# "Fast Power Supplies for Kicker and Thin Septum Magnets in a 1.2 GeV Synchrotron Radiation Source"

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## *Abstract*

The Maxwell Laboratories, Inc. (Maxwell) Model 1.2-400 Electron Storage Ring, which is being built for the LSU Center for Advanced Microstructures and Devices, is a 1.2 GeV Synchrotron which has a 200 Mev linac for injection of electrons into the storage ring. The injector section for merging the linac beam with the storage ring beam has four kicker magnets for altering the course of the stored beam and a thin septum magnet for steering the linac beam. A detailed discussion of the electrical requirements for the fast power supplies for powering the magnets, the circuits used to meet the requirements, and a comparison of the theoretical and actual data will be presented.

## I. INTRODUCTION

The commercial development of Maxwell's Model 1.2-400 Electron Storage Ring, utilizes a set of four kicker magnets, a thick septum, and a thin septum to accomplish injection of charge into the storage ring from the linear accelerator. During the injection process, the incoming beam from the linear accelerator is brought in parallel, but displaced, to the stored beam by means of the thick and thin septa. The stored beam is displaced toward the incoming beam at the thin septum by kicking the stored beam with two fast pulsed kicker magnets (outer then inner) located before the thin septum. The merged beams are kicked back to the original stored beam location by two additional fast pulsed kicker magnets (inner then outer) which are identical to the first two magnets.

A set of five fast power supplies is used to generate the electrical pulses required by the four kicker magnets and the thin septum. Two identical supplies provide the pulses for each of the two inner kicker magnets and another two identical supplies provide power to each of the two outer kicker magnets. A fifth supply generates the pulse for the thin septum. A description of the requirements of the five supplies, the circuit design of the power supplies to meet the requirements, and the theoretical and measured data is presented in this paper.

## II. MAGNET REQUIREMENTS

### *A. Kicker Magnets*

The electrical waveshape required for powering each kicker magnet is identical in shape. Only the relative magnitudes of the current amplitudes between the inner and outer kicker magnets are different. By making all the waveshapes identical in shape, the pulses do not need the fast rise time rectangular pulses as generated by other kicker magnet pulsers [1,2].

The electrical pulse must have a "flattop" duration of 200 ns and the trailing edge of the pulse should fail to less than 5 percent of the flattop magnitude in approximately 370 ns. The "flattop" variation should be less than ±5.5 percent of the nominal value during a single pulse or from pulse to pulse. The pulse amplitude must be continuously adjustable from the maximum required value to 50 percent of the maximum value. The repetition rate will be approximately 1 Hz, although repetition rates of up to 10 Hz will be achievable.

For the outer kicker magnets, the maximum current required is 915 A and the nominal current amplitude is 835 A. The nominal current corresponds to an integrated field (nominal core length of 0.15 m) of 0.0012 T•m. The inner kicker magnet requires a maximum current of 230 A and a nominal current of 210 A. The nominal current for the inner magnet corresponds to an integrated field (nominal core length of 0.15 m) of 0.0003 T•m.

### *B. Thin Septum*

Due to the short injection time of the electrons, the thin septum waveshape can be a half sinusoid, with the injected electrons only seeing the peak of the sinusoid. The maximum current required by the thin septum is 6440 A and a nominal current of 5858 A. The nominal current for the corresponds to an integrated field (nominal core length of 0.3 m) of 0.05 T•m.

The "flattop" duration should be greater than 200 ns. The maximum variation of the flattop current for a single shot and shot to shot is ≤1 percent. The current should be adjustable to 50 percent of the maximum. The nominal and maximum repetition rate for the thin septum is the same as that for the kickers, which is 1 and 10 Hz accordingly.

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## III. CIRCUIT DESIGN

### *A. Kicker Magnet Fast Power Supplies*

The circuit used to generate the electrical pulse for the kicker magnets is shown in Figure 1. To start current flowing in the magnet, the start switch is closed and energizes the under damped RLC circuit. The period of the under damped oscillations is made sufficiently long so that a 200 ns "flattop" (±5.5 percent of the nominal) can be realized at the top of the first oscillation. At the end of the "flattop," the crowbar switch is fired and the current through the magnet decays to within 5 percent of the flattop value in 370 ns.

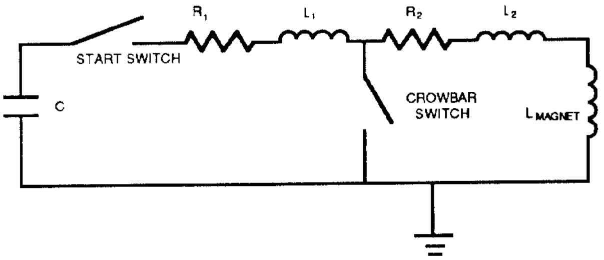

Figure 1. Circuit used for the kicker magnet supplies.

To meet the requirements of flattop and fall time, the impedances in the two loops must be carefully selected. The pulse shape for the two kicker supplies is the same, and only the relative magnitude of the required current is different. The switches in the circuit were to be implemented with thyratrons, which require a minimum voltage across them to fire reliably and have a maximum voltage which they can hold off. The limitations of the switches prevented adjusting the charge voltage of the capacitor to meet the current requirements of both inner and outer kickers. By scaling the impedances in the loops, the circuit voltages (both magnitude and shape) remain the same for both inner and outer kickers, and only the magnitude and not the shape of the current waveform is changed. Therefore, the impedances for one of the kickers had to be selected to meet the design criteria, and then the impedances were directly scaled to obtain the desired current in the other kicker. Table 1 shows the values used for the components in the drawing.

Table 1
Component values for inner and outer fast power supplies

| Kicker | C | R1 | L1 | R2 | L2 |
|---|---|---|---|---|---|
| Inner | 15 nF | 9.4 Ω | 9.6 μH | 41.1 Ω | 3.3 μH |
| Outer | 60 nF | 2.35 Ω | 2.35 μH | 11.8 Ω | 0.7 μH |

Once the main components were determined, extensive simulations of the circuit including the significant stray and connecting cable impedances were run using Maxwell's MAXCAP computer circuit simulation code. From the simulations it was discovered that oscillations in the output current would occur in the circuit as a result of the stray impedances in the circuit. The oscillations were eliminated by the addition of a small RC filter, consisting of a 2 nF capacitor and 10 Ω resistor, at the output of the supply to the buswork which connects the supply to the magnet. The oscillation prevention filter suppressed oscillations of the current allowing the flattop specification to be met in the simulations. An example of the simulated current for an outer kicker magnet is shown in Figure 2.

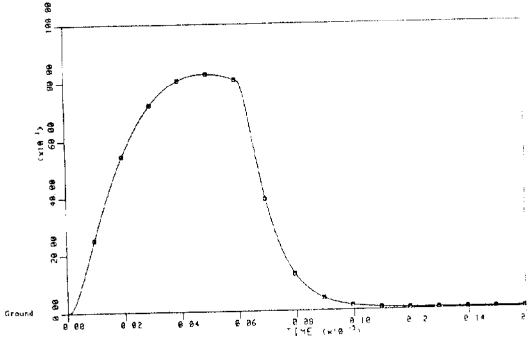

Figure 2. Simulated current in an outer kicker magnet.
*(verticle 200 A/div, horiz. 200 ns/div)*

### *B. Thin Septum Fast Power Supply*

The circuit for the thin septum power supply is shown in Figure 3. To start the current pulse into the magnet, the switch is closed and the LC circuit begins to oscillate. The current through the inductance rings up. When the current begins to reverse, the switch turns off and the current flows through the diode and resistor. The circuit is now an over damped RLC circuit. The capacitor was chosen so that the period of oscillation between the inductance in the circuit and the capacitor is sufficiently long so that the "flattop" or peak of the current waveform has a variation of less than 1 percent for 200 ns. The resistance was chosen to be small enough to allow the reverse voltage on the capacitor to discharge quickly enough to allow the capacitor to be completely recharged before the next pulse is to be applied to the magnet, yet the resistance must be large enough to prevent excessive reverse current from flowing through the magnet during the reversal discharge.

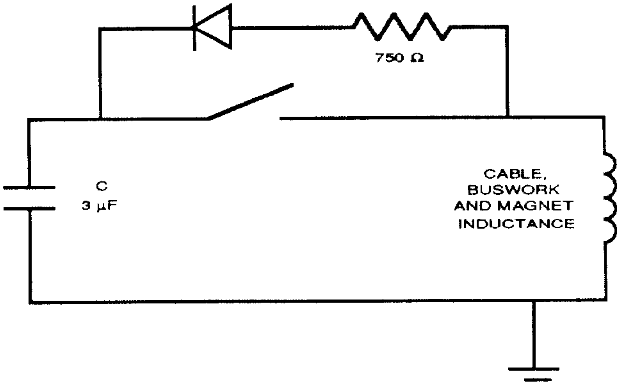

Figure 3. Thin septum circuit.

The simulations of the circuit including the strays showed small oscillations on the current waveform similar to those seen in the simulations for the kicker magnet fast power supplies. A small RC filter was placed on the buswork which connects the power supply output cable to the thin septum magnet in order to suppress the oscillations. An example of the simulated current for the thin septum magnet is shown in Figure 4.

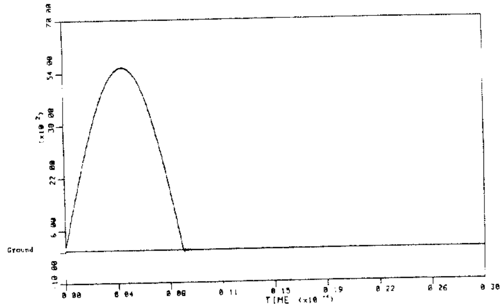

Figure 4. Simulated circuit for the thin septum magnet.
*(verticle 1600 A/div, horiz. 4 μs/div)*

## IV. RESULTS

### A. Kicker Magnet Fast Power Supplies

The kicker magnet supplies were assembled. The switches for both the start switch and crowbar switch were ITT F-130 thyratrons. An example of the current through the magnet is shown in Figure 5. The current was measured with a Pearson 5136 current probe which was mounted on the connecting buswork to the magnet. The measured waveform is as expected from the simulations, with only minor subtle differences in the waveshape. If the oscillation suppression filter is removed from the circuit, oscillation of the current waveform is seen as expected from the circuit simulations.

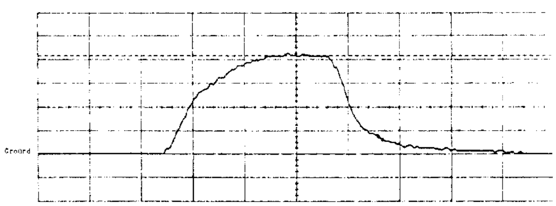

Figure 5. Measured current in an outer kicker magnet.
*(verticle 200 A/div, horiz. 200 ns/div)*

### B. Thin Septum Fast Power Supply

The thin septum fast power supply was assembled. The main switch is a ITT F-241 thyratron. The inductance budget was very small to minimize the required operating voltage. Therefore, no additional inductance was included in the circuit other than the inductance inherent in the buswork and cabling of the system. An example of the current waveform through the thin septum magnet is shown in Figure 6. The current was measured with a Pearson 5136 current probe. The measured waveform compares well with that predicted by the theory.

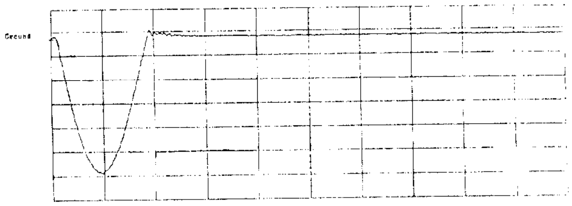

Figure 6. Measured current in the thin septum magnet.
*(verticle 1000 A/div, horiz. 4 μs/div)*

## V. CONCLUSIONS

To meet the requirements of the fast pulsed magnets used in the injection of the linear beam for the Maxwell Model 1.2-400 Electron Storage Ring, extensive circuit simulations were run to simulate the performance of the fast power supplies. The power supplies were built, and the data obtained compares with those expected from the simulations.

## VI. REFERENCES

[1] G. Nassibian, "Travelling Wave Kicker Magnets with Sharp Rise and Less Overshoot," IEEE Transactions on Nuclear Science, vol. NS-26, No. 3, pp. 4018-4020, June 1979.

[2] A. Bruckner, "Kicking Protons, Fast and Cheap," *Proc. US Particle Accelerator Conf.* Chicago, IL. 1971, p.976.