SAND2007-3939C

GAS SWITCH STUDIES FOR LINEAR TRANSFORMER DRIVERS*

J. R. Woodworth[ξ], K. Hahn, J. A. Alexander, G. J. Denison, J. J. Leckbee, S. Glover,
Sandia National Laboratories, MS 1194, POB 5800 Albuquerque, NM 87185 USA

P. E. Wakeland, J. R. Blickem
KTech Corporation 10800 Gibson Blvd, SE Albuquerque, NM 87123, USA

R. Starbird, M. J. Harden, H. D. Anderson
NS Tec, 182 East Gate Drive, Los Alamos, NM 87544

F. R. Gruner
Kinetic LLC, 1022 Marine Dr. NE # 71, Olympia WA 98501

D. Van DeValde
EG&G Technical Services, 2420 Comanche Rd. NE Albuquerque, NM 87119

Abstract

We are studying several competing gas switch geometries for Linear Transformer Drivers in an attempt to design an optimum switch for these applications as well as to increase our knowledge of the physics of the switching process. In addition to standard electrical diagnostics (V, I), we are studying the switches with a variety of optical diagnostics including fast photodiodes, a framing camera and a time-resolved spectroscopy system. In our test system, 20-nF capacitors on top and bottom of the switch are charged to voltages up to ±100 kV. Then the switch is triggered and current flows through the switch and a load resistor in a geometry that resembles the LTD 'brick' architecture. We will present results using the multistage gas switches designed at the High Current Electronics Institute [1] and compare them to results with a low inductance switch designed at Sandia that provides a 30% higher peak current through the LTD 'brick'.

I. INTRODUCTION

Linear Transformer Drivers (LTDs) represent a new pulsed power architecture that could dramatically reduce the size and cost of large pulsed-power drivers. Large LTD systems, however, will require hundreds, to tens-of-thousands, of low-inductance gas switches that can be DC-charged to ~200kV and then be triggered with low jitter and low prefire probability. Figure 1 shows a schematic of a basic LTD 'brick'. Capacitors are charged to plus and minus 100 kV and then discharged through a triggered gas switch. This would normally drive a current pulse around the return current loop (black lines) in Figure 1. However, magnetized toroidal cores block the current pulse at early times resulting in a voltage and current waveform being impressed on the magnetically-insulated transmission line (MITL). The risetime of the pulse impressed on the MITL depends only on the R, L and C parameters of the switch and capacitors. Thus, if the inductance of the circuit is kept low enough, discharging the DC-charged capacitors can directly generate a pulse on the MITL with a risetime less than 100 ns and peak currents on the order of ~25 kA.

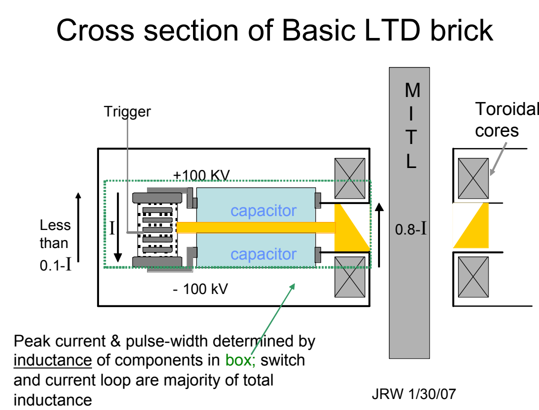

Figure 1: Schematic of basic LTD 'brick'.

* Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of National Nuclear Security Agency under Contract DE-AC04-94AL85000.

ξ email: jrwoodw@sandia.gov

In practice, a number of 'bricks' are stacked around a centerline as in Figure 2, which shows a 0.5 MA cavity developed by the High Current Electronics Institute. This cavity maintains the short risetime of the pulse, while adding current from the 20 'bricks' to produce a 500 kA current pulse. [2] In Figure 2, the current pulse is dissipated in a central resistive load rather than being used to drive a MITL.

Figure 2: 500-kA LTD cavity designed at the High Current Electronics Institute. Current from 20 'bricks' are added in parallel to provide a 500-kA current pulse.

We are studying three different gas switch geometries for LTD switches in an attempt to lower the switch inductance, optimize performance of the LTD 'brick' and improve our understanding of the switching process.

II. APPARATUS

Figures 3, 4, and 5 show the three gas switches being studied in this work. All three switches are designed for 200-kV DC operation. Figure 3 shows the switch designed at the High Current Electronics Institute. This switch has been used extensively in LTD research has a demonstrated lifetime of over 40,000 shots. The switch we studied used a polished polycarbonate insulator instead of the normal nylon insulator to allow optical diagnostics of the switch operation. This multistage switch, which is about 16-cm long, has 6ea ~1-cm wide gaps in series and is filled with 20 to 50 PSIG of dry air during operation. The electrodes are toroidal in form to encourage the formation of multiple arc channels, which would lover the overall switch inductance. The middle electrode of the switch is connected to the trigger generator and also provides the gas supply to the switch.

Figure 4 shows the LTD gas switch designed at Sandia Laboratories. This switch, which is ~10-cm long, has two 1.5-cm gaps in series and is filled with 80 to 160 PSIG of dry air during normal operation. The middle electrode of the switch is connected to both the trigger generator and the gas supply. The switch uses clear acrylic insulators.

Figure 5 shows a schematic of the switch designed by Kinetic, LLC. The switch is ~10 cm long, has a single gap that can be varied from 1.0 to 1.6-cm and has a projected operating pressure of 100 to 180 PSIG of dry air. The switch has four trigger pins projecting in towards the middle of the gap between the electrodes.

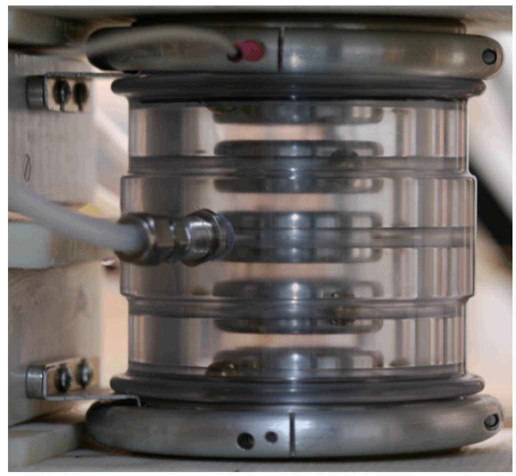

Figure 3: 200-kV gas switch designed by the High Current Electronics Institute. The switch has six gaps, two of which are hidden in the top and bottom of the switch.

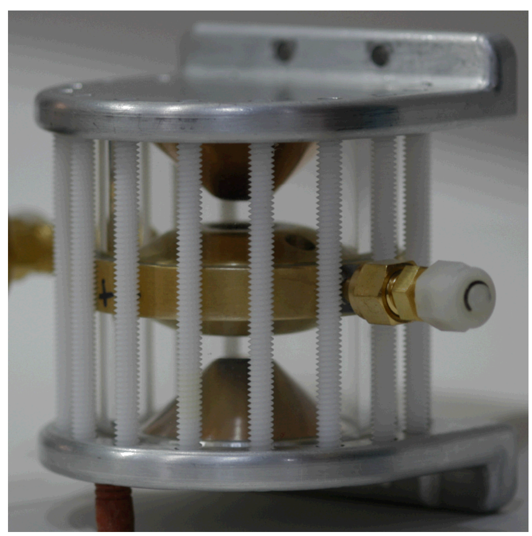

Figure 4: 200-kV gas switch designed by Sandia National Laboratories.

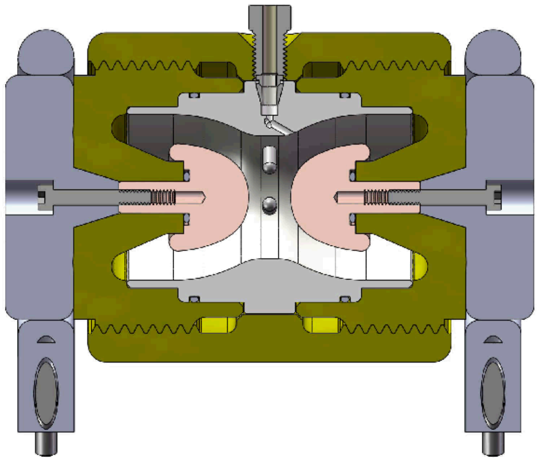

Figure 5: Schematic of 200-kV switch designed by Kinetic, LLC.

In the experiments reported here, the gas switches were in a ‘brick’ consisting of two 20-nf capacitors, the switch, and a resistive load. Charge voltage across the switches was 200-kV unless noted. The switches were submerged in transformer oil for all the tests. We monitored the switch current with a current-viewing resistor and the trigger voltage at the switch with a resistive divider. We monitored optical breakdown of the switches in two ways. First, a fast framing camera took pictures of the switches during breakdown. Second, we looked at the turn-on time of light in individual gaps by using an array of fiber optic cables leading to photomultiplier tubes that were apertured to look at light from individual switch gaps.

III. RESULTS

A. High Current Electronics Institute Switch

Figure 6 shows data from shot 295 with the High Current Electronics Institute switch. For this shot, the voltage across the switch was 200 kV, the switch was pressurized to 30 PSIG and the current was dissipated in a 7-Ohm resistive load. The switch was triggered with a positive 50kV trigger pulse. A 500-Ohm resistor between the trigger generator and the switch prevented brick energy from migrating back into the trigger generator but also limited trigger current. On the basis to 12 shots at these operating conditions, we measured a 1-sigma jitter of the HCEI switch of $\pm$ 10 ns.

Since we used positive trigger pulses and the top of the switch was charged negative, we expected the top of the switch to break down first.

In Figure 6, the trigger voltage (red trace) arrives at the switch at about 75 ns before the main current pulse through the switch begins (blue trace). The gap just above the trigger electrode, however, emits light only ~40 ns after the trigger pulse arrives. The other two gaps above the trigger electrode start emitting light about 50 ns after the trigger pulse arrives. The two bottom gaps we observed begin emitting light about 65 ns after the trigger arrives or about 10 ns before the main current pulse starts. The times when framing pictures were taken are also indicated in Figure 6. Note that we would expect to see light in the first gap during frame 2 and light in all gaps by frame 4.

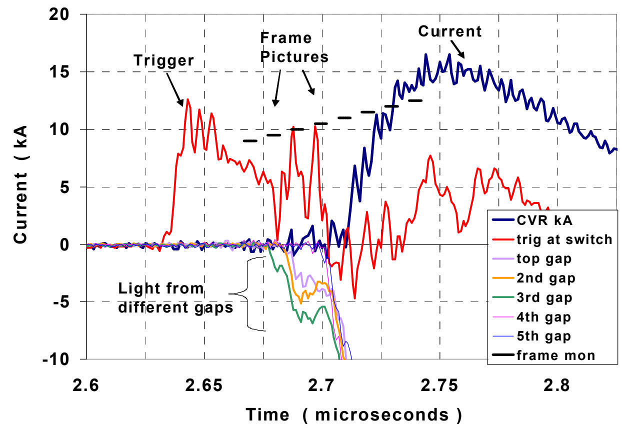

Figure 6: electrical and optical traces for shot 295 of the HCEI switch

Figure 7 shows framing camera pictures of the High Current Electronics Institute switch taken on shot 295.

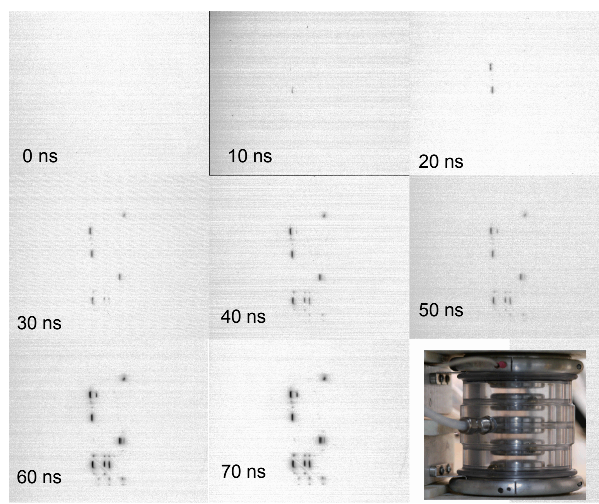

Figure 7: Framing camera pictures of the HCEI switch. Exposure time is 5 ns, with succeeding frames starting 10 ns apart. A photograph of the switch is provided for comparison.

We actually see light from all 6 switch gaps in these frames because light from the top and bottom gaps is refracted through the curved polycarbonate field-shaping ribs at the top and bottom of the switch. The gap immediately above the trigger electrode breaks down in frame 2 as expected from the light signals shown in Fig. 6. Note that we only see multiple arc channels in three of the gaps. We typically saw multiple arc channels in only the bottom two or three gaps of the switch.

B. Sandia Laboratories Switch

Figure 8 shows data from shot 642 with the Sandia Laboratories switch. For this shot, the voltage across the switch was 200 kV, the switch was pressurized to 120 PSIG and the current was dissipated in a 5-Ohm resistive load. The switch was triggered with a positive 100 kV trigger pulse. A 500-Ohm resistor was again placed between the trigger generator and the switch. On the basis to 12 shots at these operating conditions, we measured a 1-sigma jitter of the Sandia switch of $\pm$ 2 ns. Note that the Sandia switch results were obtained with a higher-voltage trigger generator than the HCEI switch results. HCEI switch triggering tests with the higher voltage trigger generator are in progress. Note also that the lower inductance of the Sandia switch, along with a slight change in the series resistor, have resulted in a significantly higher peak current through the brick.

In the Sandia switch data, the trigger voltage (red trace) arrives at the switch at about 25 ns before the main current pulse through the switch begins (blue trace). The gap above the trigger electrode, however, emits light only ~12 ns after the trigger pulse arrives, or about 5 ns before the positive trigger pulse suddenly goes negative, indicating that the impedance in the top gap has collapsed. In a similar manner, the bottom gap begins emitting light at least 5 ns before the main current pulse begins.

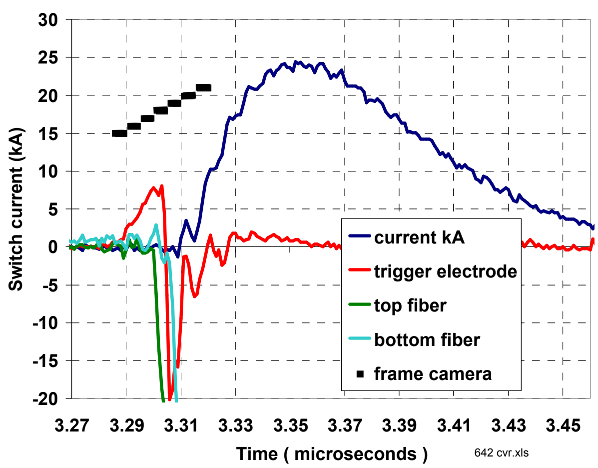

Figure 8: Electrical and optical data for the Sandia switch on shot 642.

The framing camera times in figure 8 indicate that we should begin seeing light in the top gap in the third frame and in the bottom gap in the fourth frame. This is what we see in the framing camera pictures in Figure 9.

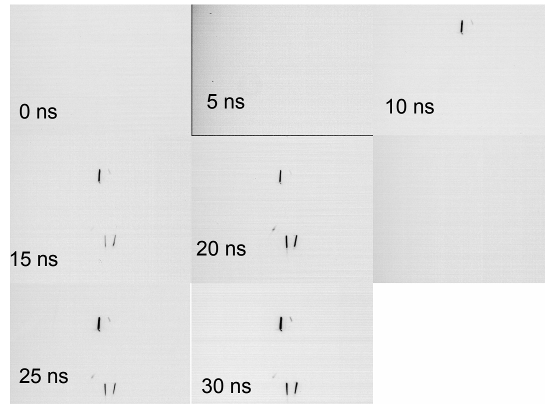

Figure 9: framing camera pictures for shot 642 of the Sandia switch.

Figure 10 shows a plot of delay and jitter for the Sandia switch at a 200 kV charge voltage as a function of self-break voltage. Each data point represents an average of 12 shots. Since we could not perform self-break tests above 200 kV, we approximated the self-break voltage at high pressures (170 PSIG for the data point at 56% of self break voltage) with a linear extrapolation of the self-break curve at lower pressures. The switch shows a broad range of triggerability with a 1-σ jitter below 4 ns for most of the range. The two prefires and one no-fire may be related to the way we were manually charging and firing the switch, but need further investigation.

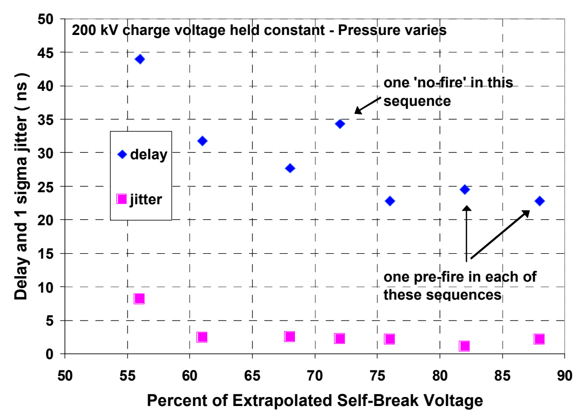

Figure 10: Delay and 1-σ jitter for the Sandia switch.

IV. References

[1] B. M. Kovalchuk et al. proceedings of the 13th IEEE pulsed Power conf. Las Vegas, 2001, p. 1739.

[2] A. A. Kim et al. "100 GW Fast LTD Stage" 13th International Symposium on High Current Electronics, Tomsk, Russia, July 2004, p. 141-144.