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HIGH-VOLTAGE TECHNOLOGY FOR THE LASL IMPLOSION-HEATING EXPERIMENT

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Summary

As described in the preceding paper, the implosion-heating power supply uses four 125-kV generators in series. Each generator consists of a fast 125-kV pulse-forming network made up of capacitors attached to a 1-m-wide parallel plate transmission line which is fed through multiple cables from a 2.5-μF, 0.5-μH Marx bank charged to 180 kV.

To simplify construction it was decided to do without oil or water for high-voltage insulation and grading. The developments described here are: (1) A low-inductance connection between the 125-kV capacitors and the parallel plate transmission line using an elastomer gasket capable of holding 200 kV. (2) Edge flashover prevention by "ballooning" the sheet insulation, by which a 10-cm edge extension of insulation is capable of withstanding a 200-kV pulse for several microseconds. (3) Using the edge flashover for over-voltage prevention. (4) Grading of voltage along insulators with conducting plastic sheets to prevent flashover at the load switches and cable connections. (5) Capacitively graded insulating supports for the Marx banks.

Introduction

This paper concerns itself with some of the technical details in the design of the LASL 40-cm diameter implosion heating experiment. Figure 1 shows a schematic diagram of the four series-connected pulse-forming networks (PFN's). It is also an approximate representation of the mechanical arrangement of the components. Each of the fast pulse-forming networks is made of two sets of 125-kV capacitors attached to a 1-m-wide parallel plate low-impedance transmission line. The PFN is pulse charged to 125 kV from a Marx bank type power supply in approximately 1.4 μsec, at which time the load switches are fired to apply the voltage to the load coil.

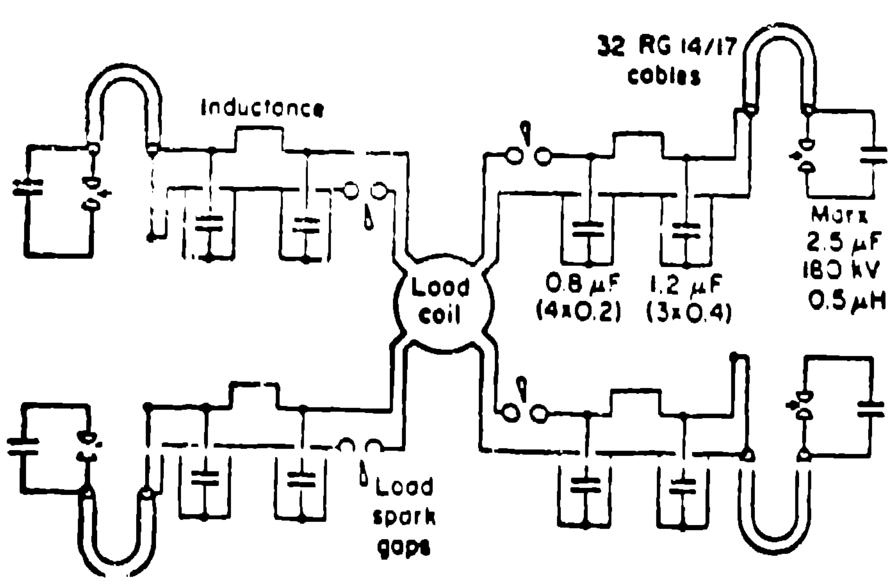

Fig. 1 Schematic diagram of the LASL Implosion-Heating Experiment.

Low Inductance Capacitor Connection

The capacitor connection to the parallel plate transmission line must have as low an inductance as possible, and it must be able to stand 125 kV very reliably. The final design shown in Fig. 2 uses a poured-in-place elastomer gasket.* The usual capacitor insulator barrier has been cut down to reduce the inductance. A very thin layer of silicone grease** is used between the gasket and each of the four layers of 0.032-in-thick polyethylene sheet insulation. An additional 0.25-in.-thick polyethylene spacer is used above the sheet insulation to reduce the electric field strength at the outside edge of the gasket. Approximately 6000 lbs. of force is used to compress the insulation on the gasket. Since the silicone rubber gasket is molded 0.010-in. higher than the surrounding plate, the force is distributed over the gasket surface at about 200 psi. This insulating arrangement has been successfully tested repeatedly with several capacitor headers to 200 kV with pulses rising in less than 1 μsec and with an RC decay time of around 100 μsec. Raising the voltage on one sample produced a breakdown through the capacitor insulator at 235 kV. This design appears to be quite adequate for the 125-kV service.

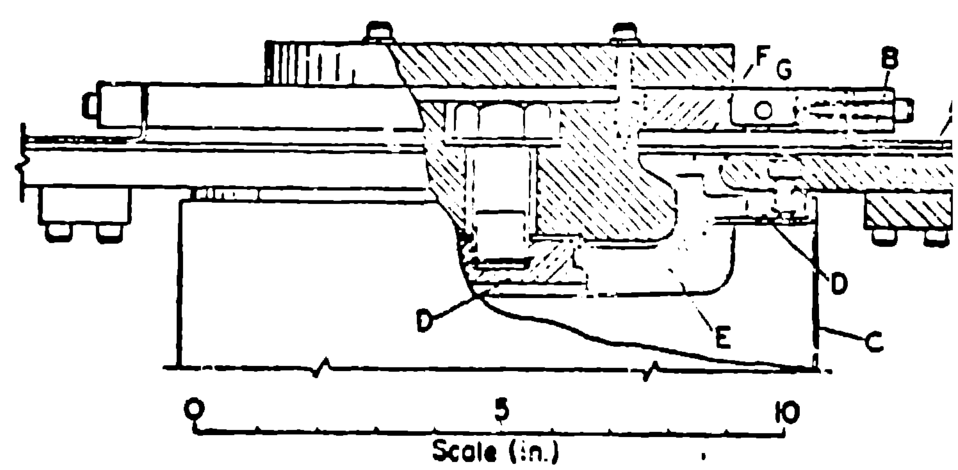

Fig. 2 Scale diagram of low-inductance connection between parallel plate line and the 125-kV capacitor header. (A) transmission line plate, (B) transmission line insulation: four sheets 1/32-in. polyethylene, (C) capacitor can, (D) capacitor terminals, (E) capacitor insulator, (F) poured-in-place silicone rubber high-voltage gasket, (G) 1/4-in.-thick polyethylene spacer.

Edge Insulation for Parallel Plate Lines

Flashover prevention provided by a simple extension of sheet insulation beyond the edge of parallel plate high-voltage electrodes diminishes in effectiveness as voltages are raised to 100 kV and higher. Tests have shown that the voltage standoff for a given voltage waveform is a function of both the edge extension of the sheet insulation and its thickness. Figure 3 shows flashover curves obtained for various thicknesses of polyethylene. The voltage waveform in these tests approximated a single cycle of a slightly underdamped sine curve rising in 5 μsec to peak. In order

* Dow-Corning Sylgard 184. This method was suggested by P. Champney of Physics International, Inc.

** Dow-Corning 5 Compound.

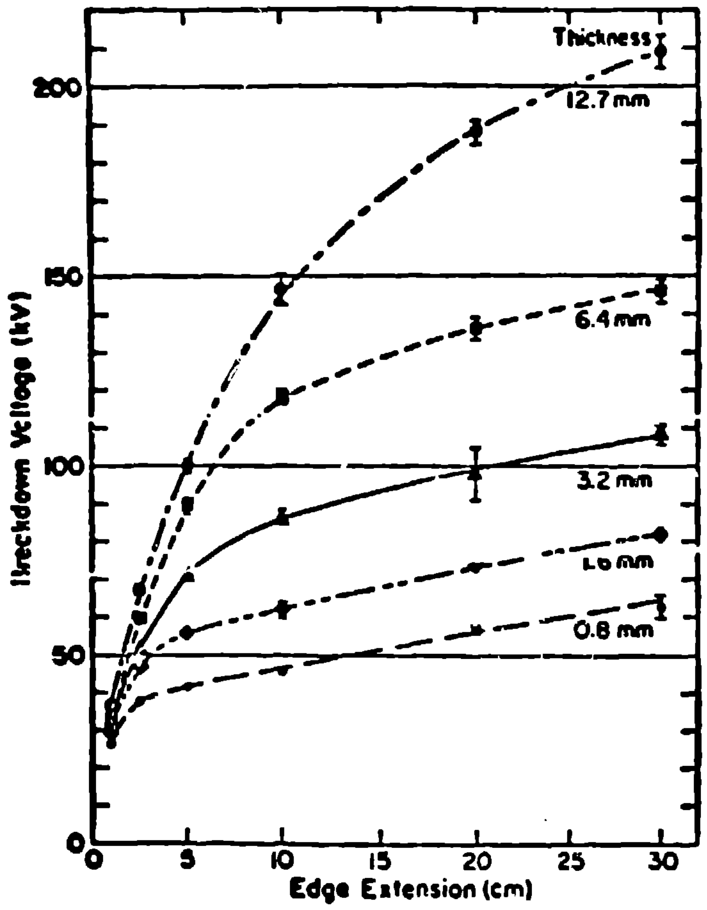

Fig. 3 Flashover voltages for a straight extension of insulation of various thicknesses and width from the edge of a parallel plate transmission line.

to minimize time effects, the voltage amplitude was adjusted so flashover occurred at 4 μsec while the voltage was still rising. We have also observed that the flashover voltages are not significantly different for the same dimensions of mylar and polyethylene.

Our understanding of the flashover process under pulsed-voltage conditions is that at the high electric fields imposed on the insulation, the air at the electrode edge breaks down and a large number of streamers start from each electrode edge. Some of these streamers may coincide on the opposite surfaces of the insulation, and since the streamers are conductors, they tend to extend the potential of each plate outward along the surface, further ionizing the air at their tips. The streamer propagation is influenced by their intrinsic impedance, the source impedance, and by the field strength at the streamer tips.*

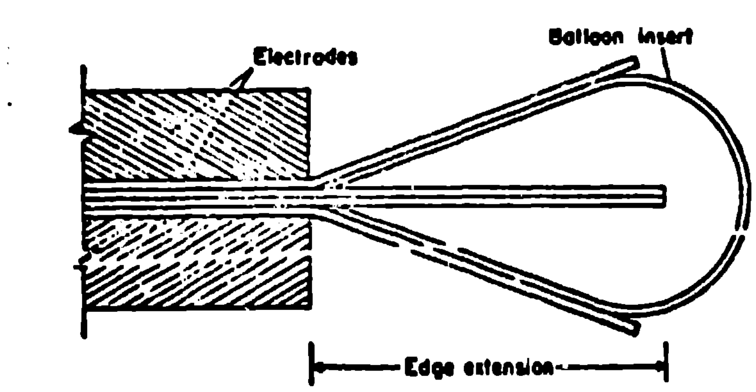

Fig. 4 Flashover prevention by "ballooning" the insulation at the edge of a parallel plate transmission line. With four sheets of 1/32-in. insulation and edge extension of 4-in., and a balloon insert 12-in.-wide, the flashover voltage is 200 kV.

Therefore, if the insulator surfaces can be separated so that the streamers propagating outward find the field strength decreasing at their tips, the flashover voltage may be increased. We do this by sticking in a sheet of insulation in a "balloon" fashion as shown in Fig. 4. In order to be effective, the separation has to start at the edge of the electrodes.

Overvoltage Protection

At the time that the PFN has reached 125 kV, the Marx bank is delivering a considerable amount of current (~ 300 KA), which normally adds to the current from the PFN to deliver the peak current of about 800 kA to the load. However, if the load switches should fail to close, this Marx current, because of the circuit inductance, would seriously overcharge the PFN capacitors. Therefore, we will need an overvoltage protection switch. At the present, the simplest and most promising method appears to be to let a flashover develop across a specified section of insulation at the edge of the transmission line. Tests with a single capacitor mockup line have shown that, for a given insulation edge extension and thickness, the flashover voltage is very repeatable with no damage to the insulation. The drawbacks to this type of switching are its high sound level and possible damage to the insulation at the higher energy levels. However, for infrequent use, these can be overcome by proper muffling and by making the insulation in that region replaceable.

Conductive Plastic Voltage Grading

Another method of flashover prevention is to grade the voltage along an insulator surface so the electric fields do not exceed the breakdown strength of air. Voltage grading has usually been done by immersing the electrode and insulator assembly in slightly conductive water solutions. A much more convenient method would be to provide the grading by a conducting sheet material. We found a suitable material to be carbon filled polyolefin film.* The film has to have a low enough resistivity to be able to charge the capacitance between the insulator surfaces sufficiently fast compared to the voltage risetime, and it has to have both a thickness and connections to the electrodes, such that current density anywhere does not exceed certain limits. We have not investigated these limits in detail, but a test with 0.006-in.-thick material with 7500 Ω per square resistance would hold off about 6.5 kV/cm for distances from 15 cm to 30 cm and voltage pulses about 5 μsec in duration. It thus appears that the maximum current density for that test sample was 0.9 A per centimeter of width. Where this limit is exceeded, as for example at connections to corners of the electrodes, the plastic blows up and breakdown occurs through the conducting plastic. This is also demonstrated by the fact that if thicker plastic of the same resistance is used, the voltage hold off increases.

We have used the conducting plastic film wrapped around the rail spark gap load switches as shown in Fig. 5 and obtained voltage hold off to 195 kV. Above that the breakdowns occur primarily because of difficulty in obtaining a uniform current connection between the conducting plastic and the switch electrodes, but is reliable at the 125 kV operating voltage.

A method of voltage grading of the skinback of a cable is shown in Fig. 6. Here a 12-in. skinback graded with the conducting plastic can withstand 200 kV, 5-μsec pulse, without breakdown. This method is used to grade the cable connections between the Marx banks and the PFN's in our experiment.

* A similar process has been suggested by J. C. Martin in one of his notes on "Dielectric Breakdown and Tracking" (SSWA/JCM/Hun/5).

* This material can be obtained in various resistivities and thicknesses from Custom Materials, Inc., Chelmsford, Mass. under the trade name of Velostat.

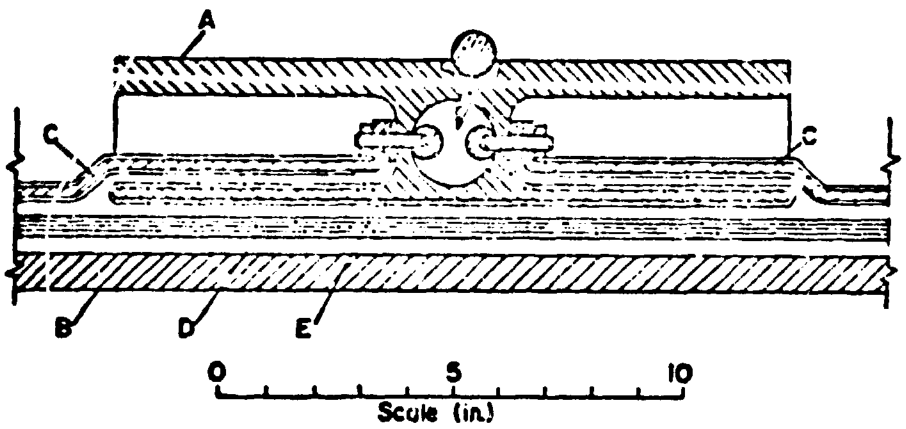

Fig. 5 Diagram of the rail electrode spark gap load switch installation. (A) Physics International Co. modified Model S1 switch assembly, (B) Continuous plate of transmission line, (C) Switched plates of transmission line, wrapped in insulation near the switch, (D) Main transmission line insulation, four sheets of 1/32-in. polyethylene, (E) Conductive plastic sheet wrapped around switch.

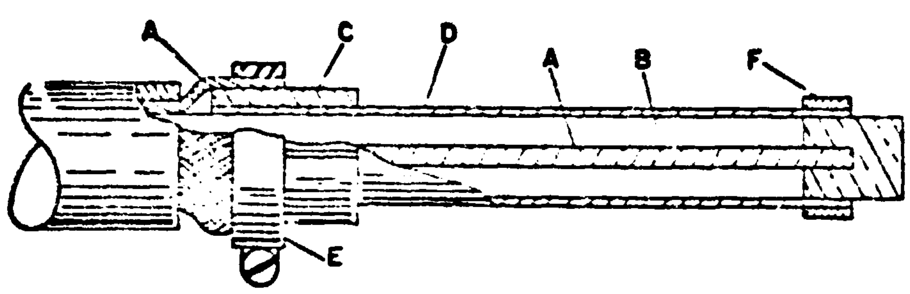

Fig. 6 Schematic diagram of conductive plastic high voltage grading of cable insulation skinback. (A) Cable conductors, (B) Cable insulation, (C) Split ring electrode and clamp, (D) Conducting plastic wrap, (E) Hose clamp, (F) Plastic cable strap.

<u>Capacitively Graded Insulating Supports for Marx Bank</u>

Each of the four Marx banks shown in Fig. 1 actually consists of two separate banks in parallel. Each of these two banks consists of six sections of 40-kV, 7.5-μF capacitors, and is erected through six field distortion spark gaps. To make use of capacitors already on hand, each section is made of two 20-kV, 15-μF capacitors in series. Because of the high inductance of these capacitors it is necessary to parallel two of these banks to charge each of the four pulse-forming network lines. All eight of the Marx banks are charged in parallel and fired simultaneously with a single trigatron type spark gap which shorts the ends of eight charged 50-Ω cables. Because of space limitations it was necessary to stack the eight Marxes in pairs with their outputs in the middle of the stack. The upper two banks in the two stacks at one end of the machine are connected to the upper pulse-forming line, and lower two to the lower line; therefore it became necessary to develop an insulating support that would mechanically support and electrically isolate the top Marx from the bottom one. This is shown in Fig. 7. The intermediate plates in this support add rigidity and provide capacitive voltage grading. The support can withstand the full maximum 240 kV output of one of the Marxes.

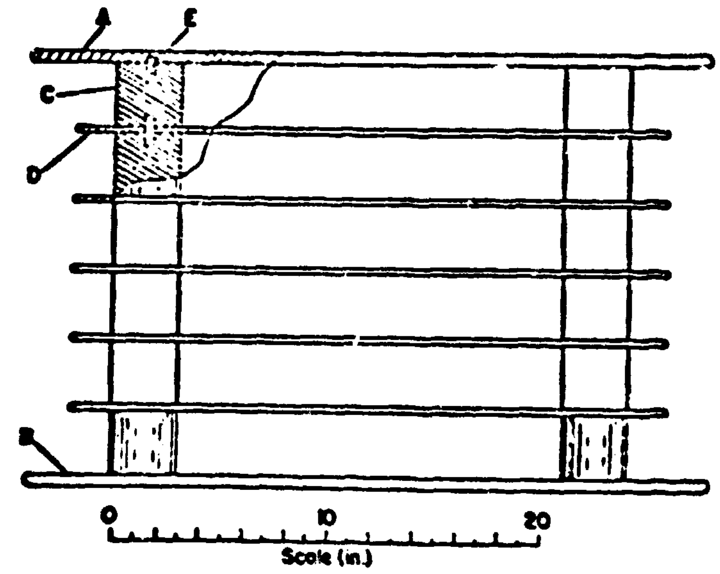

Fig. 7 Insulating support for stacked 240-kV Marx banks. (A) Output plate of top Marx bank, (B) Output plate of bottom Marx bank, (C) Cylindrical phenolic spacers, one in each of four corners, (D) Aluminum capacitive grading plates, (E) Dowel pins.

<u>Acknowledgements</u>

We want to express our appreciation to Guy Eden, Michael Kelly, Ronald Oliver, and William Smith for their assistance in construction of equipment and in carrying out the experiments.