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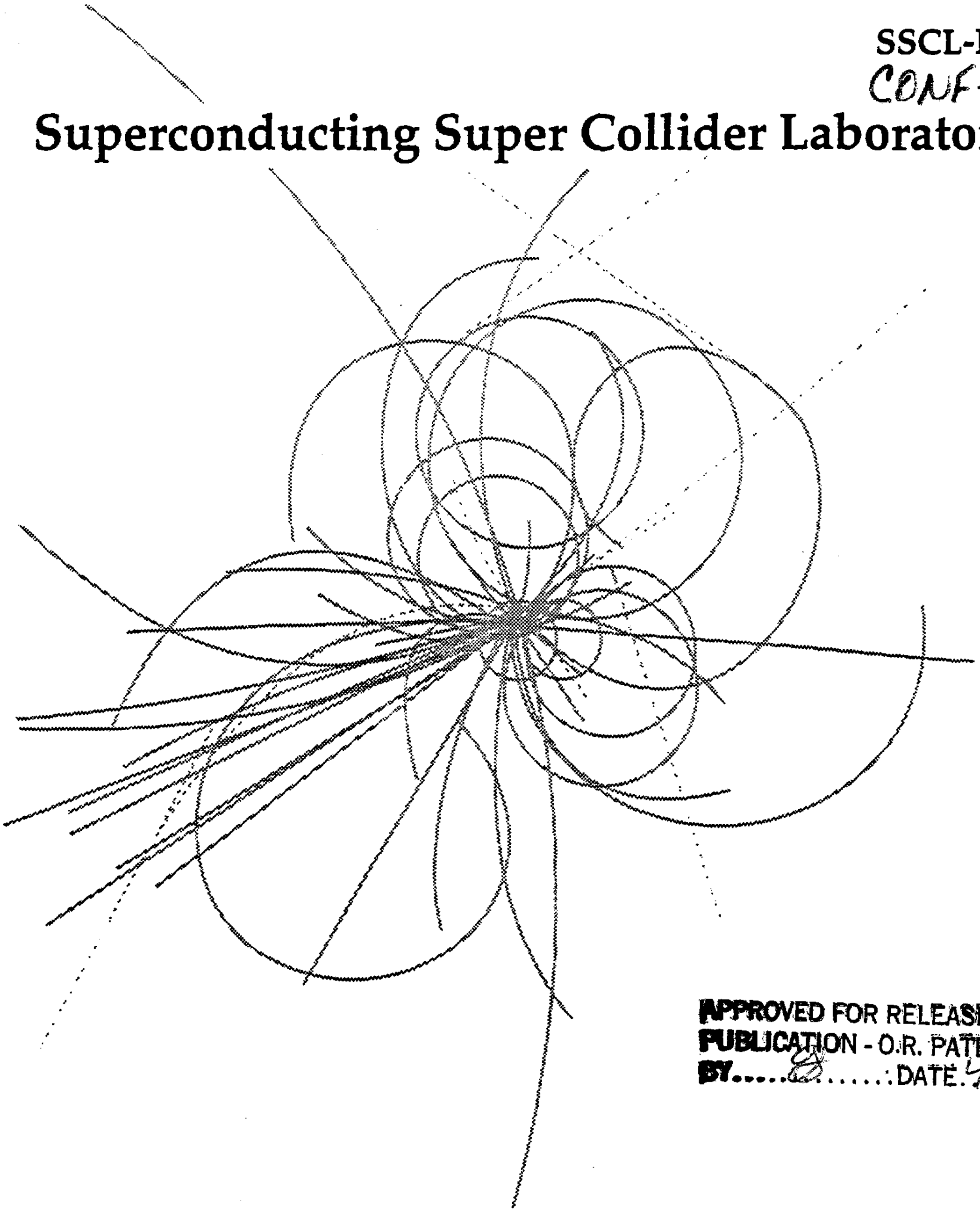
Superconducting Super Collider Laboratory



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Wide Range Voltage Modulation*

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*Presented at the 1992 Twentieth Power Modulator Symposium, Myrtle Beach, June 23-24, 1992.

†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

WIDE-RANGE VOLTAGE MODULATION *

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ABSTRACT

The Superconducting Super Collider's Medium Energy Booster Abort (MEBA) kicker modulator will supply a current pulse to the abort magnets which deflect the proton beam from the MEB ring into a designated beam stop. The abort kicker will be used extensively during testing of the Low Energy Booster (LEB) and the MEB rings. When the Collider is in full operation, the MEBA kicker modulator will abort the MEB beam in the event of a malfunction during the filling process.

The modulator must generate a 14-μs wide pulse with a rise time of less than 1 μs, including the delay and jitter times. It must also be able to deliver a current pulse to the magnet proportional to the beam energy at any time during ramp-up of the accelerator. Tracking the beam energy, which increases from 12 GeV at injection to 200 GeV at extraction, requires the modulator to operate over a wide range of voltages (4 kV to 80 kV). A vacuum spark gap and a thyratron have been chosen for test and evaluation as candidate switches for the abort modulator. Modulator design, switching time delay, jitter and pre-fire data are presented.

INTRODUCTION

The Medium Energy Booster (MEB) is the second of the three injector synchrotrons at the SSCL. The MEB accepts 2.0 μs beam batches from the Low Energy Booster (LEB) at a 10 Hz rate; the injection momentum is nominally 12 GeV/c. After accumulating six such batches, while leaving a nominal 1.0 μs abort/extraction gap in the MEB, the beam is accelerated in three seconds to the extraction momentum of 200 GeV/c. This cycle is repeated three times to fill the High Energy Booster (HEB).

The abort system for the MEB consists of a number of fast-pulsed kicker magnets, slow-pulsed septum magnets, and DC bending magnets that direct the beam from the MEB closed orbit to a remote beam dump. This magnet array is required to track the beam energy from the 12 GeV/c to 200 GeV/c, and operate reliably at any point in between. For the collider filling scenario described above, the nominal repetition rate is 0.15 Hz; however, there are commissioning scenarios where the system will be required to operate, at injection energy, at rep-rates of 1.0 Hz.

The total kicker magnet field must rise from zero to 90 percent of nominal within the beam abort gap (1.0 μs), and remain flat for the entire transit time of the ring (14 μs). To clear the septum, and stay within the abort line, requires the total kicker field to vary by no more than ±10 percent of nominal over the pulse width. The number of magnets/modulators in the kicker system is required to be five or more, so that (a) a pre-fire of one of the modulators does not remove the beam from the ring and (b) a failure of one modulator to charge or fire does not prohibit an abort of the beam. The current required for each magnet is approximately 3.5 kA at the nominal extraction energy of 200 GeV/c. The present system design consists of five magnets fed by five modulators through RG-220 coaxial cable from a head house approximately 50 m from the magnet string. A prototype modulator, that can drive twice the required current, has been designed and built at SSCL. This modulator is being used to test candidate switches for the MEB (and perhaps HEB) abort kicker systems.

MODULATOR DESIGN AND DISCUSSION

The MEB abort modulator must deliver a current pulse to the abort magnet ranging from 400 amps to 8 kA; this corresponds to a beam energy ranging from 12 GeV to 200 GeV. The rise time of the pulse, including jitter and delay, must be less than 1 μs. This 1 μs is the time the beam is not present in the beam pipe where the abort magnets are located. If the rising edge of the kicker pulse occurs while beam is present in the abort magnets, it will be swept into the septum which could cause damage to it. The pulse width required to extract all the beam from the MEB ring is 14 μs with a flat top that stays within 10% of the required current.

One of the more challenging aspects of the modulator design is the beam energy tracking requirement. The present design requires the high-voltage switch to close over a wide range of operating voltages (4 kV to 80 kV). The two commercial switches available for this application are (a) vacuum spark gap and (b) a thyratron. The vacuum spark gap (EG&G, GPV-6306), that was chosen for this application, requires a trigger pulse that is 12 kV in amplitude and 2 μs in width and a rise time as fast as possible. The switch selection for this trigger circuit was a CX-1588 thyratron which can switch 20 kV in less than 10 ns. This trigger circuit is driven from a small glass thyratron. This same thyratron trigger circuit can be used to trigger the larger main switch thyratron (EEV, CX-1171). Both of these trigger circuits are mounted on a floating deck arrangement which is required for the operation of a floating or series-mounted switch.

The pulse shaping is done with a type-E pulse-forming network which is composed of 16 sections. Each section is comprised of a .1-μfd capacitor and a 2.5-μhy inductor which yields a 5-ohm impedance PFN. Modeling of the PFN (Fig. 1), using Micro-Cap, allowed for trimming of inductors in order to

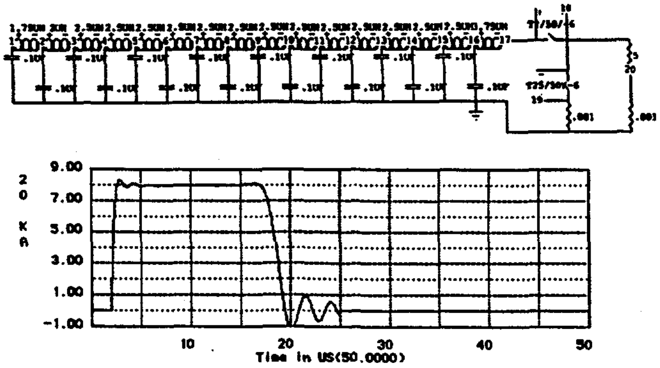

Figure 1. (a) Circuit model using Micro-Cap showing 16-section PFN (b) Output pulse into a matched 5-ohm resistive load

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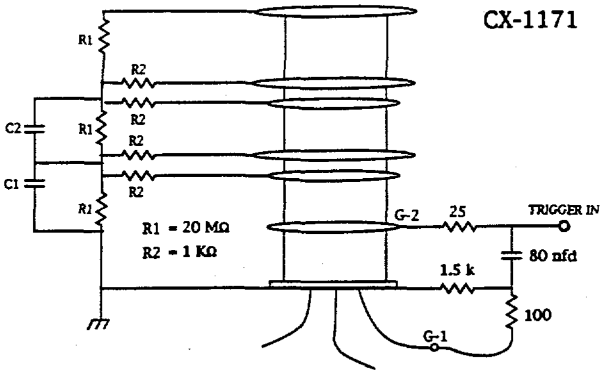
* Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under contract No. DE-AC35-89ER40486.

and triggered in the proper manner, this thyratron can switch in less than 10 ns. The spark gap is designed to switch voltages ranging from 300 V to 80 kV. The schematic of the MEB abort modulator with vacuum spark gap and driver circuits is shown in Figure 4.

CX-1171 LOW-VOLTAGE TEST RESULTS

With the reservoir voltage set to the manufacturer's recommended value of 5.0 volts for the CX-1171 tube being tested, the minimum switchable anode voltage reached was 6.1 kV. Increasing the reservoir by .5 volt raised the minimum switchable anode voltage to 7.5 kV. Decreasing the reservoir by .5 volt lowered this voltage to 5.5 kV. The addition of capacitance to the two lower high-voltage gaps yielded the results as seen in the table in Figure 5 [3]. The addition of capacitance to the high-voltage gaps increases the available charge allowing the control grid to conduct sufficiently until complete gap break down occurs. Once the control grid breaks down, the other gaps conduct; and ultimately, the anode breaks down and full conduction of the tube occurs.



	C2=0 C1=0	C2=180pF C1=180 pf	C2=470 pF C1=470 pF	C2=1 nF C1=1 nF	C2=180pF C1=470pF	C2=300pF C1=470pF	C2=180pF C1=1nF
5.5V	7.5kV	5.5kV	4.4kV	2.7kV	4.5kV	4.5kV	2.7kV
Recommended Reservoir Voltage 5.0V	6.1kv	5.5kV	4.2kV	3.4kV	4.3kV	4.3kV	2.6kV
4.5V	5.5kV	4.8kV	3.5kV	3.4kV	3.2kV	3.3kV	2.5kV

Figure 5. Minimum anode voltage reached by varying the lower two high-voltage gaps' capacitances

When the control grid of a thyratron is driven with a higher voltage and more current, the expected result is a decreasing anode delay time [4]. At the lower voltages (<10 kV) using the CX-1171 3-gap thyratron, this has not been observed. Anode delay time is defined as the difference in time between the control grid voltage when it passes through zero from a negative bias point and when the anode voltage falls to 50% of its value. The data (Fig. 6) without capacitors on the high-voltage gaps illustrates that as the grid drive is increased, the anode delay increases. At the 1.5-kV to 2.5-kV drive levels, the delay decreases as expected but increases on each side of this level.

After adding the optimum capacitance (C1=1 nfd, C2=470 pfd) to the two lower high-voltage gaps, the control grid drive was again varied to see the effects on the anode delay with the different anode voltage levels. The results are shown in Figure 7. As before, with the lower anode voltages, increasing the drive voltage increased the delay time. The varying delay times with the different anode voltages indicates an interaction between the amount of charge that is available on the high-voltage gaps and the amount of drive voltage delivered. Once the anode was increased to 10 kV, increasing the drive level did decrease the delay time; but as the drive was increased above 2.5 kV, the delay began to increase. The test without capacitors demonstrated that the delay decreased or remained the same at the 10 kV level. The anode voltage was increased to 50 kV without anymore significant decrease in anode delay.

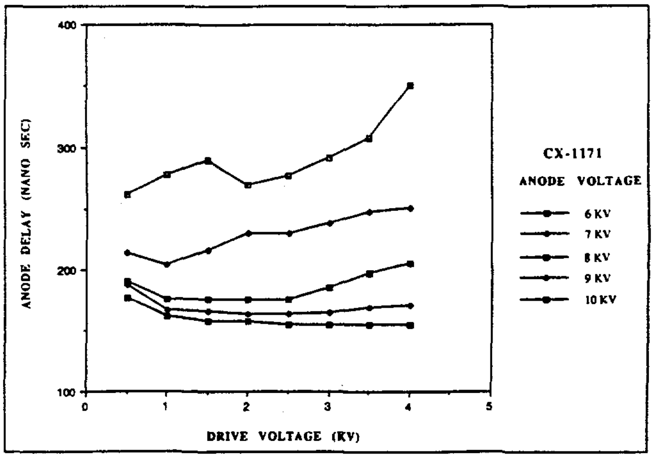


Figure 6. Anode delay vs. G-2 drive voltage without high-voltage gap capacitors

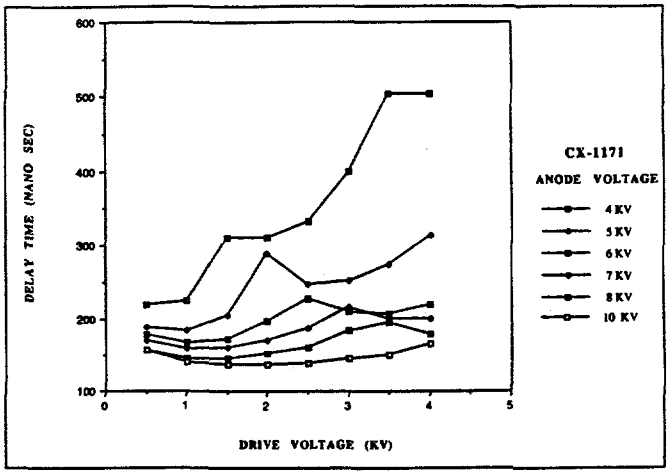


Figure 7. Anode delay vs. G-2 drive voltage with the two lower high-voltage gap capacitors (C1= 1 nfd, C2= .5 nfd)

CX-1593C LOW-VOLTAGE TEST RESULTS

The same tests were preformed on the CX-1593C as were done on the CX-1171. The CX-1593C is a 4.5 inch, hollow anode tube, with 4 high-voltage gaps. This tube has 3 grids which can be configured in different ways to trigger it. The data obtained and reported on in this paper was produced with the grids configured as shown in figure 5. The third grid (G0) on the CX-1593C was connected to the cathode. With the reservoir voltage set to the manufacturer's recommended value of 5.0 volts for this CX-1593C tube being tested, the minimum switchable anode voltage reached was 5 kV. Increasing the drive voltage significantly reduced the anode delay time (Fig. 8). As with the CX-1171 there is an optimum drive voltage (2 kV to 3 kV) which is higher and expected due to the larger size of the tube. Jitter was 100 ns with a 500 v drive and the anode at the 5 kv level but when the anode voltage was increased the jter decreased to <20 ns.

The additional capacitance to the lower two high-voltage gaps reduced the anode delay 600 ns (Fig. 9). With the drive voltage set to 500 v the delay was 1100 ns without the extra capacitance. With the high-voltage gap capacitance, the delay decreased to 550 ns and the tube could be triggered down to 2 kV on the anode. The anode delay varied from 440 ns to <300 ns as the anode was changed from 4 kV up to 10 kV. The anode delay was observed at the 20 kV and 40 kV anode voltage levels with <30 ns change.