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Gas Gun for Impact Studies*

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A detailed description of a 10.16 cm gas gun that has been designed and installed at Washington State University is presented. The design velocity is 1.5 mm/μsec; the maximum velocity achieved to date is 0.9 mm/μsec with an 1100 g projectile. Angular misorientation of the projectile with respect to the target surface is consistently below 0.5 mrad. Brief descriptions of ancillary instrumentation and equipment are also given.

INTRODUCTION

THIS paper describes the gas gun and associated instrumentation that have been designed and installed at Washington State University. One year was spent in design and construction of the gun.[1] It was installed at the beginning of the second year, and active research began some three months later after a number of shakedown experiments and minor modifications.

A gas gun was chosen as the principal experimental tool of the Shock Dynamics Laboratory for several reasons. A gun is capable of very precisely controlled impacts in which initial conditions of the projectile and target are well determined; the velocity range (up to about 1.5 mm/μsec) is adequate for the study of a wide range of physical phenomena including, for example, the study of phase transformations and constitutive relations; they are relatively safe and can be operated by a small number of personnel in a campus environment.

Although powder driven guns can be shorter for a given projectile velocity and are therefore less expensive, they are less suitable for precision impact studies because of problems of cleanliness and high recoil forces. Further, the problems of storage and handling of gunpowder in a campus environment are substantial inconveniences.

Some of the conceptual design considerations leading to the choice of length, diameter, operating pressure, and mode of operation are discussed in Sec. II. Section III includes detailed descriptions of the major features, and Sec. IV describes the instrumentation developed for use with the gun, while Sec. V describes the performance of the gun.

DESIGN CONSIDERATIONS

The major design parameters are length, diameter, operating pressure, and gas reservoir volume. Projectile diameter is probably the most important parameter. Good measurements of plane stress wave propagation can be obtained only while the stress wave is accurately one dimensional, i.e., before any signal from the lateral edges of the sample under investigation can influence the measurement. This restriction requires that the ratio of diameter to thickness of the sample be at least 3 and preferably 4 or more. If sample thicknesses up to 25 mm are to be studied, or if it is desired to compare two or more thinner samples under identical impact conditions, a projectile diameter of about 10 cm is necessary. The experience of other investigators with guns varying between 6.35 and 15.24 cm indicates that these are reasonable limits.[2–4] Previous experience of the authors with explosive experiments and with a 6.35 cm gun led us to believe that 10.16 cm diameter would give reasonable flexibility in operation at reasonable expense.

At 413 bars operating pressure, which is a convenient limit in terms of availability of compressors, gauges, and tubing, a barrel length of more than about 16 m does not materially increase the attainable projectile velocities. The length chosen for the gun was 14 m in order to fit conveniently into the room available. Figure 1 shows the projectile velocity as a function of barrel length for various values of the ratio of mass of driver gas to projectile mass. The length chosen for the gun is clearly well beyond the knee of these curves and is sufficient to extract nearly all the velocity possible from a given reservoir at the maximum operating pressure (413 bars).

The gas reservoir volume was chosen to give a maximum ratio of mass of gas to projectile mass (G/M) of about five. The maximum velocity increases very slowly with G/M beyond this value, as shown in Fig. 2, and higher reservoir volumes increase the cost of gas which, in the case of helium, is not trivial. For a projectile mass of 450 g, which is about the minimum weight that can be fired with adequate strength and rigidity, the corresponding reservoir volume for helium at 413 bars is 28.3 liters and this value was therefore adopted. The curves shown in Figs. 1 and 2 were taken from Seigel,[5] and were verified by similar calculations in this laboratory by White.[6]

Thus, within the bounds of reasonable practicality the gun is designed to give nearly the maximum velocity (~1.5 mm/μsec) and maximum diameter attainable in a single stage gun. Improved performance would result from use of hydrogen, but this gas was ruled out because of handling and safety problems.

Aside from the choice of operating parameters indicated above, the most important feature of the gun is the method for absorbing recoil. Detailed gas dynamical calculations indicate a maximum momentum of about 2×10^8 dynes·sec and a maximum unbalanced force of 3.36×10^5 N.[6]

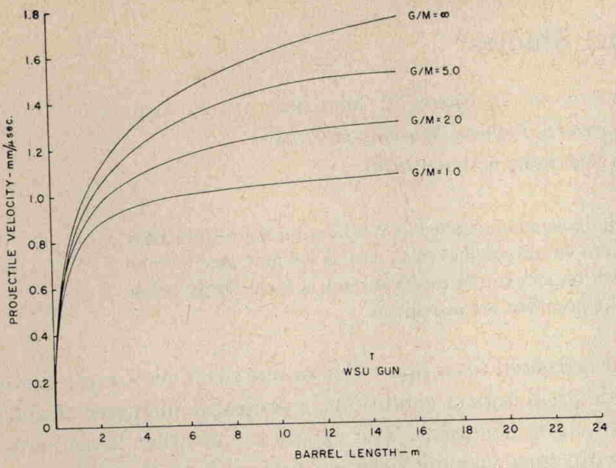

FIG. 1. Projectile velocity as function of barrel length for various ratios of mass of gas, G, to mass of projectile, M; helium gas at 413 bars (after Seigel[5]).

It was decided to let the gun slide freely while holding the target stationary, rather than to attempt to hold the gun rigidly with the target fastened to the barrel.The recoil forces are then substantially reduced and can be accommodated by standard shock absorbers. This has the additional advantage that no appreciable vibrations are transmitted to the target from the barrel. The principal concern with this scheme is whether sufficient control can be maintained of the tilt of the projectile with respect to the target. In order to fully utilize the time resolution available from our recording techniques a maximum tilt of $\frac{1}{2}$ mrad must be maintained in a typical experiment. (Projectile velocity is 0.5 mm/μsec, active gauge diameter is 10 mm.) Consideration of the possible extent of misalignment during the approximately 2.5 cm of motion of the gun barrel before impact indicated, however, that significant bending or rotation would not be expected.[7] This conclusion has been subsequently verified by tilt measurements that are consistently below 0.5 mrad and are frequently much less.

Other advantages of the design are (1) capability for evacuating all sides of the target to avoid distortion, (2) breech mechanisms which can be precisely triggered and have fast opening times, and (3) quiet operation.

Two interchangeable breeches with different projectile firing mechanisms were designed and built because no single breech of an existing gun performs optimally throughout the desired velocity range (~0.1 to 1.5 mm/μsec). Several new concepts for a breech design that would accommodate the complete velocity range were considered, but were rejected in favor of two breeches on the basis of simplicity and reliability.

The need for fast breech opening times was shown by computer simulation studies performed by White.[8] The results show that, for maximum performance, the breech mechanism must provide unrestricted gas flow within a few milliseconds.

The low pressure breech (to 206 bars) is of the wraparound type developed by Muhlenweg at Sandia Corporation. This design is very convenient to use, employs no moving parts under pressure except the projectile itself, and is automatically fast opening. Its only disadvantage is that the projectile must be strong enough to withstand the initial pressure; the relatively large projectile mass provides the primary limit on the velocity attained with this breech.

A double-diaphragm breech, also patterned after a Sandia design, was built to operate to 413 bars. It imposes no limitation on projectile weight, but is more expensive and less convenient to operate since two burst diaphragms must be inserted between breech and barrel for each shot.

There was substantial concern about the acoustic noise produced by the gun inasmuch as it is located directly below a large lecture room. Partly to help control noise and partly for safety purposes, a catcher tank was constructed that contains all the fragments and gas. This tank, which incorporates a large evacuated target area, and the heavy concrete shielding around the muzzle, reduce the noise to surprisingly low levels. We have been able to fire at pressures up to 206 bars without disturbing classes in the room above.

DESIGN DETAILS

A. Location

The room in which the gun facility is located is a basement room in a large classroom and office building on the WSU campus, Sloan Hall. It is approximately 22.8×7.6 m and is partially below ground level. Inside this room we constructed a very heavy, doubly reinforced concrete muzzle room approximately 3.3×4.8×2.1 m. The walls, ceiling, and floor are reinforced and are 30 cm thick. The

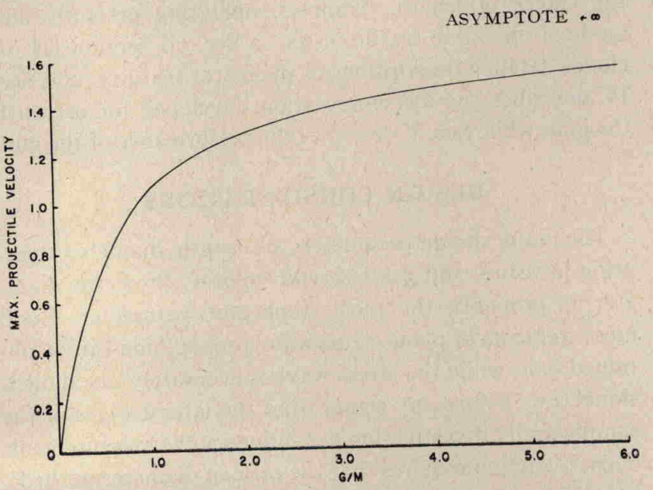

FIG. 2. Maximum projectile velocity as a function of G/M for 14 m barrel; helium gas at 413 bars (after Seigel[5])