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PERFORMANCE OF A 100-KV, 78-KJ ELECTRIC-GUN SYSTEM

H. Chau, G. Dittbenner, K. Mikkelsen and R. Weingart
Lawrence Livermore National Laboratory

K. Froeschner
Martin, Froeschner and Associates

R. Lee
Kansas State University

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ABSTRACT

We have constructed a new electric gun system for use in high-pressure EOS studies. The system is powered by a 100 kV, 15.6 μ F capacitor bank. At 100 kV charging voltage the system inductance is 23 nH. This system has driven 0.3 mm-thick Kapton projectiles to >20 km/s and 0.3 mm Kapton/30 μ m Ta projectiles to ~ 10 km/s. Projectile velocity is modeled phenomenologically by an electrical Gurney model.

INTRODUCTION

At LLNL we have made extensive use of a device, which we call an electric gun, to generate planar shock waves for high explosive initiation experiments. An electric gun system operates by discharging a capacitor bank through a thin metallic foil. Ohmic heating of the foil deposits a significant portion of the stored capacitor bank energy into the foil, causing the foil to explode. The explosion of the foil drives a thin plate of material, placed on top of the foil, down a barrel to impact a target. We have discussed the operation of electric gun systems in some detail in a recent publication.¹

As a result of our experience with electric gun systems in high-explosives experiments, we have come to believe that electric gun systems offer potential for ultra high-pressure research (pressures greater than 0.5 TPa). We have developed a new electric gun system for use as a shock wave generator for equation of state (EOS) experiments in the 0.5-1 TPa pressure range. With further development we feel that substantially higher pressures can be achieved.

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EXPERIMENTAL ARRANGEMENTS

The heart of our new system is a 100 kV, 15.6 μF capacitor bank produced by Maxwell Laboratories, Inc. The bank is connected to the exploding-foil load through a rail-gap switch and a large, flat-plate transmission line. The exploding-foil load is aluminum, typically 51-152 μm thick and 9.5 mm wide. The transmission line and load are sketched in Fig. 1. Total system inductance at current start varies from 23 nH at 100 kV to 32 nH at 35 kV bank charging voltage. Variation in system inductance with charging voltage is due to the operation of the rail-gap switch, which breaks down more uniformly at high voltages. Total system resistance up to the time the foil bursts is about 10 m Ω . At 100 kV the bank stores 78 kJ of energy.

FIGURE 1: Sketch of Transmission Line and Load

Also shown in Fig. 1 are the evacuated barrel assembly and target configuration used for our high-pressure EOS experiments. The transmission line from the bank tapers down to a width of 15.2 cm and is terminated by a disposable 15.2 cm-width, flat-plate transmission line, shorted at one end. The exploding-foil element (bridge foil) bridges a gap in a disposable section of the line. The evacuated barrel assembly is usually made of brass. The barrel itself may be an insert of some other material, e.g. alumina, boron carbide (B_4C). We have found that barrels with high shock impedance give the highest-quality flyer plate impact. We have not yet observed any significant difference in flyer velocity when using conducting or non-conducting barrels and metal/plastic composite flyer plates. With less massive and non-conductive projectiles we have some evidence that insulating barrels give higher velocities. Since all-metal barrels are far easier to make, we continue to use them in all our experiments unless we have conclusive evidence that insulating barrels give superior performance. For most of our experiments we use 3.2 mm-long, 8.3 mm-diameter barrels. The projectiles accelerate all the way down the barrels, so we can obtain substantial increases in velocity by using longer barrels (5-7.5 mm) but there is some degradation of projectile flatness with longer barrels. The exploding foils are aluminum, 51-152 μm thick and with the 8.3 mm-diameter barrels we use foils 9.5 mm in width. Depending on the desired projectile diameter and velocity, foil widths can vary from 3.2-38 mm.

Electrical diagnostics are fairly standard. Bank current is obtained by electronic integration of the signal from a calibrated Rogowski probe. We also routinely measure bank charging voltage and voltage across the transmission line.

Shock transit times are recorded with an Imacon image converter camera. Projectile velocities are measured with a Fabry-Perot laser velocimeter or by recording impact times on a glass step.

Tantalum projectiles are of rolled foil 30-76 μm thick, bonded to 0.3 mm Kapton with epoxy adhesive. Tantalum targets are also of rolled foil, 76-152 μm thick with a step cut in the outer edge as shown in Fig. 2.

RESULTS AND DISCUSSIONS

The specifications for a capacitor bank used to power an electric gun depend on its end use. The intended purpose for the bank described here is to generate ultra-high-pressure shock waves suitable for equation-of-state measurements. For this purpose, projectile velocity and simultaneity of projectile impact (flatness) are of paramount importance. Our experience with the smaller banks used for high-explosives work has been very useful, both in deciding on initial specifications and in understanding the behavior of projectiles powered by the new bank.

In our work with the smaller, 40-kV banks we found that bank characteristics and projectile velocity were related through a phenomenological theory developed by Gurney² and extended to projectiles accelerated by exploding foils by Tucker and Stanton³. The electrical Gurney theory relates projectile velocity, V_F , to projectile mass/area, M , mass/area of the exploding foil, C , and current density in the foil at burst time, J_B through the equation,

$$V_F = f(J_B)(M/C + 1/3)^{-1/2}, \quad (1)$$

where $f(J_B)$ is experimentally determined from measured projectile velocities and burst current densities. Eq. (1) describes electric gun performance over a remarkable range of foil/projectile masses and foil geometries^{1,4}. To complete the model one must relate J_B to the bank characteristics and charging voltage. This is done through the expression for an underdamped capacitor discharge,

$$I = I_0 \sin \omega t e^{-t/\tau} \quad (2)$$

and the empirical result of Anderson and Nielson⁴,

$$g = \int_0^{t_B} J^2(t) dt = \text{constant}. \quad (3)$$

I. Eq. (2), $I_0 = V_0/L\omega$, $\tau = 2L/R$ and $\omega = (1/LC + R^2/4L^2)^{1/2}$, where V_0 , R , L and C are bank charging voltage, system resistance, inductance and capacitance, respectively, and t_B is the time the foil explodes.

To achieve high projectile velocities, Eq. (1) indicates the desirability of large values of J_B . Eq.'s (2) and (3) show that to achieve large values of J_B one needs a fast-rising current, i.e. small L and large V_0 . The value of J_B can also be optimized by reducing the conductor cross-section. For our EOS experiments we have chosen Al foils with 9.5-mm width and 51-153 μm thickness.

Fig. 2 shows $f(J_B)$ for the 100 kV bank, determined for a range of M/C values using Eq. 1 and measured values of V_F . For the 40 kV banks used in earlier work we found that $f(J_B)$ was best described by a power law, but the data for the 100 kV bank are better described by a linear function,

$$f(J_B) = 11.01 J_B + 2.64, \quad (4)$$

where J_B is in TA/m^2 . The fit to the data worsens at large values of J_B , so Eq. (4) should not be used beyond the range of the data.

FIGURE 2: Graph of $F(J_B)$ for the 100 kV Bank

Fig. 3 shows projectile velocity, V_F , as a function of charging voltage, V_0 , for 0.3 mm-thick Kapton projectiles and composite, 30- μm Ta/0.3-mm Kapton projectiles. Solid lines are calculations using Eq. (1) and values of $f(J_B)$ determined from experimental data, e.g. Fig. 3. Data are shown for both 100 kV and 40 kV systems. To compare the performance of the banks, we compare data for the same type of projectiles and the same barrel length. From the two bottom curves we see that at 35-40 kV the performance of the two systems is virtually identical. This is because of high switch inductance at low charging voltages. As

charging voltage is increased to 100 kV, there is a substantial difference in performance of the two systems. Data for 0.3-mm-thick Kapton projectiles shows an even greater difference in performance. Using 5-mm barrels, the projectile velocity from the 100-kV system is more than double that of the 40-kV system.

FIGURE 3: Flyer Velocity vs. Charge Voltage

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