program to design and install a TS gun capable of providing higher projectile velocities was undertaken several years ago. After making trips to a number of TS gun facilities in the United States, Canada, France, and Germany, we decided to use the gun design developed by Alois Stilp at the Ernst Mach Institut (EMI) in Freiburg, Germany. In fact our gun is a near copy of the convertible TS/SS gun located at the EMI range[2] in Wintersweiler, Germany, south of Freiburg.

The Stilp design employs two large hydraulic clamps to clamp the transition section during a shot. One clamp joins the transition section and the pump tube and the other joins the transition section and launch tube. Large interlocking "bayonet" arrangements on the end of the transition section (external) and inside the hydraulic clamp (internal) allow for interlocking the two pieces before the clamps are pressurized to about 10,000 psi when preparing to shoot. The use of these clamps adds considerable versatility to the overall gun design, i.e., this allows it to be setup as a SS powder gun, a SS gas gun, or a TS powder gun. The Stilp design includes 30-, 40-, and 50-mm diameter launch tubes, a 100-mm diameter pump tube, a SS powder breech, a TS powder breech, and a SS gas breech. Sealing the joints in the high pressure region at the output of the transition section is done with metal delta-ring seals also designed by Stilp[3].

We modified the design to include a third hydraulic clamp on the breech end of the pump tube. This was accomplished by duplicating the pump tube/transition section clamp system. The TS powder breech design was modified to include an external bayonet. A schematic of our new gun setup as a TS powder gun is shown in Fig. 1. A gas breech was designed which can be substituted for the powder breech so our gun can operate as a gas driven TS gun. Information surrounding this design is discussed in this paper. A brief description of the DF-Site gun facility will be given to provide information about the general facility setup and the type of diagnostics used.

## Los Alamos DF-Site Gun Facility Description

The DF-Site gun facility includes several connected buildings situated so that access to each gun for control and diagnostics is achieved. The SS gun is housed in a metal "Butler" building with a breech/barrel room (5 m wide by 7 long) and a target chamber/catch tank room (5 m by 7 m). The TS gun is also housed in a metal Butler building 8 m wide by

30 m long. An optical instrumentation room and a gun control/digitizer room are located between the two gun buildings so that optical diagnostics have direct access to either of the target chambers through wall ports. Each of these rooms is 6 m by 7 m and of concrete construction.

Single-stage gun control is accomplished using a MAC computer/LabVIEW software[4] based system which allows operation of the valves, pumps, etc., using the mouse to click on symbols on the MAC screen. Embedded in the control system program logic are various constraints that keep the operator from pressurizing the breech until all the interlocks are closed or from firing until all the vacuum pumps are isolated from the gun. It also contains provisions for an orderly system shutdown if an interlock is opened or something out of the ordinary happens. This same control system is being modified to control the TS gun; a separate program is being developed to monitor and control its operation.

Diagnostics available at the facility, in addition to the magnetic gauging system, include push-pull VISAR interferometry, spectroscopy equipment, electronic streak cameras, a conventional continuous writing streak camera, and single-frame image intensifier ($I^2C$) cameras. These diagnostic techniques, which are used in SS gun experiments, will also be used in TS gun experiments. To make this possible, the TS gun target chamber/catch tank system design was only slightly modified from that in use on the SS gun. Most of the instrumentation setups and target arrangements will fit either gun.

## Two-Stage Gun Design and Calculations

Since explosive initiation experiments usually involve multiple magnetic particle velocity gauging, it was necessary to design the TS gun with the maximum diameter launch tube in order to maximize the experimental area available for one-dimensional experiments. Because of this the Stilp design, consisting of a 100-mm diameter pump tube and a 50-mm diameter launch tube, was ideal. We have some concern about the diameter ratio (pump tube diameter to launch tube diameter) being only 2 (rather than 2.5 or larger as it is in most TS guns). This may lead to pump piston extrusion into the launch tube during a shot, a problem that has been experienced by others in the past. Two transition sections were designed, one with a ten-degree and the other with a twenty-degree included angle transition. It is hoped that the larger angle unit may help alleviate the extrusion problem if it occurs. The choice of a 50-mm diameter launch tube means we have sacrificed velocity for experimental area. Based on the calculations discussed below, we expect the TS gas gun with this launch tube to produce projectile velocities between 1.5 and 4 km/s. This will allow us to do the IHE initiation experiments we have in mind.

In order to help us decide the exact gun dimensions, a number of calculations using the gun code developed by Charters and Sangster[5] (a copy of which resides on the LANL Group M-6 VAX) were made to estimate TS gun performance when various parameters were changed. This code was previously used to calculate the performance of our SS gun (calculated projectile velocities were slightly higher than those measured) so we had some confidence in the projectile velocities it calculates.

Because we do not want to deal with the problems of using hydrogen as the reservoir gas and do not require the extra velocity it provides, all calculations were done with helium as the reservoir gas. In addition all gas breech calculations were done using helium as the breech gas. This new gun will only use helium.

We started with the Stilp design and then made changes to pump tube length, launch tube length, breech volume, and launch tube diameters to determine the best design parameters. Of particular interest was the effect of changing the launch tube length and diameter on projectile velocity. Increasing both the pump tube and launch tube lengths from 4.9 m to 7.6 m increased projectile velocity by about 0.3 to 0.4 km/s. Decreasing the launch tube diameter from 50 mm to 33 mm (with the projectile mass decreased a corresponding amount, from 200 g to 50 g) led to increases in the projectile velocity of about 2 km/s.

Baseline calculations for a powder driven TS gun with the design parameters of our gun were made. Results of these calculations are plotted in Fig. 2. Breech pressures become higher than we want somewhere between a 2000 and 2500 g powder charge so a maximum projectile velocity of about 4.6 km/s would be expected for this setup. Calculations were made with a 15,000 psi gas breech substituted for the powder breech to see how a gas breech driven gun would compare to the powder driven gun. It became clear that this system was nearly as good as a powder breech in terms of projectile velocity but the optimum breech volume was unknown. The breech volume was varied holding all other parameters constant. Figure 3 shows how the projectile velocity changes with breech volume. We picked 1.5 ft$^3$ (42.5 liters) as the design volume because this seemed to be in the area where projectile velocity gains from increasing the volume were minimal. In order to calculate the overall performance of this breech so that it could be compared to the powder driven gun performance shown in Fig. 2, we used this breech volume and all the applicable parameters used in the powder breech calculations. By varying the breech pressure the gas breech performance curve show in Fig. 4 was calculated. An attempt to optimize some of the parameters (such as reservoir pressure and piston mass) produced a calculated maximum projectile velocity of about 4 km/s. Making the comparison between the data of Fig. 2 and that of Fig. 4 indicates that the gas breech system gives a maximum projectile velocity about 13% less than the powder breech. Based on this analysis a double-diaphragm gas breech was designed.

We also did a number of calculations for a gas driven TS gun with a 33-mm diameter launch tube. The data plotted in Fig. 5 show the projectile velocity as a function of maximum reservoir pressure (one of the important calculated numbers). Several parameters were varied to produce this data. We expect to keep our maximum reservoir (transition section) pressures below 200,000 psi so the data indicate that, with a projectile mass of 50 g, projectile velocities between 4 and 7 km/s will be obtained from this gas driven TS gun setup. These data confirm the earlier statement that projectile velocity increases of up to 2 km/s may be attained by replacing the 50-mm diameter launch tube with a 33-mm diameter launch tube.

## Our Final Gun Configuration

These calculations (and others not discussed) helped considerably in setting the final gun design, using the Stilp design as a starting point. The pump tube and launch tube lengths were increased from 4.9 to 7.6 m, the TS powder chamber volume was increased from 2.7 liters to 4.3 liters, and a gas breech with a volume of 42.5 liters and a 15,000 psi pressure capability was designed. Based on our design, the following gun parts were purchased from Honematic Machine Corporation[6]: a 100-mm diameter pump tube 7.6 m long; three launch tubes 7.6 mm long, two of them had a bore of 50 mm and one had a bore of 33 mm; two transition sections, one with a ten-degree included angle transition and the other with a twenty-degree included angle transition; three large "bayonet type" hydraulic clamps; a SS powder breech; a TS powder breech; and the gas breech.

## Gas Breech Design

One of the prime reasons for wanting to use a gas breech with our TS gun was to eliminate the safety, handling, and cleaning problems associated with gun powder and the combustion products. Since our existing SS gun[1] has a 15,000 psi breech, configuring the TS gun to use the same pressurization system was simple and cheap. After the calculations discussed above showed that the gun could be effectively driven with a gas breech system, we began in earnest to change the design to accommodate it. The overall gun design was modified to include the third hydraulic clamp at the breech end so breech changes would be relatively simple. This change made it necessary to modify the TS powder breech to include the bayonet arrangement so it could be clamped rather than screwed onto the pump tube.

The original gas breech design for the TS gun included only a double-diaphragm package. It was based on the 15,000 psi double- diaphragm breech we have routinely used on our SS gun for several years. After we looked carefully at the data plotted in Fig. 4, it became apparent that breech pressures between 3000 and 8000 psi produce projectile velocities between about 1.5 and 3.0 km/s, the range where we expect most of our shots to be done. Since a wrap- around breech design could be operated in this pressure regime, we decided to modify the breech design to include a wrap-around insert in addition to the double-diaphragm insert. We had been involved with the design and fabrication of another SS gas gun breech which had interchangeable inserts for wrap-around and double-diaphragm operation[7] so the breech inserts were based on this design. Cross-sectional views of the hydraulic clamp/breech arrangement with the double- diaphragm insert in place and the wrap-around insert are shown in Fig. 6. The wrap-around unit will be used in shots where breech pressures up to about 8000 psi are required. The double-diaphragm unit will be used for breech pressures between 8,000 and 15,000 psi.

The pump piston will act as the breech valve in the wrap-around mode so an aluminum piston back with o-ring seals is being designed to perform this function. The front of the piston will be polyethylene as is normally the case. Firing the gun is accomplished by injecting gas behind the piston to start it moving and uncover the breech gas channels that connect the barrel to the breech volume.

The double-diaphragm unit is operated by pressurizing the breech to full pressure while the region between the two diaphragms is maintained at half the breech pressure, i.e., each diaphragm has half the breech pressure across it. Firing the gun in this mode is accomplished by slowly venting the gas between the diaphragms, causing the breech gas to overpressure the first diaphragm, then the second diaphragm, and then accelerate the pump piston. Pure nickel diaphragms approximately 5-mm thick will be used. They will have V-shaped grooves machined in a cross pattern. The depth of the grooves controls the burst pressure. This diaphragm design is based on the diaphragms now in use on our SS gun. The diaphragms are expected to cost about $150 each, so using the wrap-around breech will save the cost of diaphragms.

## Schedule for Gun Installation

We received the pump tube, launch tubes, one transition section, the SS powder breech, the TS powder breech, the gas breech, and the three hydraulic clamps from Honematic Machine Corporation in August. The target chamber/catch tank system and gun support structure were purchased and installed earlier. We are now installing the gun parts and expect this to be completed in October. The hydraulic power packs for the clamps have been purchased but must be installed. All the various gun and building interlocks and control points must be defined and wired to the gun control panel. A TS gun control program must be developed by modifying the SS gun control program. Pressure tests (to 25,000 psi) of all the gun parts will be made while they are clamped in place as they will be on the gun during a shot. Three separate tests will be required to test all the launch tubes and breeches. This will be done before the gun is operated. In addition a DOE required operational readiness review must be completed and the gun setup approved before it can be used for routine testing. Because many things are yet to be completed, we expect to start testing the gun in early 1993. If all goes well, IHE experimentation will begin shortly after.


## Acknowledgements

The EMI gun design was purchased from PTS[8] which is a company that sells EMI technology. Alois Stilp helped a great deal in making sure we knew what materials were called out and helping to get English translations of the drawings. He also provided operational data on the gun at EMI, Wintersweiler, Germany. Mike Williams, a mechanical engineering summer student, redrew many of the gun support structure components and the breech and transition section carriages. He also modified the SS target chamber and catch tank drawings for application to the TS gun. Henry Olivas designed the gas breech system, modified the TS powder breech and clamp interface, and redrew the launch tube holders. The target chamber/catch tank system was manufactured by Terminal Manufacturing Co. , Berkeley, CA. George Friedman and the late Allan Glazer of Honematic Machine Corporation helped a great deal to make sure the gun fabrication went as planned. Doug Dugan of Sandia National Labs. designed the first interchangeable double-diaphragm/wrap-around breech system that our breech insert design was based on.


## References


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2. A. J. Stilp, **The New EMI Terminal Ballistics and Hypervelocity Impact Range**, unpublished report, Ernst Mach Institut, Freiburg, Germany, August 1987.
3. A. J. Stilp, **Diaphragm and Delta Ring Sealing Technique for Two-Stage Light Gas Gun Operation**, unpublished report, Ernst Mach Institut, Freiburg, Germany, no date.

4. LabVIEW is a computer program developed by National Instruments, 6504 Bridge Point Parkway, Austin, TX. It was designed to allow MAC computer control of equipment.
5. A. C. Charters and David K. Sangster, **Fortran Computer Program for the Interior Ballistic Analysis of Light-Gas Guns**, July 1973, unpublished report, Santa Barbara, CA.
6. Honematic Machine Corporation is located at 222 Shrewsbury Street, Boylston, MA 01505.
7. S. A. Sheffield and D. W. Dugan, **Description of a New 63-mm Diameter Gas Gun Facility**, in Shock Waves in Condensed Matter, Ed. Y. M. Gupta, Plenum Press, New York, 1986, p. 565.
8. PTS is an abbreviation for Physikalisch-Technische-Studien GmbH, Leinenweberstr. 16, D-7800 Freiburg, Germany. Peter Seidl was the contact.

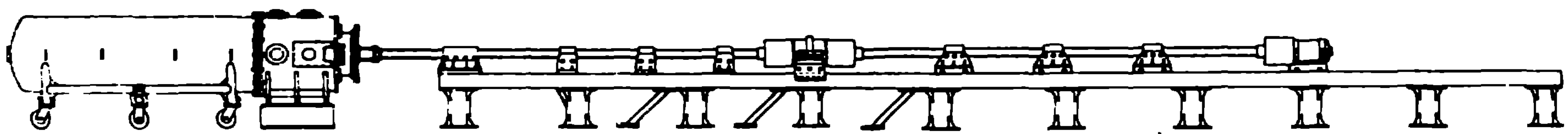

**Figure 1.** Schematic of the new two-stage gun at DF-Site including the support structure and the target chamber and catch tank. The support structure is 18-m long with each of the barrels 7.6-m long. The target chamber/catch tank assembly is 1-m diameter and 4.7-m long with the walls 19-mm thick pressure vessel steel.

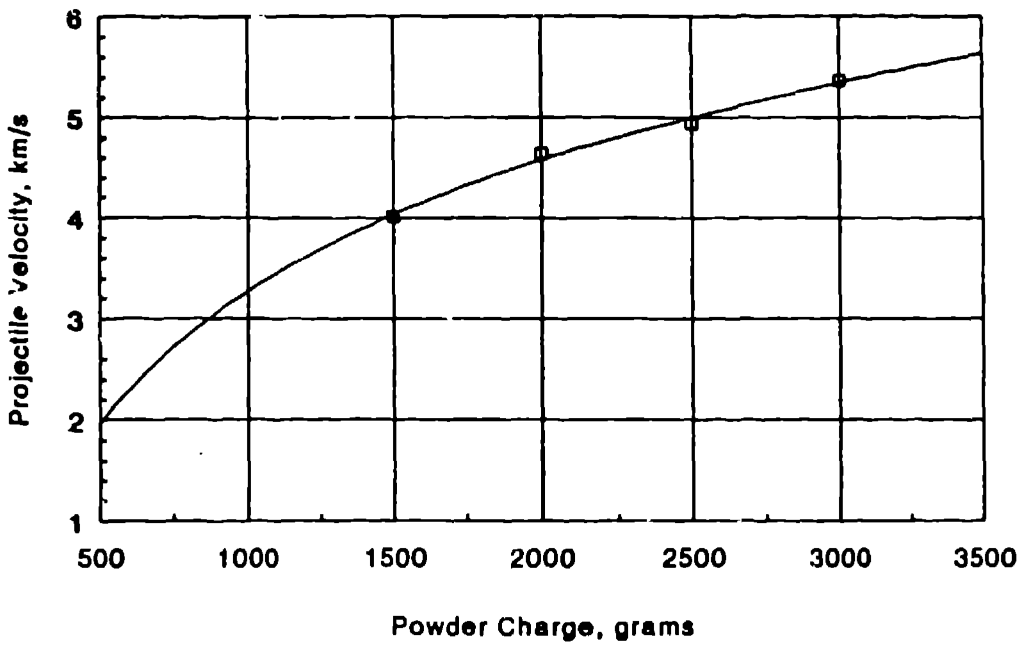


**Figure 2.** Plot of results of projectile velocity versus powder breech charge mass calculations for a TS powder gun with the design parameter indicated in this paper. The launch tube was 50-mm diameter and the projectile mass 200 g.

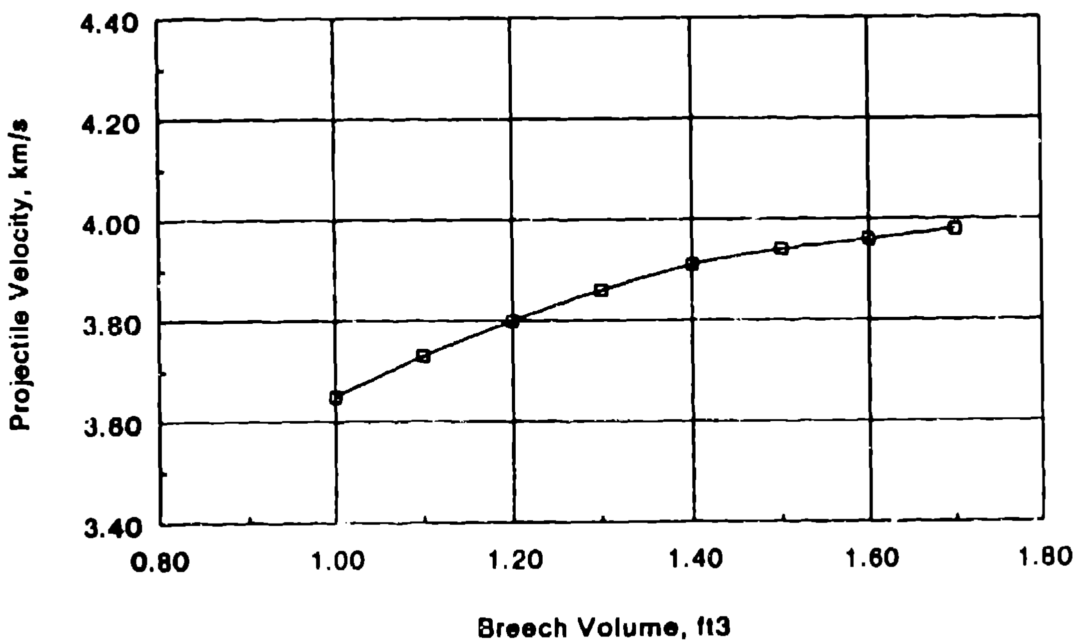


**Figure 3.** Results from calculations to determine the optimum gas breech volume. The volume was changed while all the other parameters were held constant. The gun configuration was the gun described in this paper. The launch tube was 50-mm diameter and the projectile mass 200 g.

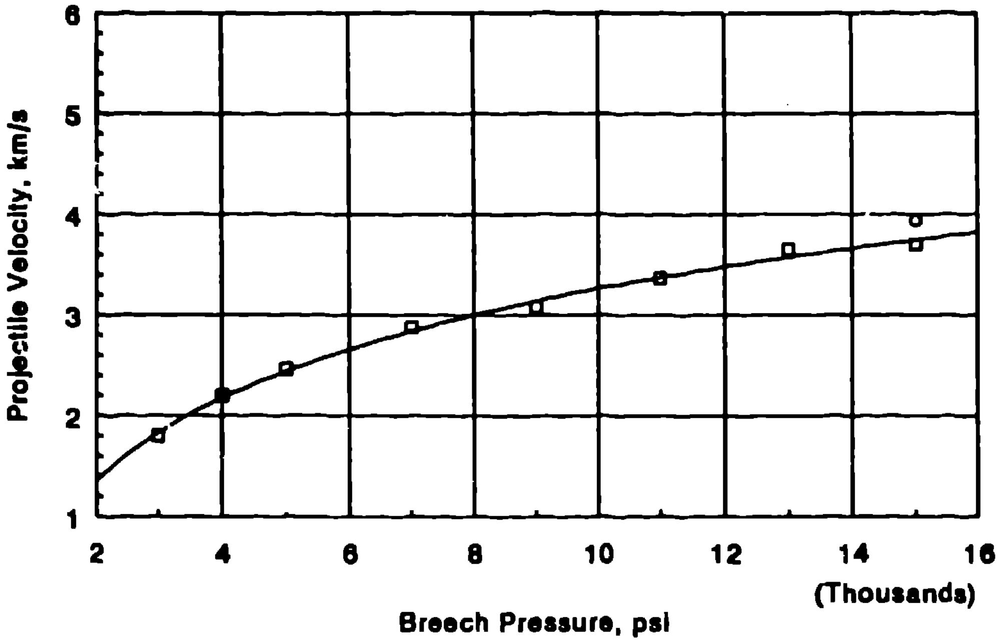


**Figure 4.** Plot of projectile velocity versus gas breech pressure for the gas breech (volume 1.5 $ft^3$) driven gun described in this paper. The launch tube was 50-mm diameter and the projectile mass was 200 g.

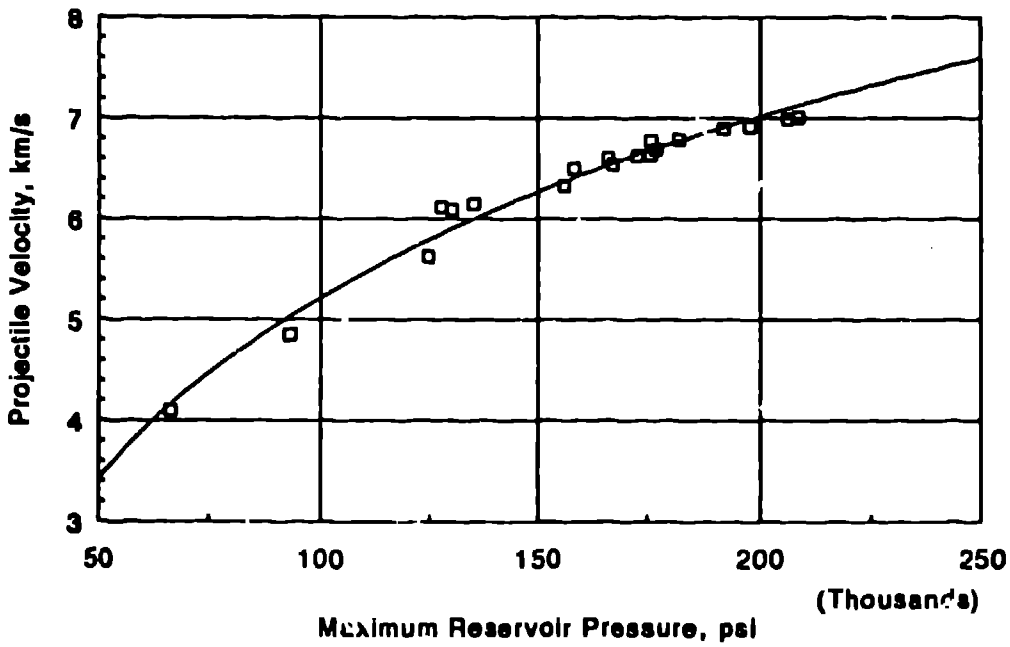


**Figure 5.** Plot of projectile velocity versus gas breech pressure for the gas breech (volume 1.5 $ft^3$) gun described in this paper. The launch tube was 33-mm diameter and the projectile mass was 50 g.

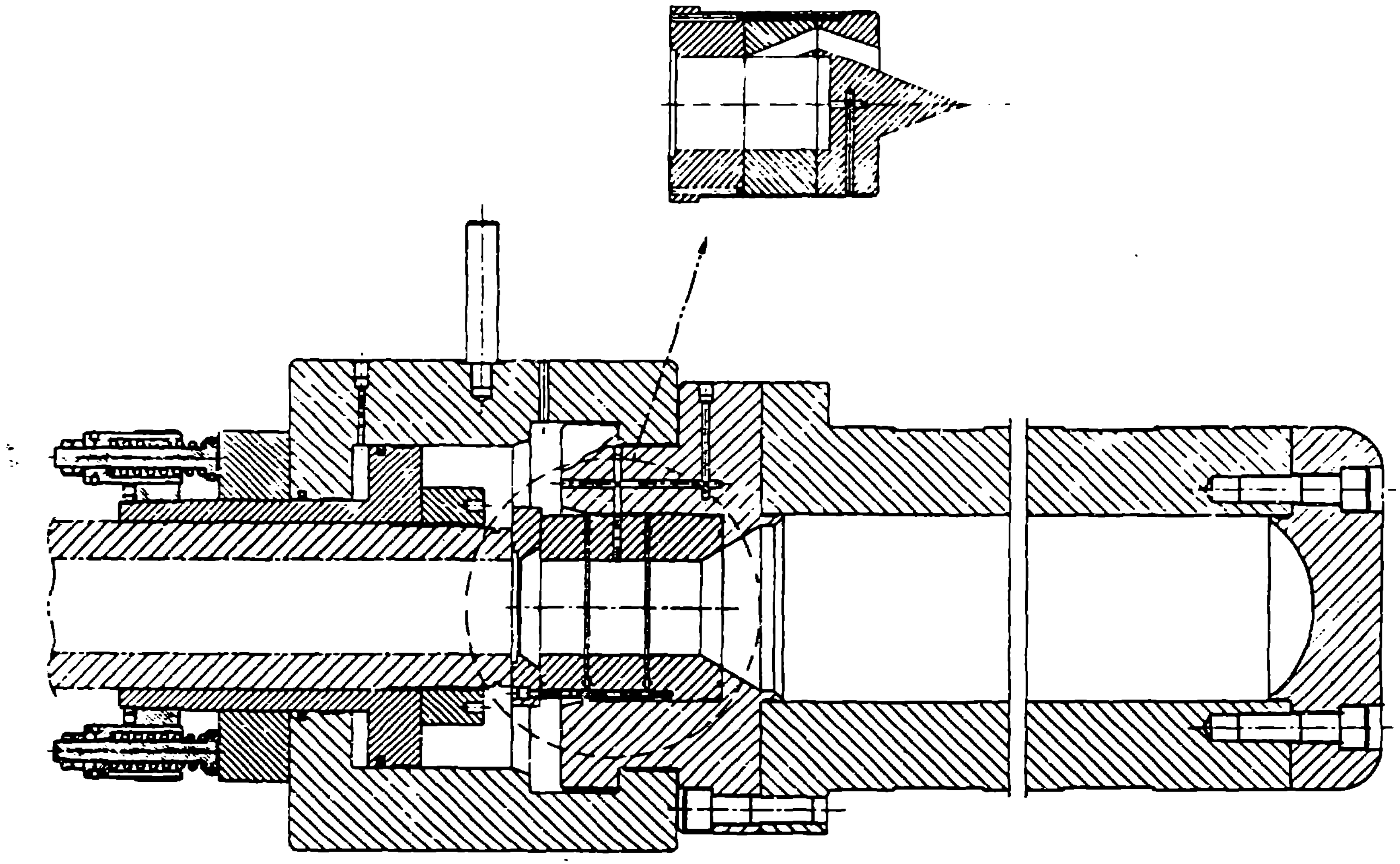

**Figure 6.** Cross-section of the gas breech/pump tube joint with the double diaphragm package in place. A cross-section of the wrap-around insert is also shown.