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A gas-loading system for LANL two-stage gas guns

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Abstract. A novel gas loading system was designed for the specific application of remotely loading high purity gases into targets for gas-gun driven plate impact experiments. The high purity gases are loaded into well-defined target configurations to obtain Hugoniot states in the gas phase at greater than ambient pressures. The small volume of the gas samples is challenging, as slight changing in the ambient temperature result in measurable pressure changes. Therefore, the ability to load a gas gun target and continually monitor the sample pressure prior to firing provides the most stable and reliable target fielding approach. We present the design and evaluation of a gas loading system built for the LANL 50 mm bore two-stage light gas gun. Targets for the gun are made of 6061 Al or OFHC Cu, and assembled to form a gas containment cell with a volume of approximately 1.38 cc. The compatibility of materials was a major consideration in the design of the system, particularly for its use with corrosive gases. Piping and valves are stainless steel with wetted seals made from Kalrez® and Teflon®. Preliminary testing was completed to ensure proper flow rate and that the proper safety controls were in place. The system has been used to successfully load Ar, Kr, Xe, and anhydrous ammonia with purities of up to 99.999 percent. The design of the system and example data from the plate impact experiments will be shown.

INTRODUCTION

Gas gun-driven plate impact experiments provide a versatile means of generating well-defined shock input conditions into a variety of materials. Los Alamos National Laboratory (LANL) has interests in improving the equations of state (EOS) of elevated density (pressure) gases, including noble and molecular gases, such as those that comprise the dense fluid mixture of high explosive detonation products. Earlier work on Ar employed explosive-driven flyer plates to obtain Hugoniot data in the gas-phase[1-5]. However, to date, elevated density *gas-phase* Hugoniot data has not been obtained in gas gun-driven plate impact experiments. In order to fill gas gun target assemblies with gases at elevated initial densities, a remote gas loading system was developed and coupled to two two-stage gas guns at LANL: a 50 mm launch tube bore two stage light gas gun with a maximum projectile velocity of 3.6 km/s,[6] and a 28 mm launch tube bore high performance powder gun with a maximum projectile velocity of ~8 km/s [7]. The described gas loading system was developed to provide remote, controlled loading of gases at room temperature up to 1000 psi, with continuous monitoring of gas pressure and temperature up to impact time. Furthermore, while demonstrated first with inert noble gases [8-9], the system is designed to be compatible with molecular gases such as NH_3, CH_4, CO_2 and others[10].

Loading system components

A gas loading system was developed to remotely fill gas gun target assemblies with elevated pressure (density) gases from ~200-1000 psi at room temperature. The loading system was developed to meet the following requirements: 1) the system had to meet pressure safety compliance at LANL, 2) the loading system and target materials needed to be compatible with both inert and molecular gases, 3) the target pressure could be controlled from 200-1000 psi at room temperature, and 4) the system needed to be able to load and hold pressure for extended handling times due to the timescales associated with firing the gas and powder guns. The designed gas loading system is based on the combination of valves shown in Figure 1, that were implemented to allow for multiple pump-purge cycles prior to the final loading of the gas pressure for a gas gun experiment.

The gas loading system, Figure 1, contains CGA -350 fittings to connect to the pressure cylinder valves (Fig. 1, CV1). The CGA fitting connects to the high pressure regulator by a flexible hose lined with Teflon®, and encased with a stainless steel braid. The high pressure regulator (Fig. 1, PR1) regulates cylinder pressure down to the pre-determined target pressure. This regulator is a spring-regulated diaphragm-sensing general purpose regulator from Swagelok with FKM/PTFE wetted seals. There are two gauges used to monitor the pressure regulation. The first is a 0 to 2000 psi (50 psi increments) dial gauge to monitor cylinder pressure (Fig. 1, CV1), and the second is a 0 to 500 psi dial gauge (10 psi increments) to monitor regulated gas pressure into the loading system. The low pressure regulator (Fig. 1, PR2) is a spring-regulated diaphragm-sensing general purpose regulator with FKM/PTFE wetted seals. The low pressure regulator is fed from the high pressure side of PR1 using the previously mentioned 0 to 2000 psi gauge to monitor cylinder pressure, and another gives regulated pressure from 0 to 60 psi (1 psi increments) which is provided to the loading system. Also included in the system are two pressure-relief valves; they are certified compliant and were pre-set by Swagelok at 500 psi and 60 psi respectively, with wetted components made of FKM/PTFE. The ball-valves used in the system are ¼ turn valves using PTFE seals. There are two 40 cc cylinders (Fig. 1, TK1,2) to add volume to the gas system to compensate for temperature/ pressure changes in the system.

An external vacuum pump (Fig. 1, P1) is connected to the system to allow evacuation of the system as well as the target. There are two pressure transducers (Stellar Technologies model IT2000); one in the high pressure side (Fig. 1, PT1) of the system, and one in the low pressure side (Fig. 1, PT2) of the system. The digital readouts for these transducers are in 0.1 psi increments. 1/4" o.d. stainless steel tubing was used to connect all components in the system along with nut and two-piece ferrule Swagelok fittings.

The components were subjected to rigorous testing to ensure they met the ASTM pressure piping B31.3. Pressure testing included testing one of each component to 8000 psi, and in the case of the small volume cylinders, cutting a sample of the wall to verify engineering tolerances. The system was engineered to precisely regulate and supply gas to targets mounted in the gas gun target chamber while protecting personnel and equipment.

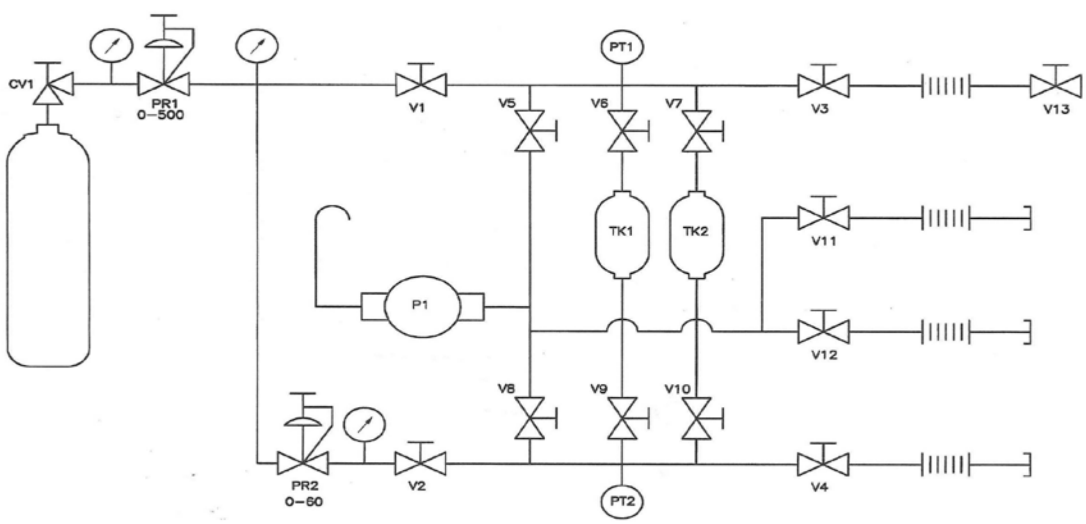


FIGURE 1. Valve diagram for the remote gas loading system implemented at Los Alamos National Laboratory for filling gas gun target assemblies with 200-1000 psi gases at room temperature. The components of the gas loading system are described in the text.

For portability, the loading system is mounted in a cabinet (Fig. 2) that houses a #4 gas cylinder of the desired gas for the shock compression experiment. To provide gas delivery from the loading system through the target chamber and to the target, 1/16" o.d. 0.030" i.d. stainless steel tubing was used. The small diameters of the tubing allow for flexibility to aide in routing and minimize the effects of temperature change in the system.

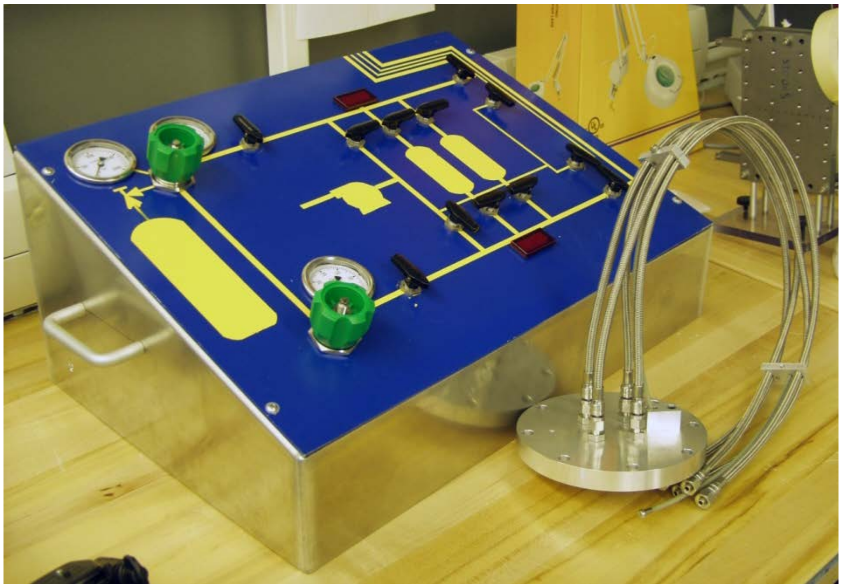


FIGURE 2. Outside view of the gas loading system cabinet that shows the valves accessible to the user. Also shown is the feedthrough and tubing used to connect the gas loading system to the gas gun target assemblies in the target chamber of the LANL two-stage gas and powder guns.

System operation

The target assembly is first aligned to the exit interface of the launch tube of both two-stage guns at LANL. The loading system and target are connected by routing the connecting tubing though a bulk-head connector. The gas is supplied to PR1, where it is regulated to the desired pressure as indicated by PT1. The regulated gas is fed through valves V3 and V13 to the target via 1/16' stainless steel tubing. The gas feeds through the target and back to V11, which is connected to an external vacuum pump. The external dry-type vacuum pump has separate pressure and vacuum gauges mounted on it. The pump is used during the purge cycles on the cell to ensure that only the sample gas is in the cell, and is not mixed with ambient air. The vacuum gauge is between the pump and the target and is used to verify there are no leaks before the target is loaded before the shot the loading system the target and all plumbing are leak checked with by evacuating the system. When the system is evacuated, valves V1 and V11 are closed and vacuum is observed for a short period of time. If there is no vacuum leak, a pressure test is conducted using the selected gas for the experiment. The system is charged with gas to the desired shot pressure. If there is no pressure leak, there is a series of purge and charge cycles to ensure the target is charged with only the gas to be tested and eliminate atmospheric air contamination. After the purge cycles are completed, the gun is configured to fire. The target is filled in a short time frame before the experiment to ensure the correct pressure is achieved. The low pressure side of the system can be used for purging and leak detection as well as filling the target to low pressure. Gas flows from PR1 to PR2, and then via valves V8 and V11, can be directed to the target.

Target design and example experimental results

Targets were designed as a metal cup with a 3-5 mm thick front impact face or "baseplate," Figure 3A. The gas thickness was ~ 1 mm, and the volume of the gas is ~1.38 cc for the largest target geometry with ~ 38 mm diameter gas cavity, and 6.35 mm thick rear z-sapphire or oriented [100] single crystal LiF window, allowing optical access for velocimetry diagnostics such as VISAR (velocity-interferometer-system-for-any-reflector) and PDV (photonic Doppler velocimetry) [11,12]. Targets are made from EOS standard materials to include 6061 aluminum and OHFC Copper. The metallic inner surface of the target is turned to a mirror finish using a diamond tool process that provides a specular surface. The window has a small area that is aluminum vapor coated (0.8 microns thick). Targets are measured to verify thickness of the impact surface, gas thickness, and cell volume following assembly, and pressurized to the anticipated experiment pressure. Additional details about the targets and experimental results for Ar gas at 3 initial gas-phase densities are described in References 8 and 9 [8,9].

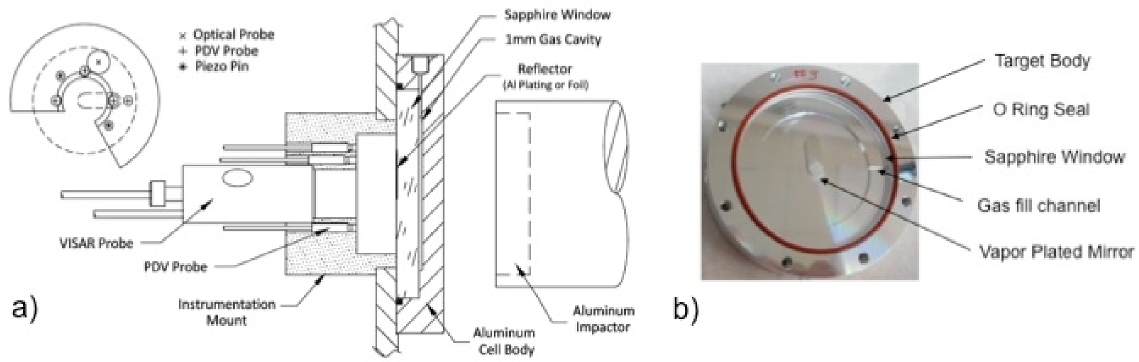
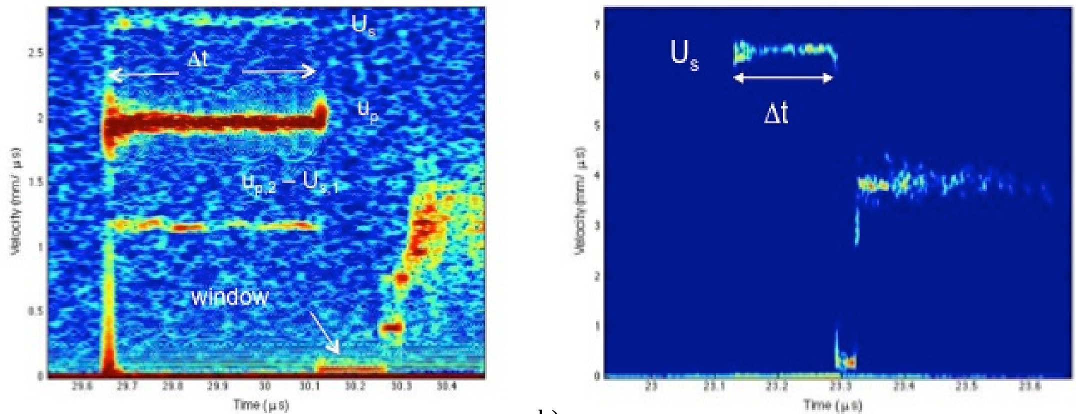


FIGURE 3. a) Side view of experimental configuration. An Al impactor contained within a Lexan projectile impacts a front "baseplate" on the front of the target at the exit aperture of the two stage gun. A thin (1 mm) gas cavity is sandwiched between the baseplate and a rear window (z-sapphire or LiF). Multiple PDV probes and a center VISAR probe are focused onto the baseplate and an 8 kÅ thick Al mirror on the window. An optical fiber was also used to collect emitted light at the rear of the target. b) A photograph of the rear view of a partially assembled 6061 Al/z-sapphire target.

The gas loading system was implemented on over 30 plate impact experiments to date on noble (Ar, Xe, Kr) [8,9] and molecular (NH_3) [10] gases at impact velocities up to ~ 6 km/s. Figure 4 shows examples of PDV spectrograms from two experiments on Ar gas starting at an initial density of ρ_0 = 0.0565 g/cm^3 (~220 psi). Hugoniot data for Ar gas initial densities of ρ_0 = 0.0250, 0.0338, and 0.0563 g/cm^3 obtained using the gas loading system are reported in Reference 8 [8]. Figure 4A shows the PDV spectrogram from a probe focused on the rear surface of the 6061 Al baseplate. In this experiment, a symmetric impact of a 6061 Al impactor at V_{proj} = 2.003 ± 0.002 km/s imparts a shock wave into the gas with shock velocity U_s = 2.74 ± 0.11 mm/μs, particle or mass velocity u_p = 1.984 ± 0.002 mm/μs, and shock pressure P = 0.31 ± 0.02 GPa. At this condition, the Ar has a compression ratio of $\eta = \rho/\rho_0 = 3.7$, and the gas is not ionized upon 1st shock. The PDV spectrogram is rich with information. One can clearly observe the particle velocity at the 6061 Al/gas interface, as well as combinations of the shock and particle velocities. Furthermore, shock wave arrival at the rear z-sapphire window is observed, followed by step-wise increases in particle velocity at the rear window as the Ar gas is shock reverberated to higher pressures. By contrast, Figure 4B shows the PDV spectrogram from shot 2s-809. In this experiment, a Ta impactor is impacted into a layered baseplate comprised of 304 SS/6061 Al at V_{proj} = 3.428 ± 0.001 km/s. The asymmetric impact condition produces a higher shock state in the Ar gas, also at ρ_0 = 0.0565 g/cm^3. In this experiment, U_s = 6.55 ±0.03 mm/μs, u_p = 5.454 ±0.005 mm/μs, and P = 0.95 ±0.07 GPa. The Ar is ionized promptly by the incident shock wave, and the PDV spectrogram shows the measurement of the shock velocity, as the 1550 nm PDV light is reflected off of the shock front. The measured shock temperature is T = 24600±1600 K as determined by absolute radiance at 625 nm. The arrival of the shock wave at the rear window is still clearly observed, as is the off-principal Hugoniot shockwave reverberation of the gas.



a) b)

FIGURE 4. a) Photonic Doppler velocimetry (PDV) spectrogram from shot 2s-568. In this experiment, a 6061 Al impactor impacted a 6061 Al target filled with Ar gas at ρ_0 = 0.0565 g/cm^3, backed by a z-sapphire window at V_{proj} = 2.003 ± 0.002 km/s. The gas is below the ionization threshold on the principal Hugoniot with $\eta = \rho/\rho_0$ = 3.7, and the particle or mass velocity and combinations of the particle and shock velocities can be observed in the spectrogram. Shock wave arrival and subsequent shock reverberation of Ar to several off-Hugoniot states is also clearly observed in the spectrogram. b) By contrast, above the ionization threshold, only the shock velocity is measured by PDV as the 1550 nm light reflects off of the shock front. In this experiment, 2s-809, Ar gas with ρ_0 = 0.0565 g/cm^3 is shocked to P = 0.95 ±0.07 GPa. The measured shock temperature is T = 24600±1600 K as determined by absolute radiance at 625 nm. Details of the experiments are described in Reference 6.

CONCLUSIONS

In summary, a gas loading system was developed to load targets for gas gun-driven plate impact experiments on two two-stage light gas guns at Los Alamos National Laboratory. The gas loading system was successful implemented and applied to over 30 shockwave compression experiments on noble gases [8,9] and anhydrous ammonia [10]. The gas loading system allows for multiple pump-purge cycles, and maintenance of gas pressure to < 1 psi at room temperature for extended periods of time leading to firing of the gas and powder guns. The system will be further applied to additional molecular gases in the future for improvement of detonation product fluid equations of state.

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