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H5 FAST-KICKER-MAGNET PULSER*

W. Frey, S. Ghoshroy and J.G. Cottingham

Brookhaven National Laboratory
Associated Universities, Inc.
Upton, New York 11973

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The fast extraction kicker magnet for the AGS is powered by a novel pulse generator. A pulse forming network (PFN) is discharged into nearly 100 percent mismatched load. The pulser delivers a current pulse of 3000 amperes peak pulse with a 2 percent flat-top ripple into a 1.4 μ H single turn ferrite core magnet. The pulse is 2.8 μ sec wide with a 180 nsec rise time, at a 0.5 to 1.5 pps repetition rate. The pulse rise time is required to provide clean extraction of the 28 GeV proton beam by bringing the kicker magnet field up to 1.25 kG within the 220 nsec space between proton bunches in the machine.

The pulser is mounted adjacent to the kicker magnet in the AGS ring. The thyratron's characteristics are not affected by the ionizing radiation environment during operation of the AGS (Alternating Gradient Synchrotron).

Introduction

The fast extraction magnet for the AGS is a single-turn ferrite core magnet. The magnet must reach a field strength of 1.25 kG within the 220 nsec space between proton bunches in the machine. The pulser that drives the kicker magnet will have to have the following pulse parameters:

- 3000 A peak pulse current
- 2.8 μ sec pulse width
- 180 nsec rise-time (10% to 97%)
- 2% flat top ripple
- 0.5 to 1.5 pulses per second

The inductance of the kicker magnet is 1.4 μ H. Assuming 0.2 μ H stray lead inductance, the pulser will have to drive a load inductor of 1.6 μ H with dc resistance less than 1 milliohm. The minimum voltage step required to get the magnet current up to 3000 A in 180 nsec is:

$$V = L \frac{di}{dt} = 30 \text{ kV}$$

A standard matched load pulser with the same characteristic impedance would require a PFN voltage of 60 kV.

Figure 1 is a simplified schematic diagram of a typical kicker magnet pulser. The pulser of this design will have to be mounted outside the ring since ionizing radiation levels in the ring will degrade the dielectric properties of most dielectric fluids used as insulation.

However, since the magnet is a current device, the maximum current transfer from the PFN to the load inductance will occur when either the terminating resistor or the network impedance is reduced to zero. Since we cannot reduce the network impedance to zero

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we will reduce the terminating resistance to zero. In this mismatched mode, the current delivered by the PFN to the inductor is limited only by its characteristic impedance. Therefore, for a PFN voltage of 30 kV, a PFN characteristic impedance 10 Ω will deliver 3000 A into an inductor load. The PFN voltage will be approximately 30 kV so air can be used as an insulator for the PFN, and the PFN can be moved down into the ring next to the magnet. Since the switch and PFN can be mounted very close to the magnet, this configuration will have the least amount of stray inductance. The mismatched PFN will have a faster rise time than a matched line (see Appendix A). Figure 2 is a simplified schematic diagram of the mismatched pulser.

Design

Figure 3 is a simplified schematic of the H5 pulser. The network impedance of 9.7 Ω was selected to ensure a nominal 3000 A pulse with less than 30 kV on the network. The network is a Guillemin E type with a 0.005 μ F speed up capacitor at the input. The first section of the network is 1/2 delay section to aid in trimming the rise-time. Resistors are paralleled with the inductors to fine tune the top of the pulse.

The PFN was designed using the standard design equations to determine network capacitance and inductance, ($C_n = \frac{1}{2Z} = 0.144 \mu\text{F}$ and $L_n = \frac{1}{2Z} = 13.6 \mu\text{H}$). Since the magnet inductance is part of the solenoid inductance, the solenoid inductance is reduced to 12 μ H. Low-level testing indicated that a minimum of 10 sections would be needed to get the flat-top ripple down to 2%. Thus, a 12 section solenoid with 1 μ H/section and 0.011 μ F/section was selected.

The front end of the network was tailored to provide the maximum current rise-time through the magnet. The speed-up capacitor of 0.005 μ F is a compromise between discharge current and rise time.

A 1/2 time section was used to follow the speed-up capacitor to control the shape of the front of the pulse. Damping resistors in parallel with the inductors were used to get the ripple down to 2% after the inductances were adjusted.

The mismatched PFN will charge to -100% V_{PFN} unless an inverse diode and a line terminal resistor is used at the open end of the line. With the inverse circuit the capacitors can be rated for 50% voltage reversal instead of 100% voltage reversal. The inverse diode also limits the inverse voltage on the main switch tube at the end of the current pulse. The inverse diode is connected as shown to prevent inverse current flowing through the magnet. Tetrode thyratrons, CX1154, are used as the main switch and the inverse diode.

Due to space limitation, (the kicker is in a 3-foot straight section in the H superperiod of the AGS

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ring), the PFN had to fold back on itself. Figure 4 is a photo of the prototype unit, and Figure 5 is a photo of the kicker mounted in the ring.

Performance

The prototype pulser has been in operation for several months. Figure 6 is typical current pulse and Fig. 7 shows the pulse rise time. Figure 8 illustrates the voltage across the magnet referenced to the current pulse. Figures 9 and 10 illustrate the voltage across the switch tube referenced to the pulse current.

The prototype unit received an estimated total radiation dose of 10^9 rads during operation at an estimated rate of 10^5 rad/hr. There was no noticeable degradation of thyatron performance during operation. The prototype used pulse capacitors with a mineral oil wetting agent. The capacitors failed as a result of radiation exposure. Radiation causes the mineral oil to change its physical and electrical properties. The capacitors failed mechanically before electrical failure. Radiation causes gases to be liberated from the oil and this eventually burst the phenolic case. Reconstituted mica pulse capacitors are being evaluated to determine whether there is any radiation effects on capacitor performance.

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Appendix 1

Comparison of Mismatched and Matched PFN Discharge Characters

The artificial transmission line (PFN) can be represented by a ladder of T equivalent section of equal characteristic impedance. The rise time of the network is determined by the 1st section elements in the discharge

A. Mismatched Line

$$Z_n = (L/C)^{1/2}$$

$$i = \frac{V_{PFN}}{Z_n}$$

B. Terminated Line

$$Z' = R_L = (L'/C')^{1/2}$$

$$i' = \frac{V_{PFN}}{R_L + Z_n'} = \frac{V_{PFN}}{2Z_n'}$$

For the conditions of $L = L'$, $i = i'$ and $V_{PFN} = V_{PFN}'$ then

$$Z_n' = \frac{1}{2} Z_n$$

$$(L'/C')^{1/2} = \frac{1}{2} (L/C)^{1/2} \text{ but } L = L'$$

$$\frac{L}{C'} = \frac{L}{4C}$$

$$\Delta C' = 4C$$

Measurements on several low impedance (about 10 to 15 ohms) indicate that the mismatched line will have a slightly faster rise than a matched line of $1/2$ the characteristic impedance. The mismatch line rise time was 0.8 the rise time of a matched line of $1/2$ the impedance.

Figure 1 - Typical Kicker Magnet Pulser

Figure 2 - Mismatched Pulser

Figure 3 - Prototype H5 Kicker Magnet Pulser, Simplified Schematic

Figure 4 - Prototype H5 Pulser

Figure 5 - Pulser Mounted on H5 Kicker Magnet in AGS Ring

Figure 6 - Magnet Current Pulse; 3000A Peak, 500 nsec/cm

Figure 7 - Magnet Current Rise Time; 3000A Peak, 100 nsec/cm

Figure 8 - Upper Trace - Magnet Current
Lower Trace - Voltage Across H5 Magnet
Time Base - 1 μ sec/cm

Figure 9 - Upper Trace - Magnet Current
Lower Trace - Voltage Across the Switch
Tube
Time Base - 2 μ sec/cm

Figure 10 - Upper Trace - Magnet Current
Lower Trace - Voltage Across the Switch
Tube