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HEATING AND COOLING GAS-GUN TARGETS: NUTS AND BOLTS

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Summary - The nuts and bolts of a system used to heat and cool gas-gun targets is described. We have now used the system for more than 35 experiments, all of which have used electromagnetic gauging. Features of the system include a cover which is removed (remotely) just prior to projectile impact and the widespread use of metal/polymer insulations. Both the cover and insulation were required to obtain uniform temperatures in samples with low thermal conductivity. The use of inexpensive video cameras to make remote observations of the cover removal was found to be very useful. A brief catalog of useful glue, adhesive tape, insulation, and seal materials is given.

INTRODUCTION

The context in which we heat or cool gas-gun targets is that of electromagnetic particle velocity gauging[1,2] in shock wave and detonation physics experiments. This method measures the local particle velocity through Faraday's law of induction. A conductor moving in a magnetic field will have an induced voltage proportional to the magnetic field strength, the conductor length, and importantly, the conductor's velocity. By embedding small conductive elements within samples for shock wave experiments, the local particle velocity can be measured at multiple locations in a single impact experiment.

Restrictions on the method are that the samples must be electrical insulators. The projectile and impactor must also be insulators. Metals can be used within the target structure, but must not be ferromagnetic (no iron). The metal also must not move at early times while data is recorded from the gauges.

Electrical insulators, materials which are poor electrical conductors, are also poor thermal conductors. In a poor thermal conductor, it is very easy to get temperature gradients and non-uniform temperatures. These are undesirable. In a poor thermal conductor, it is difficult to get uniform temperatures. In summary, trying to heat and cool samples which are poor thermal conductors, trying to get uniform temperatures in the samples, all in the context of electromagnetic gauging drove the experimental developments which we will present in the following paragraphs.

EXPERIMENTAL

Temperature Controlled Target Design

Figure 1 is an illustration of the projectile and target.[3-5] The target shown is in nearly its final form, but many parts have been omitted for clarity. Heating or cooling of the sample is achieved by flowing heated or chilled gas through an aluminum base-plate and a copper coil. The sample is instrumented with 5 thermocouples, two interior and 3 on the outside diameter. These give a measure of the sample's temperature uniformity. As you can see in the figure, the projectile is of smaller diameter (50 mm typical) than the inner diameter of the copper coil (150 mm). This ensures that no metal moves at early time.

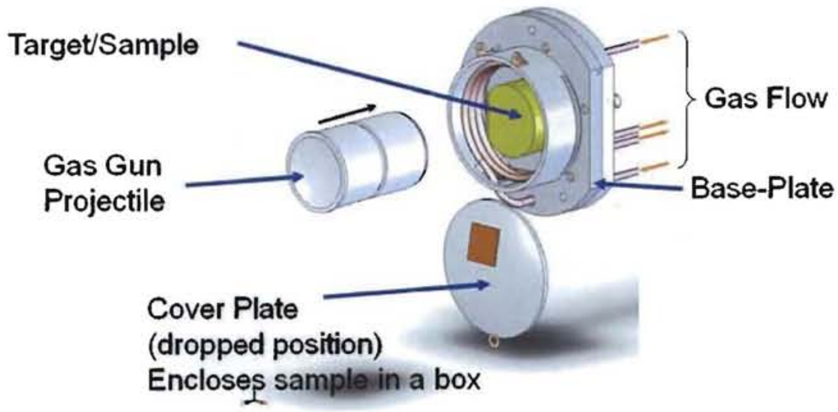

Fig. 1. Illustration of the target used for heating or cooling gas-gun samples.

Because the target/impact chambers of our gas-guns are under vacuum, I initially believed that we could get good temperature uniformity with little difficulty. This turned out to be wrong. The vacuum does eliminate convective heat transfer, and the sample is in good thermal conduction contact with the baseplate. Nevertheless, we could not get the impact face of the sample very close to the same temperature as the interior. We believe that radiative heat transfer between the gun muzzle and sample was taking place. The cover plate, shown in Fig. 1 is intended to block radiative heat transfer, and in its present form is quite effective.

The cover plate is built from several thin layers of insulation (Lydall CRS wrap) and aluminum foil. Early versions were flat, but we found that domed versions result in better temperature uniformity. The cover plate is suspended from a length of Nichrome wire using a Zinc hook. At the last moment before the shot is fired the cover is dropped; a current is run through the Nichrome wire which heats up and melts through the zinc hook. An inexpensive video camera costing about $30 (e.g. Samsung CMB5000ST) is used to verify that the cover drops and does not occlude the front of the target. (The copper square shown in Fig. 1 is a weight attached to the cover. It is intended to help the cover drop correctly.) Finally, in the emergency situation when the cover does not drop correctly, we have tied a string to the bottom of the cover. This is attached to the drive shaft of a small DC electric motor (Radio Shack part #273-223). Switching on the motor, the string is wound up on the shaft pulling off the cover.

The inexpensive video cameras have been useful in other gas-gun applications as well. For instance, we have used them to verify that a reactive liquid properly filled a test cell at the last minute.[6] By the last minute, I mean after the target chamber was evacuated and the pump tube and breech pressurized.

The other important factor in getting uniform temperatures in poor thermal conductors is the use of copious amounts of insulation. A barrier of several layers of insulation was used to separate every heated or cooled surface from those at ambient temperature. The insulators we found most useful are made from alternating layers of metal (aluminum) and foam. These are listed in Table 1, below. The way that these insulators help to get uniform temperatures is as follows. The layer of good thermal conductor, the metal, wants to be all at the same temperature. The layer of poor thermal conductor (the foam) separates this layer from the next layer of good conductor. This kind of system sets up layers of nearly constant temperature. Ultimately, the system forms a nearly isothermal box around the sample, helping to improve the temperature uniformity. Insulation is attached to the target using adhesive tape, 5 minute epoxy, or for very high temperatures, GE RTV 116.

Table 1. Temperature ratings of various non-metal components.

Category	*Item*	*Min. Temp.*	*Max. Temp.*	*Comment*
O-rings	Viton o-rings	-25°C	+204°C	
	Silicone rubber o-rings	-110°C	+ 232°C	Can be used up to + 370°C for short times (hours)
Adhesives	Devcon 5 minute epoxy	-40°C	+90°C	We use this routinely at -55°C and + 80°C
	Epoxy Technology 353ND	-50°C	+200°C	
	Epoxy Technology 301	-70°C	+200°C	We are permitted to use this with explosives
	General Electric RTV116	-60°C	+260°C	Silicone
Insulation	ESP Micro-E	-70°C	+115°C	Our tests
	Lydall CRS wrap	-70°C	+260°C	Our tests
Adhesive tape	Glass cloth electrical tape	-70°C	+260°C	
	Duct Tape	-70°C	+100°C	Dept. of Energy Yellow duct tape
Misc.	Teflon plumbing tape	-240°C	+260°C	
	Ultratherm vacuum grease	-60°C	+280°C	

Systems for Heating and Cooling

Figure 2 shows the system for heating the air which flows through the target base-plate and copper coil. House air at about 20 PSI (1.4 bars) passes through a mass flow regulator. Next, the air is split into a channel for the target base-plate and a separate one for the copper coil. Each channel then passes through a 400 Watt gas flow heater, (MSC Industrial Supply #37027299), through a solenoid valve (Asco/Red-Hat #SD8263G205LT), and on to the target base-plate or coil. Return gasses are carried out on a separate line and exhausted.

Some other notes on this system are that permanent lines are ¼ inch stainless steel, while those inside the target chamber are 3/16 inch copper. We have used stainless steel lines inside

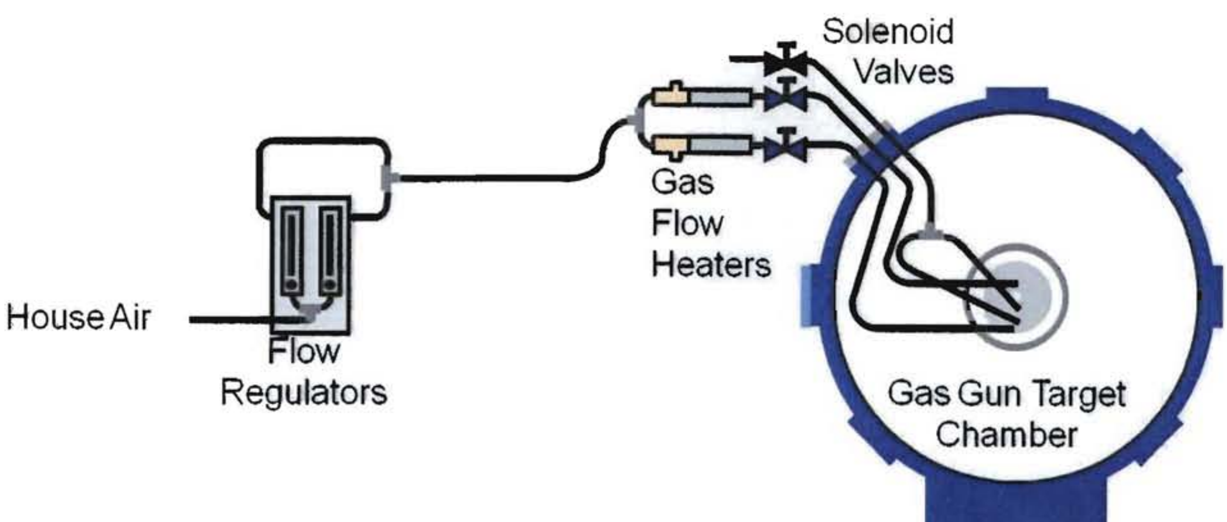

Fig. 2. Target heating system.

the target chamber, however it is more difficult to work with than copper. All lines downstream of the heater are insulated. Swagelock fittings are used for all connections. Lastly, the gas-flow heaters are controlled by hand using variable transformers or Variacs. There is a Variac for the base-plate line, and one for the copper coil line. The experimenter monitors the readings of the thermocouples in the sample and adjusts the Variac voltages to try to achieve the desired temperature. An automatic control system is desirable.

Figure 3 shows the target cooling system. For cooling, dry nitrogen gas is used. The nitrogen gas is chilled by bubbling it up through liquid nitrogen in a 160 liter Dewar. The chilled gas is subsequently reheated to the desired temperature using the gas flow heaters. Note that from the gas flow heaters onward, the system is identical to the heating system.

The dry nitrogen source is a pair of industrial gas bottles connected using regulators which have settings differing by about 10 PSI. When one bottle runs out of gas, the system automatically switches to the second bottle and gas flow is not interrupted. With two full tanks, the system can run unattended for up to 3 hours. This is important because our breech pressurization sequence often takes up to an hour. Likewise, the 160 liter liquid nitrogen Dewar will chill Nitrogen for 2 – 3 experiments.

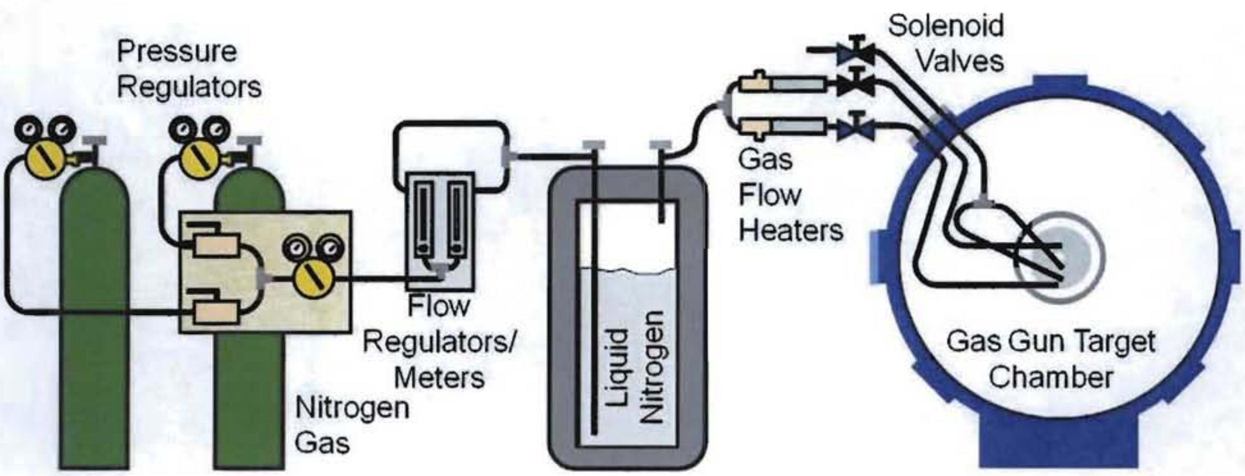

Fig. 3. Target cooling system.

RESULTS

Figure 4 shows the results of two tests in which Teflon samples were heated to 150°C and 250°C. Heating time was 150 – 200 minutes or about 3 hours, for both experiments. Slow heating or cooling of these poor thermal conductors is necessary to minimize thermally induced stresses. The final spread in temperatures for the 250°C experiment was 7°C. The final spread in temperatures for the 150°C experiment was 4°C. We have also heated PBX 9502, a plastic bonded explosive based on tri-amino-tri-nitro-benzene (TATB) to 75°C. Here the temperature spread was only 1°C, probably because TATB is a better thermal conductor than Teflon. In summary, this system gives us good control of the heating rate and fairly small temperature gradients in the sample.

Figure 5 shows the result of an experiment in which PBX 9502 was cooled to -55°C. As with the heating experiments, the cooling took place over more than 3 hours. The final temperature spread is about 1°C. This is typical of the more than 25 cooling experiments we have completed on PBX 9502.

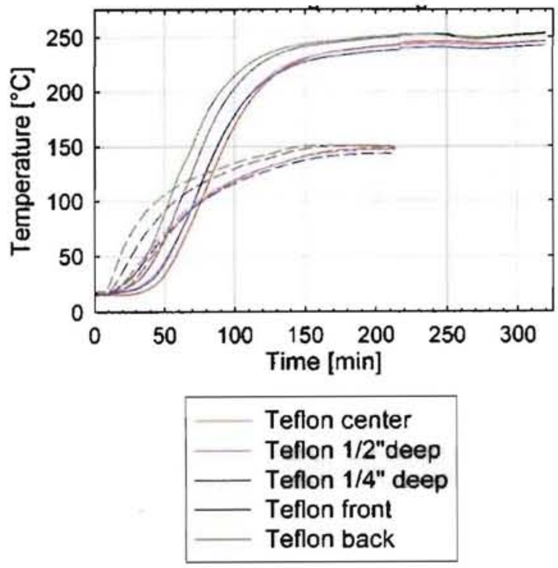

Fig. 4. Results from heating two samples of Teflon.

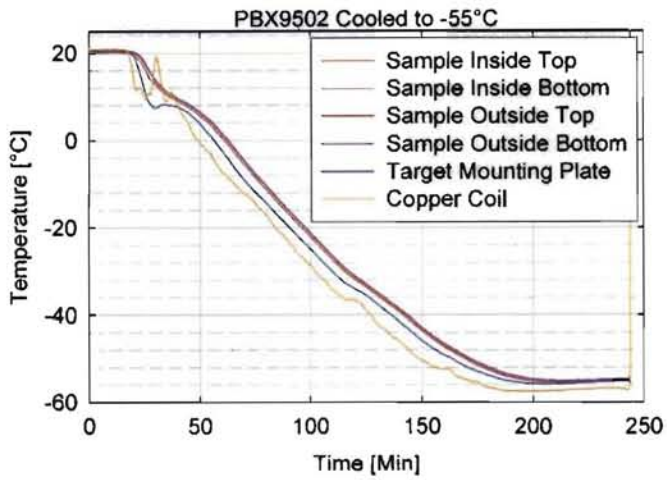

Fig. 5. Results from cooling a PBX 9502 sample.

CONCLUSIONS

To date, more than 35 experiments have been completed on heated and cooled samples using the system described here. Most of these have been on the TATB based plastic bonded explosive PBX 9502 at temperatures of -55˚C and +76˚C. All experiments on PBX 9502 had temperature spreads on order of 1˚C. All but experiment yielded good quality wave profiles from the electromagnetic particle velocity gauges.

Outstanding issues with the system are first, the hand adjusting of the variable transformers supplying power to the heaters. This is tedious and makes the experiments quite labor intensive. Automatic systems are available and could be incorporated into this system. The second issue is increased impact tilt. On our two-stage gas-gun we typically get impact tilts of about 2 – 5 milliradians. With the heated and cooled targets, the tilt is typically 5 – 12 milliradians. This is undoubtedly caused by non-uniform thermal expansion or contraction of the various target parts during heating or cooling, and there is no easy solution to the problem.

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