ELECTRICAL BREAKDOWN IN TRANSFORMER OIL IN LARGE GAPS

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ABSTRACT

The Aurora accelerator uses four parallel Blumlein pulse-forming lines to provide an intense flash x-ray pulse. Proper timing of the pulses generated by each Blumlein is important to the quality of the radiation. The pulse on each Blumlein, and the synchronization between the Blumleins are affected by the closure of high-voltage triggered oil switches in each line. The triggered oil switch utilizes a uniform field geometry with a gap spacing between 40 and 50 cm, a unique environment for observation of arc development in transformer oil. High-speed photography of switch closure shows timing to be influenced by the initiation and spatial development of prebreakdown streamers.

INTRODUCTION

The Aurora accelerator [1] is a flash gamma-ray simulator operated by the Defense Nuclear Agency. The device uses four Blumlein pulse-forming lines that may be fired separately or in concert to generate a burst of hard x-ray radiation. Each line consists of an oil-insulated Blumlein coupled to a magnetically insulated transmission line that is terminated in an electron-beam diode. The Blumleins are charged by an 8 MJ Marx generator, and high-voltage pulses are launched by closure of triggered oil switches in each line. Recent improvements in the risetime of the radiation pulse generated by a single Blumlein [2, 3] place new constraints on the acceptable timing jitter during parallel operation and motivate re-examination of design and operating parameters.

The 12 MV oil switch is one element critical to synchronizing the Blumleins. This report describes the normal operation of the oil switch, identifies the sources of variability for closure of the switch, and suggests strategies for reducing switch jitter. Other aspects of synchronization include: reduction of the jitter in the gas switches and equalizing the pulse charging voltage on each Blumlein [4, 5].

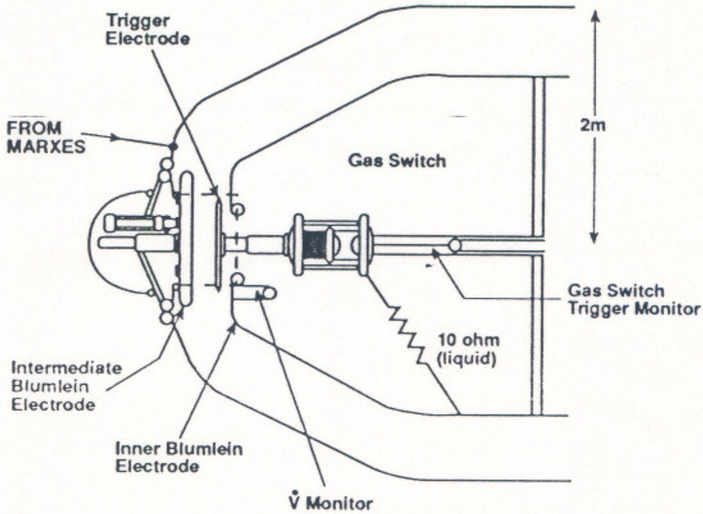

Figure 1. Schematic of Aurora's V/N oil switch.

OIL SWITCH OPERATION

The oil switch is shown schematically in the above figure. The operation of the oil switch is monitored by a capacitive probe mounted within the inner Blumlein, the $\dot{V}$ monitor shown in the figure. The $\dot{V}$ signal is proportional to the current from the high-voltage electrode: $I = dQ/dt = d(CV)/dt$, assuming the capacitance of the trigger electrode is constant and that stray current may be neglected. The trigger voltage is obtained by hardware integration of the $\dot{V}$ monitor signal. The oil switch trigger voltage is shown together with other monitor signals in Figure 2.

The oil trigger electrode is a circular, steel plate 95 cm in diameter. The electrode is 1.25 cm thick and the circumference is machined to an edge having a 125 μm radius of curvature. The trigger is held approximately 5 cm into the gap and is electrically connected to the

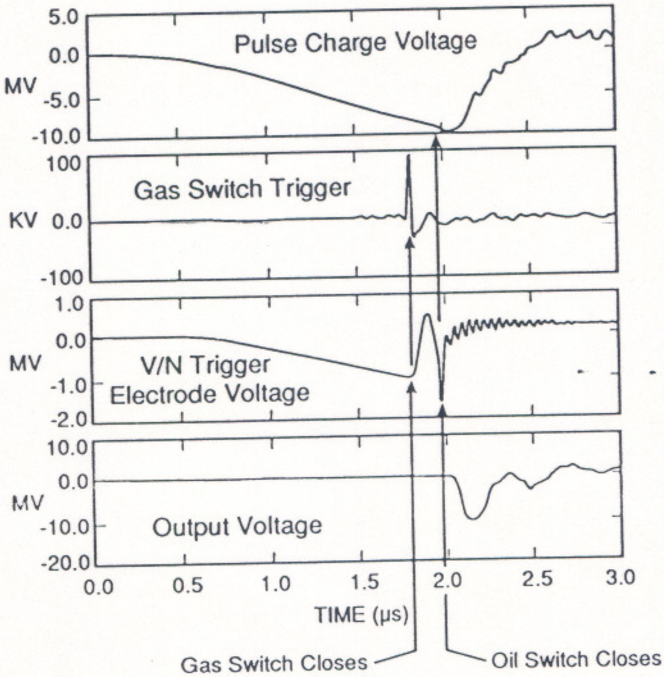

Figure 2. Blumlein voltage monitor signals.

high-potential side of the gas switch. The gas switch's ground electrode is electrically connected to the inner Blumlein through a solid aluminum frame. The intermediate electrode is charged to approximately -10 MV by erection of the Marx generator. During pulse charging, the oil switch trigger reaches a voltage V/N, where the capacitance of the trigger to the inner Blumlein is $N-1$ times the capacitance to the intermediate Blumlein electrode. Closure of the gas switch allows the charge on the trigger electrode to flow to the inner Blumlein, and dramatically increases the electrical stress at the trigger's edge. Prebreakdown streamers originate at the sharp edge and propagate across the gap toward the intermediate electrode. Conducting arcs develop along the path of the streamers, connecting first between the oil switch trigger and the intermediate Blumlein and then to the inner Blumlein, thus closing the switch. The negative going spike appearing in the trigger signal indicates that electrical contact has been made between the high-voltage electrode and the trigger.

The switch run time, that is, the delay between closure of the gas switch and closure of the oil switch, is one measure of switch performance. In general, switch run time, t_r, depends on the average electric field strength, E_{av}, in the gap [6]:

$$t_r \simeq 22\, E_{av}^{-1.33}.$$

Here E_{av} is in units of MV/cm and t_r is in ns. The intermediate and inner Blumlein electrodes are separated by approximately 50 cm, and, for the conditions described, the average electric field strength is on the order of 200 kV/cm, which yields a mean run time of 180 ns.

OPTICAL DIAGNOSTICS

Two high-speed photographs, obtained during switch closure under identical conditions, are shown in Figure 3. Each photograph consists of a sequence of eight exposures: The time separations between frames and the frame exposure times are approximately 50 ns and 10 ns, respectively. The field of view is represented by the broken line in Figure 1.

These data are consistent with the initiation of multiple prebreakdown streamers that are uniformly distributed on the circumference of the trigger. The luminous regions along the edge of the trigger that appear in the second frame of each sequence correspond to streamer initiation sites. The streamers appear to grow relatively uniformly at initiation. However, at switch closing only a few streamers have bridged the gap. Indeed, a single channel appears to close the switch in many of the photographs. Open-shutter pictures taken under similar conditions also confirm that the gap is bridged by a few large arcs.

These photographs verify that the spatial development of the streamers contributes to the shot-to-shot variability in the switch run time. Photographs A and B correspond to switch closures having run times of 160 and 140 ns, respectively. Note that the luminous region in photograph B, the switch closing with the shorter run time, is

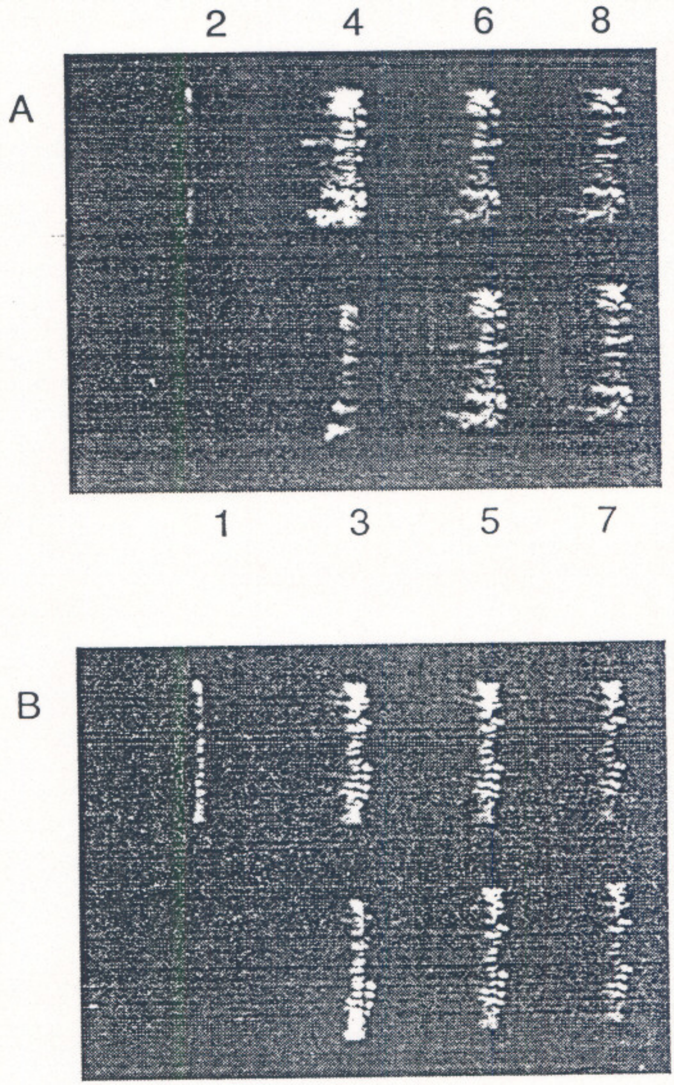

Figure 3. High-speed photographs of switch closure. Individual frame exposures are 10 ns and the frames are separated by approximately 50 ns. The field of view is shown by the broken line in Figure 1. The second frame is approximately 75 ns after closure of the gas switch. Closure of the oil switch occurs between the third and fourth frames in A and between the second and third frames in B.

significantly less extensive than for A. The transition from densely packed streamers to the propagation of a few dominant streamers is one characteristic of switch closure. An early transition, as in the case of runaway growth of a single streamer, reduces the run time. Thus, modification of the switch to favor early transition to a few dominant streamers would reduce switch jitter. For example, restricting the number and location of streamer initiation sites would favor an early transition.

The streamer initiation time is another source of jitter. The impulse breakdown voltage of insulating fluids depends on the rate of voltage rise: Tests using a small gap and nonuniform fields [7] show that the variance in the time-to-breakdown decreases with increased rate-of-rise. Thus increasing the rate of rise of the trigger voltage will reduce switch jitter. In a recent series of tests, the standard deviation of the switch run time was reduced from 9 ns to 3 ns by a modest reduction in the capacitance of the trigger electrode and by providing a low inductance current path between the gas switch and the inner Blumlein [8].

CONCLUSIONS

Timing jitter for closure of the oil switch has two components: variability in the streamer initiation time and in the temporal development of the streamers that bridge the gap. The variance in the streamer initiation time may be reduced by increasing the rate of voltage rise at the trigger electrode. The variability in the spatial and, hence, temporal development of the streamers is likely to be reduced by restricting streamer initiation to a few sites.

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