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THE AURORA ACCELERATOR'S TRIGGERED OIL SWITCH

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Abstract

Achieving a radiation pulse with 15 ns risetime using all four of the Aurora accelerator's Blumlein pulse-forming lines demands synchronization of the Blumleins to within 10 ns (in addition to a 15 ns risetime[1,2] for a single line). Timing of each Blumlein is controlled by a triggered 12 MV oil switch. A smaller-than-customary trigger electrode makes the switching time more reproducible.

Time-resolved photography of the oil arcs suggests that triggering occurs simultaneously around the sharp edge of the trigger electrode, perhaps with small deviations that grow into the most prominent arcs characteristically seen in open-shutter photographs. However, many smaller arcs that are usually overlooked in open-shutter pictures may contribute to current conduction in a closed switch.

Introduction

The risetime of the radiation produced by one of the Aurora accelerator's[3] four Blumlein pulse-forming lines can be reduced from a nominal 60 ns to 15 ns by modification of the vacuum diode,[1,4] and can be further reduced to 7 ns with a gas cell.[2] Maintaining the improved risetime using all four Blumleins demands that the radiation pulses arrive within a 10 ns window, and hence requires synchronous Blumlein switching.

The 12 MV oil switch is one element critical to synchronizing the Blumleins. Two switch geometries are investigated: the conventional switch[5] and a switch that has been modified to increase the rate-of-rise of the voltage at the trigger electrode. Other aspects of synchronization, discussed in previous reports,[5,6] have resulted in less than 2% shot-to-shot variation in the radiation dose.[7]

Oil switch triggering

Figure 1 shows Aurora's 12 MV oil switch. After Marx erection, a pulse charge voltage of approximately −10 MV charges the intermediate Blumlein electrode with a 1.8 μs half period. In the switch region, the electrodes are separated by approximately 50 cm, which yields an average electric field strength on the order of 200 kV/cm.

In the conventional switch, the oil trigger electrode is held approximately 5 cm into the gap by a support pipe that is attached to the high potential side of the 1 MV trigatron gas switch. The gas switch's ground electrode is electrically connected to the inner Blumlein electrode through a solid aluminum frame, which also physically supports the trigger assembly. During pulse charging, the voltage on 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 electrode. Upon closure of the gas switch, the charge on the oil switch trigger flows through the gas switch and support structure to the inner Blumlein, dramatically increasing the electrical stress at the trigger's sharp edge. Prebreakdown streamers originate

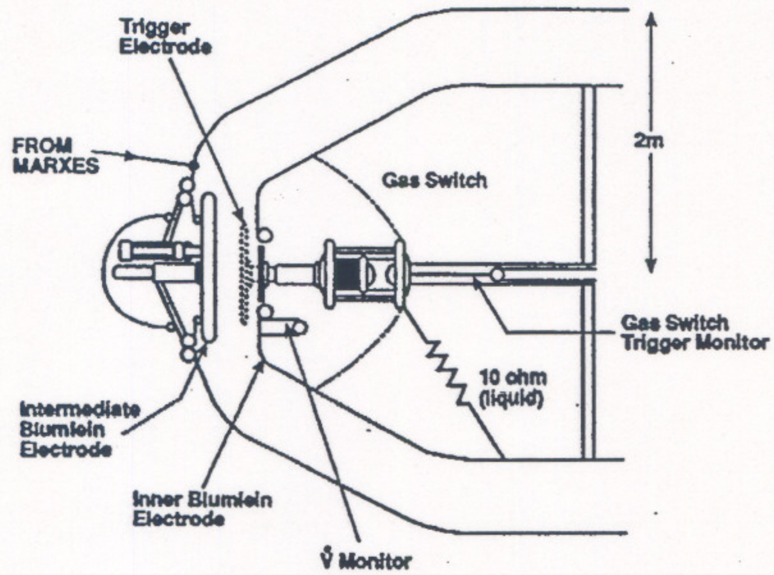

Figure 1. Schematic of Aurora's V/n oil switch. Modifications to the switch include reducing the trigger electrode diameter (the standard trigger electrode is shown by the broken line) and the addition of a low inductance path to ground at the gas switch. Eight conductors, indicated by the dot-dash line, are connected in parallel between the ground electrode of the gas switch and the inner Blumlein.

at the edge of the trigger electrode 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 operation of the oil switch is monitored by a capacitive probe mounted within the inner Blumlein, the $\dot{V}$ monitor shown in Figure 1. 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.

Figure 2 shows representative data obtained by integration of the $\dot{V}$ signal for the standard trigger. At the beginning of the trace the voltage on the trigger electrode is proportional to the pulse-charge voltage. The gas switch closes at time t_o and produces a rapid change in the trigger electrode voltage. The plummeting voltage at about 200 ns indicates that electrical contact has been made between the high-voltage electrode and the trigger electrode.

The switch run time t_r is the time delay between closure of the gas switch and closure of the oil switch as indicated in the figure. Measurements obtained during operation of the conventional switch[8] give the switch's run time as

$$t_r \simeq t_{1r} \left[\frac{E_{av}}{1\ \mathrm{MV/cm}}\right]^{-\alpha} .$$

Here $t_{1r} = 22$ ns is the run time for an average field E_{av} of 1 MV/cm, and the exponent α is approximately 1.33. In the standard configuration the mean run time is on the order of 130 ns, with a shot-to-shot standard deviation of approximately 5.5 ns:[5] switch closure

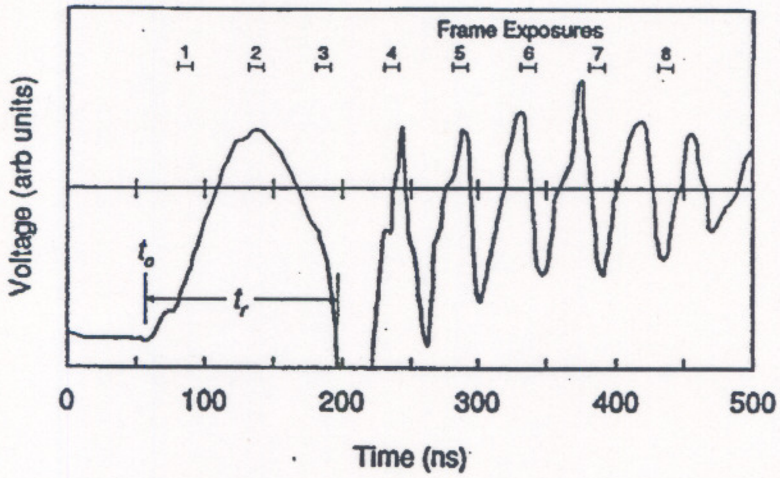

Figure 2. The voltage on the oil switch trigger electrode. The integrated $\dot{V}$ signal is plotted for a single shot using the conventional switch geometry. The gas switch closure time t_o and oil switch run time t_r are shown. The numbered sequence along the top of the figure corresponds to the exposures of the high-speed photograph shown below.

occurs within windows of 13 ns for 9 shots and 28 ns for 95 shots.

The impulse breakdown voltage of insulating fluids depends on the rate of voltage rise: Tests using a small gap and nonuniform fields[9] show that the variance in the time-to-breakdown decreases with increased rate-of-rise. Thus a faster-rising pulse on the trigger electrode should reduce the switch jitter. The trigger network approximates a *LRC* circuit with the support structure's inductance L, the parallel 10 Ω damping resistor R, and the capacitance C of the trigger electrode. This circuit has a half-cycle time $T = \pi\sqrt{LC}$, and, for the standard switch configuration, $T \simeq 75$ ns. A faster-rising pulse is achieved by adding eight parallel conductors between the gas switch and the inner Blumlein, and by reducing the diameter of the trigger electrode from 95 cm to 60 cm.

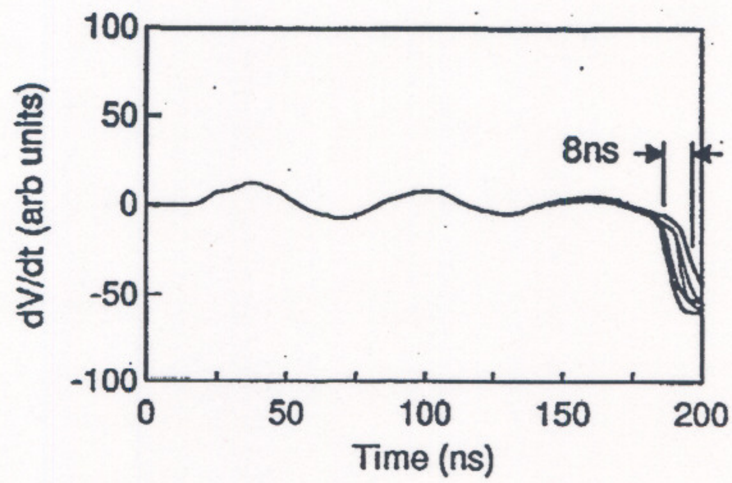

Figure 3. $\dot{V}$ signal for the modified trigger electrode. $\dot{V}$ signal traces obtained from nine consecutive shots are plotted.

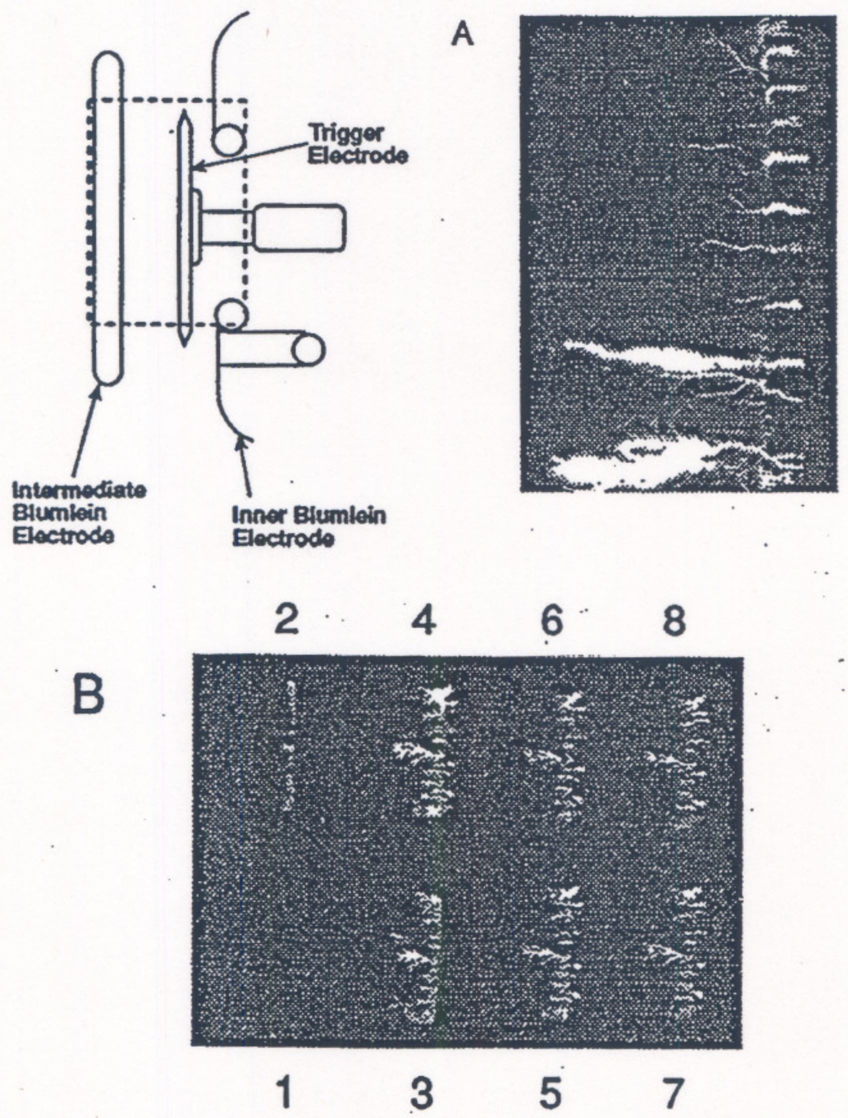

Figure 4. Photographs of switch operation. Open-shutter (A) and high-speed (B) photographs for different shots are shown. The approximate field of view is shown schematically on the upper left. The multi-frame photograph corresponds to the voltage trace shown in Figure 2 where the frame exposure times plotted together with the trigger voltage. Individual frame exposures are 10 ns and the frames are separated by approximately 50 ns.

Oil switch timing is most accurately determined by direct measurement of the $\dot{V}$ signal. Figure 3 shows representative traces of the $\dot{V}$ signal for the small electrode. Compared with the conventional switch, the half-cycle time is nearly halved to 34 ns. It should be noted that, due to the reduction in the trigger electrode capacitance to the intermediate Blumlein electrode, the peak voltage on the trigger electrode is about 60% of that for the conventional switch. Therefore, the voltage rate-of-rise is increased by a factor of 1.2 rather than 2 as indicated by the oscillation frequency alone. The nine consecutive shots shown in Figure 3 have run times that fall within an 8 ns window and an estimated standard deviation of 3 ns.

Optical diagnostics

Two photographic techniques were employed to record light emitted from the oil switch during closure: open-shutter and high-speed photography. Representative photographs of each type for the conventional switch geometry are shown in Figure 4. These pictures provide intriguing information about the switch's operation, such as the number and spatial distribution of the conducting arcs.

In the open-shutter pictures the gap is typically bridged by a few large arcs. It should be noted, however, that the open-shutter photographs emphasize persistent arcs that continue to carry current during late-time ringing of leftover energy in the Blumlein. Therefore these arcs give little information about the pulse forming part of the switch discharge.

In contrast, the multi-frame photographs show many luminous regions close to the trigger electrode. Apparently, the oil switch triggers many channels that are relatively uniformly spaced on the trigger electrode. The first detectable light emission for the sequence shown in Figure 4B appears in the second frame, 75 ns after closure of the gas switch. These data appear to be consistent with the initiation of multiple prebreakdown streamers, the precursors to the fully developed arcs.[10] The streamers start at the sharpened edge of the trigger electrode, presumably when the electric field at the sharp edge exceeds some critical value. The streamers appear to grow uniformly at initiation. However, the photograph suggests that at switch closing only three channels have bridged the gap. In other high-speed photographs, a single channel appears to close the switch.

The photographic data suggest that the detailed temporal development of the streamers may contribute to the variability in the switch run time. Indeed there is some evidence in the photographic data that may explain the "compensation" effect, which is an inverse correlation between switch run time and the rate of discharge of the Blumlein, identified earlier.[5,8] Closure of the oil switch with a single arc, as in the case of runaway growth of a single streamer, seems to reduce the run time and to result in a slightly slower discharge of the Blumlein. However, although light emission is certainly related to currents in the oil, it seems clear that the measurement optics do not fully resolve the structure nor detect the full extent of prebreakdown streamers, and that these photographic data must be evaluated with some care.

It is not yet clear what factors influence arc initiation and the subsequent number of arc channels. Detailed studies of the threshold field and the dependence of streamer initiation on voltage risetime are in preparation.

Acknowledgements

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