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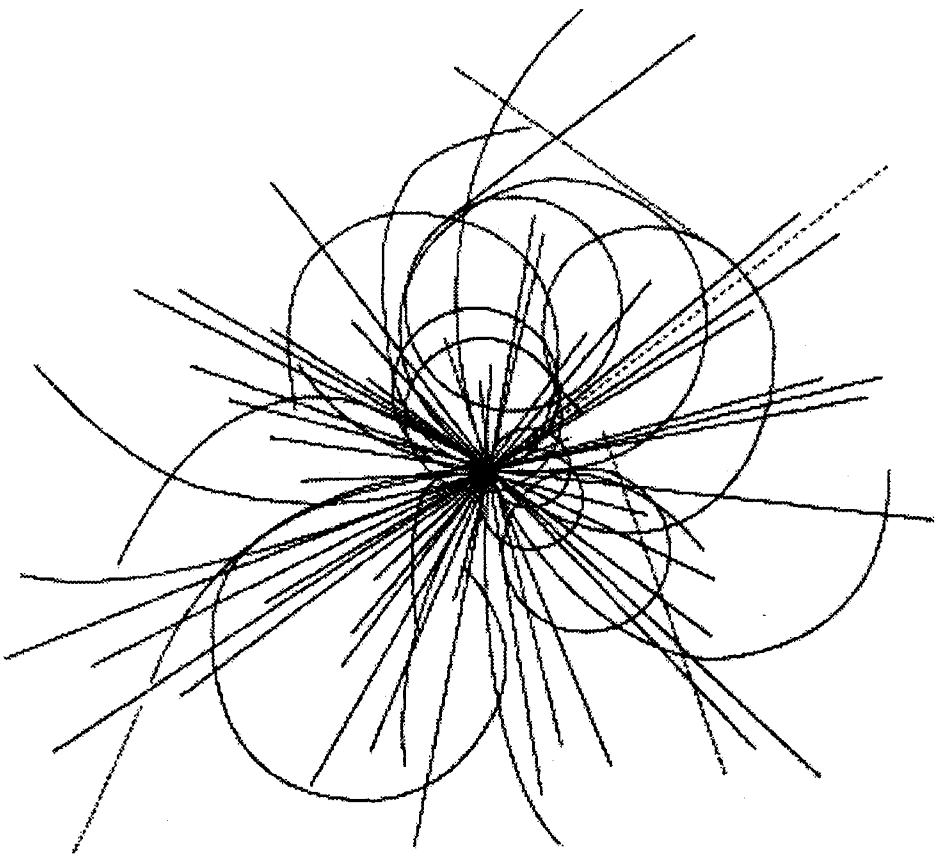

Superconducting Super Collider Laboratory

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Preliminary Testing of the LEB to MEB Transfer Kicker Modulator Prototype*

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Preliminary Testing of the LEB to MEB Transfer Kicker Modulator Prototype*

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Abstract

The extraction kicker for the Low Energy Booster (LEB) is used to deflect a 12 GeV/c proton beam from the synchrotron into a transfer line. A kicker system of similar design is used to inject the beam from the transfer line into the Medium Energy Booster (MEB). The modulator requirements for these kicker systems are to deliver a pulse train of seven 1.6 kA, 2.5 µs pulses at a pulse repetition frequency of 10 pps, every seven seconds for one hour. The impedance of the modulator is 12.5 Ω, resulting in a charge voltage of 40 kV. The 10-90% rise time of the pulses is 20 ns, and the 1-99% fall time is 2 µs. The allowable pulse ripple is ±1% of the peak current during the pulse, and ±0.3% from pulse to pulse. The shot -to-shot timing jitter requirement is less than 2 ns. This paper describes the design and performance of the prototype modulator which was fabricated to meet these specifications.

I. INTRODUCTION

A LEB extraction kicker prototype power system has been fabricated at the SSC. This system consists of a command, resonant charging system, a coaxial cable pulse forming line, and a thyratron switch tube, which delivers a 1.6 kA, 2.5 µs pulse to two parallel-connected magnet loads terminated by matching resistors [1], [2]. A photograph of the power system is shown in Figure 1.

Figure 1. LEB Extraction Kicker Power System Prototype (The PFL is shown in foreground, with the charging tank on the left and modulator to the right)

II. THE CHARGING SYSTEM

A prototype of the charging power supply designed to charge four 254 m, parallel connected spools of RG-220 cable, to 40 kV in 1.8 ms, has been fabricated. A schematic of the charging supply and test circuit is shown in Figure 2. The DC power source is a commercially available 300 V, 8 A supply. The capacitor bank consists of fifteen parallel 680 µF, 350 WVDC, electrolytic capacitors. The SCR is a S15CG12AO, stud mounted type. Low voltage testing of the charger showed that all components performed as designed.

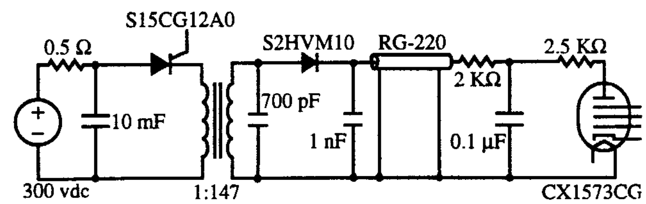

Figure 2. Charging Supply Test Circuit

The circuit was tested by gradually increasing the voltage, at repetition rates of less than one Hertz. At a charge voltage of approximately 30 kV, and a PRF of 0.9 Hz, a "double current pulse" was observed. This double pulse could also be seen at lower voltages as the PRF was increased. An oscillograph of this pulse is shown in Figure 3.

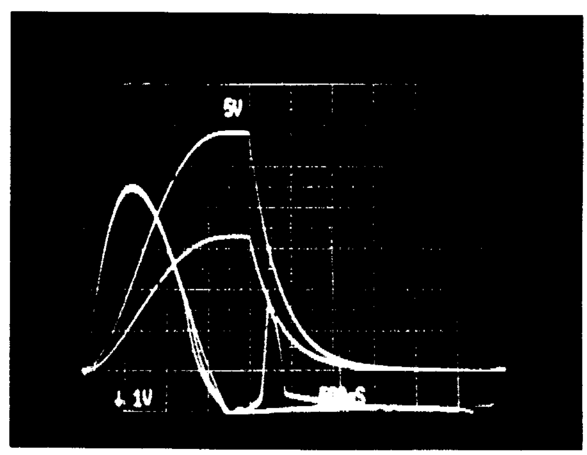

Figure 3. "Double Current" Charging Pulse (Primary current is 100 A/div, secondary voltage is 5 kV/div, time base is 500 µs/div)

One possible explanation for this phenomenon is that the open circuit inductance of the transformer is below that specified. A low open circuit inductance would allow enough magnetizing current to flow in the transformer at the end of the pulse to latch the SCR. Several hundred microseconds later the trans-

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former saturates, and the double pulse is seen.

The open circuit inductance, leakage inductance, and the winding capacitance of the transformer were measured with an HP 4284A LCR meter. The open circuit inductance was highly dependant upon frequency, and the transformer resonates at approximately 380 Hz. The measured values at 300 Hz were 100 mH for the open circuit inductance, 104 µH for the leakage inductance, and 374 pF for the winding capacitance. The specified values were >450 mH, <145 µH, and <10.8 µF respectively. All of these values are referred to the primary. SPICE analysis of the charging circuit was run with the measured transformer parameters. The results of this analysis is shown in Figure 4, and verify that the SCR does not commutate at the end of the pulse.

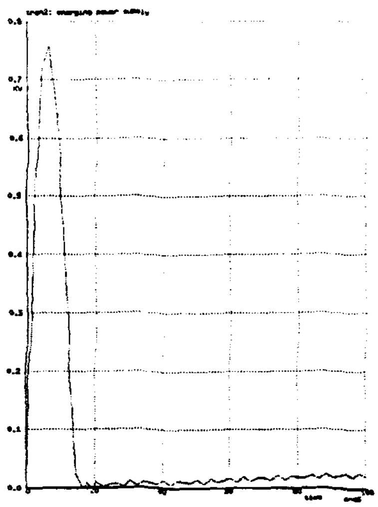

Figure 4. SPICE Analysis Showing the SCR Latching (Primary current is shown at 100 A/div, time base is 2 ms/div)

Another transformer with twice the core area and twice the open circuit inductance has been ordered. In order to continue testing while waiting on the new transformer, force commutation of the SCR was investigated. However, a suitable commutating circuit could not be found because of the very low impedance of the primary circuit. It was estimated that the open circuit inductance could be doubled with core reset, so a tertiary winding was wound around the secondary to carry a DC reset current. The tertiary winding had sixteen turns, one fifth the number of the primary, and carries 15 A to reset the core. This approach did not work because the impedance of the tertiary circuit was the output stage of a power supply, or essentially a short circuit. Isolating the tertiary circuit with an inductor was investigated, but the required inductance was approximately 20 H which is not feasible for an air core inductor. Further SPICE analysis showed that adding a small capacitor directly across the secondary could provide enough reverse current through the SCR for circuit commutation. A 700 pF capacitor was placed across the secondary, and the SCR now commutated. Figure 5 shows an oscillograph of the charging waveforms with the secondary charging to 35 kV at a PRF of 10 Hz. The charging system was tested to 40 kV secondary voltage at 10 Hz. The storage capacitor finally began arcing, as the capacitor was only rated for single shot duty. Further testing was postponed to fabricate the modulator.

It has been proposed to charge two PFLs with one charger in the final system. This topology would limit the number of reflections caused be a load arc to one, and should not require a hollow anode tube. SPICE analysis of this topology has been run and show that the ordered transformer should be adequate. Pulsed core reset will probably be required. The present charger and modulator design will allow testing of this topology.

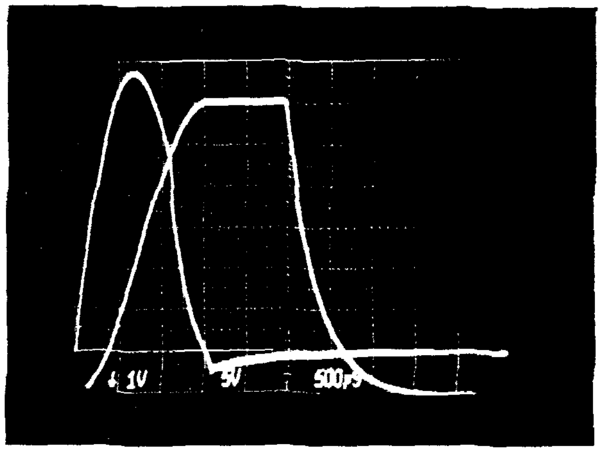

Figure 5. Charging Waveforms (Primary current at 100 A/div, secondary voltage at 5 kV/div, and time base at 500 µs/div)

III. THE MODULATOR

A photograph of the modulator section of the kicker power system is shown in Figure 6. A tail biter tube has been added to the modulator to provide pulse width control, to protect against load arcing, and to test different topologies of the pulse forming line. EEV CX 1573CG hollow anode tubes are used in the prototype to guard against current reversals in the event of a load arc. Cathode heater, reservoir, and bias power supplies are located on a floating deck inside the modulator tank. Grid drivers are grounded, with the grid pulses coupled through one-to-one pulse transformers also in the tank. All grid drivers, and low voltage electronics have been tested, and perform to the design requirements. Custom high voltage connectors for the RG-220 cable have also been tested and meet design specifications.

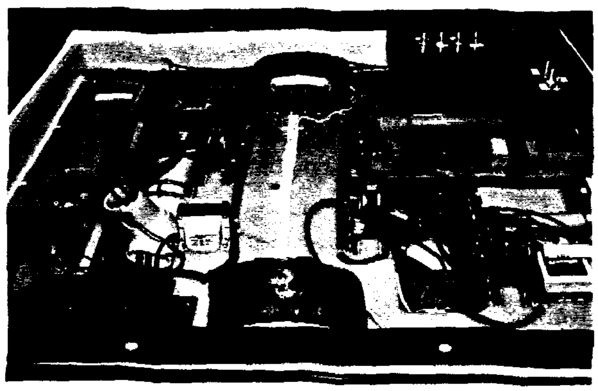

Figure 6. The Prototype Modulator.

The fabrication of the modulator section was finished only a few weeks before the writing of this paper, so only very preliminary data is available. Figures 7 and 8 show the load current rise time and flat top respectably. Figure 9 shows the entire load current pulse. The poor rise time current, and flat top may be explained by several different hypotheses. Calibration of the probes has not been completed. The resistive load designed for the system has not been delivered at the time of writing. A temporary load was fabricated using four 50 Ω Carborundum type 1028 resistors mounted in individual coaxial housings. The measured resistance of this array is approximately 16 Ω. Reflections from this load are clearly visible at the end of the pulse, but deleterious effects on rise time and flat top are not known. The coaxial housing for the switch tube could not be built to be 12.5 Ω because this would require placing the inner diameter of the housing inside of the switch tube grid flanges. The actual impedance of the housing is probably between 30 to 60 Ω, with an electrical length of approximately 10 ns. Again there has not been time to characterize the housing, but this mismatch could explain the steps seen on the rising edge of the current pulse. If the tube housing is found to be the problem, an easy fix could be to add discrete capacitors axially along the tube housing.

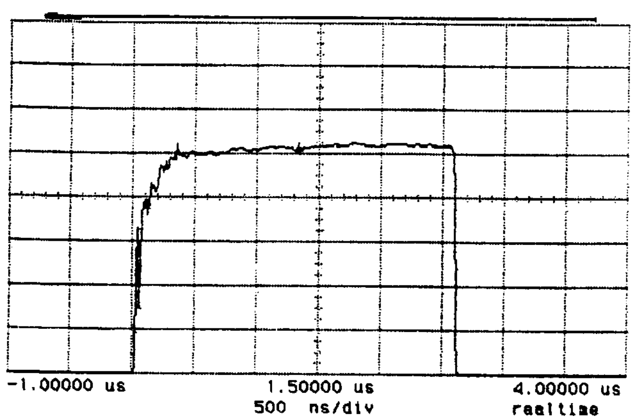

Figure 7. Load Current at 16 A/div, Peak Current is 1468 A (Time base is 500 ns/div)

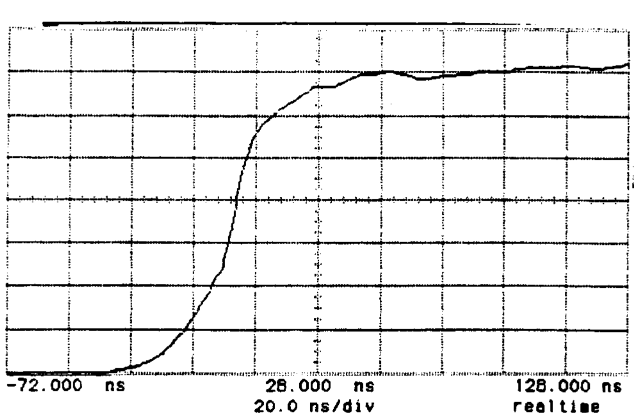

Figure 8. Load Current at 200 A/div (Time base is 20 ns/div)

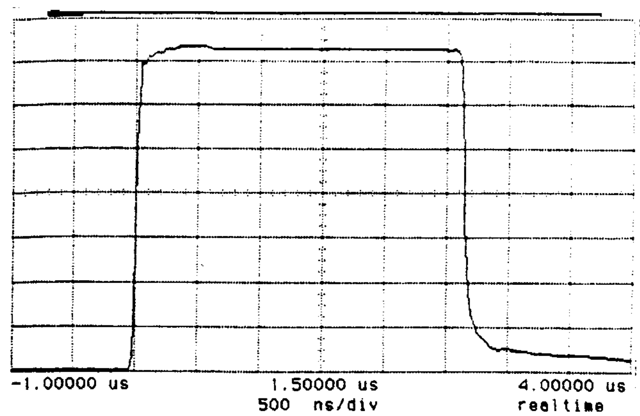

Figure 9. Load Current Pulse at 200 A/div (Time base is 500 ns/div)

The last possible cause for the poor pulse fidelity may be attributed to not properly setting the reservoir heater voltage. Testing the effects of cathode heater, reservoir, grid bias and grid drive voltages, as well as grid triggering delays will be explored. Future testing will include timing jitter measurements, pulse-to-pulse ripple, and prefire and misfire rates.

IV. CONCLUSIONS

The charging system has been fully tested for functionality. The system meets or exceeds all design specifications, however much more testing needs to be done to get reliability data. The initial testing of the modulator is encouraging. Pulse fidelity does not seem to be within the requirements of the kicker specifications, but testing has just begun, and several easily corrected problems have been identified. The modulator has been run at charge voltages of approximately 35 kV, at a PRF of several Hertz. No arcing, prefire or misfire problems have been identified. Full characterization, and tuning of the charger and modulator, is scheduled for completion by the late summer of 1993, when high voltage testing of the kicker magnet will begin.

V. REFERENCES

[1] C. Pappas, etal, "Low Energy Booster Extraction Kicker Prototype Modulator", *Twentieth Power Modulator Symposium.*

[2] D Anderson, "Design and Preliminary Testing of the LEB Extraction Kicker Magnet at the SSC", presented at this conference.