THE RHIC INJECTION FAST KICKER*

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I. INTRODUCTION

The purpose of the injection kicker is to provide the ultimate deflection to the incoming beam from the Alternating Gradient Synchrotron (AGS) into the Relativistic Heavy Ion Collider (RHIC). The beam is kicked in the vertical direction to place it on the equilibrium orbit of RHIC. Each bunch in the AGS is transferred separately, and stacked box-car fashion in the appropriate RHIC rf bucket. In order to achieve the required deflection angle four magnets powered by four pulsers will be used for each ring of RHIC. When the bunches are stacked in RHIC the last few rf buckets are left unfilled in order to provide a gap in the beam to facilitate the ejection or beam abort process. This also means there is not a severe constraint on the fall-time of the injection kicker. One prototype pulser has been built and tested. Much of the development effort has gone into the magnet design. Although lumped ferrite magnets are simpler to build and require less power to reach full field[1] a transmission line magnet was developed because of the very fast rise-time requirement and the tolerances imposed on the field variation and ripple.

II. GENERAL DESIGN

A performance specification for the kicker is given in Table 1. The performance is achieved using four Blumlein pulsers each connected to a magnet forming a matched transmission system. The pulsers will be located outside the RHIC tunnel and will be connected to the magnets by about 75 m of high voltage cable. The Blumlein pulser consists of rigid, oil-filled, transmission lines in a folded, triaxial, configuration of the type developed at SLAC[2]. The magnet consists of a "C" cross section formed of interspersed ferrite and high dielectric constant bricks. If properly oriented with respect to the beam both the electric and magnetic fields can contribute additively to the deflecting force, although by far the largest contribution is made by the magnetic field. In high power, fast rise-time systems the impedance of the grounding connection has an effect on ground transients at the magnet and pulser. These effects must be carefully considered when choosing insulation withstand levels.

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Table 1
Performance Specification

Deflection angle: 1.86 mrad
Beam rigidity: 97.5 Tm
Rise time (1-99%): 95 ns
Flat top: 20 ns
Flat top tolerance: ± 1%
Fall time: Less than 800 ns
Min. repetition period: 33 ms
Life time : 10^6 shots

III. PULSER

The major dimensions of the storage lines are given in Table 2. The triaxial delay line pipes are insulated with Teflon spacers and filled with Calumet Caltran 60-15 oil under slight positive pressure. The dielectric constant is 2.35. The delay lines are assembled from sections each about 2.4 m in length. The combination provides two delay lines of 12.5 Ω impedance which feed a 25 Ω load formed by the connecting cables (2 x 50 Ω in parallel), the magnet and a 25 Ω oil-filled hockey puck resistor assembly. The electrical properties of the Blumlein are shown in Table 3. The pulser is switched by a two-gap deuterium thyratron designed for high di/dt applications (EEV type CX 1168C). An R-C networks in parallel with the switch tube provides a small amount of overshoot in the current waveform, this improves the field rise-time by a few nanoseconds.

Table 2
Blumlein Dimensions

Outer coaxial pipe: 134.5mm O.D.x98.0mmI.D.±0.1mm
Inner coaxial pipe: 76.2mm O.D.x55.5mmI.D.±0.1mm
Length: 10.95 meters
Material: 6061 - T6 Aluminum
Insulating oil: Caltran 60-15
Insulting Standoffs: PTFE Teflon

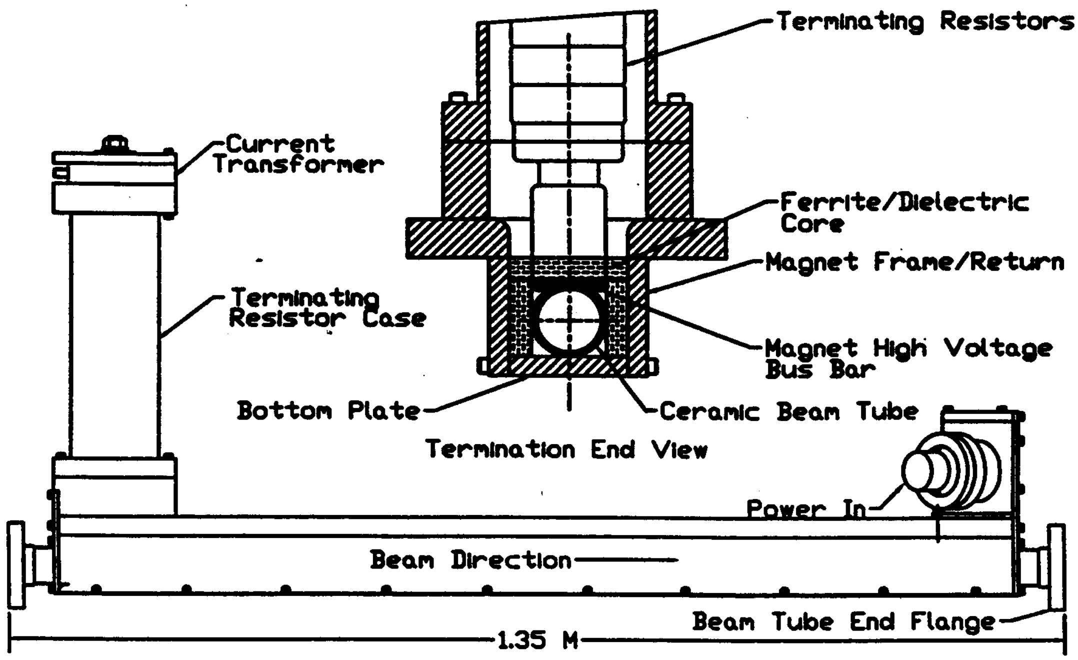

Fig. 1. General assembly of transmission line magnet.

Table 3
Blumlein Pulser Characteristics

Load impedance: 25Ω
Two-way propagation time: 110 ns
Operating voltage: 50 kV
Operating load current: 2000 A
Max. voltage: 60 kV
Current rise-time: 30 ns
Storage line capacitance: 10 nF

IV. MAGNET

The magnet is a type first developed at SLAC[3] which uses high dielectric ceramic interspersed with ferrite to approximate a transmission line. The characteristics are given in Table 4. The dielectric selected has a relative dielectric constant of ~ l00. This approach greatly reduces the cost usually associated with the machining of capacitance elements associated with a transmission line magnet. The use of rectangular bricks of similar dimension apart from the longitudinal direction assures easy assembly for potting in epoxy. The drawback to this design approach is the poor high voltage performance. The cross-section shown in Figure 1 illustrates the problem: the high voltage conductor fits into the rectangular corners of ferrite/dielectric "C" magnet but despite shaping the conductor the local electric stress in the corners is very high, particularly in the longitudinal direction in the vicinity of the dielectric sections. The stress is further enhanced in the gap adjacent to the conductor by the difference in dielectric constant between the ceramic brick and the epoxy potting compound. The first full-length magnet failed due to high-voltage flashover at 20 kV using the epoxy originally tested at SLAC.[4] A series of half-length model were then made to improve the high voltage performance. Loading the epoxy with high dielectric constant powder seemed promising but adhesion to the bricks was poor. Two RTV-insulated magnets were built and tested but they failed at 40 kV. A clear epoxy (RN1000 from Conap) gave the best results. A gap of 0.7 mm between the bricks can be inspected during and after the pour to ensure no voids exist. RN1000 has low viscosity. (600-800 cps) a long pot life below 22^{o}C and only 0.8% shrinkage during cure. The magnet is designed to permit high temperature bake-out of the ceramic beam tube. For this procedure the bottom plate shown in Figure 1 is removed and the magnet elevated above the beam tube.

A magnet made with this material was given a life test of 1.2 million shots at 50 kV without damage. This life is perfectly adequate for RHIC as filling the machine will occur only a few times a day during normal operation. After the test some flashover was observed at 57 kV. The finite elements comprising the magnet result in a frequency cut off in the 25 MHz range; this increases the effective current risetime to about 40 ns. The combination of risetime and propagation time results in an integrated field risetime of about 85 ns.

Table 4
Magnet Characteristics (each)

Strength at 2000 A: 0.0465 Tm
Number per ring: 4
Propagation time: 45 ns
Impedance: 25 Ω
High frequency cut off: ~ 25 MHz
Magnet aperture: 48.4 mm wide x 51.2 mm high
Magnet length: 1.12 meter
H field deflection: ~ 94%
E field deflection: ~ 6%
Ceramic beam tube: Circular aperture 41.3mm
3.2mm wall
Core material-ferrite: Ceramic magnetic CMD 5005
15 sections: 50mm long x
13.9mm thick
Core material-dielectric: Trans-Tech MCT-100
14 sections: 25mm long x
13.9mm thick
Bus bar/return frame: 6061-T6 aluminum
Epoxy potting material: Conap Inc. RN1000

V. TEST RESULTS

The first six magnets to be made (1 long and 5 short) had a measured impedance of 24.5 Ω ± 2%. The magnets met the specifications shown in Tables 1 and 4. The short magnets had a propagation time of about 23 ns and the long magnets about 45 ns. The deflecting force specification was met with about 45 kV charging voltage ± 10%. The wide tolerance indicates the difficulty of accurate measurement of ∫Bdl in the presence of the high electric field. Oscillograms of the field integral vs time are shown in Figure 2a and Figure 2b. These data are for a half-length magnet. Figure 2b illustrates the field perturbation at ~ 800 ns after the injection kick; corresponding to the effect on the first injected bunch when RHIC is filled. The 7th magnet (long version) possessed an impedance of ~ 27 Ω; significantly higher than the earlier magnets. The magnet also performed poorly in high voltage tests - both results suggestive of poor contact to the dielectric bricks resulting in less capacitance.

VI. CONCLUSION

The Blumlein pulser is a good solution to the problem of providing short, very high power waveforms for the injection magnet. The oil-filled version came on line with virtually no development problems. The magnet, on the other hand, has required considerable development to achieve an acceptable high-voltage performance. This performance has been demonstrated for the short version, but not, as yet, for the full-length magnet.

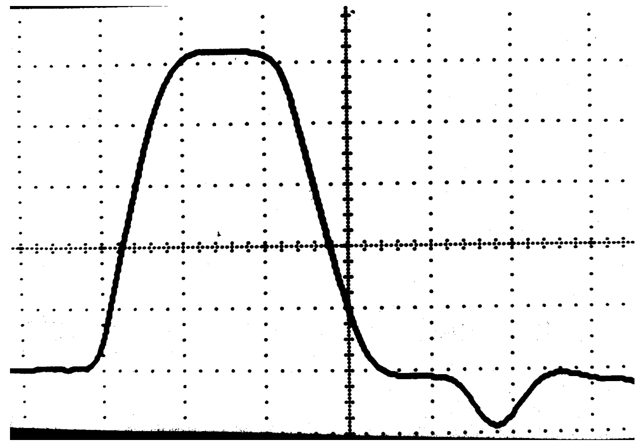

Fig. 2a. Integral field waveform vs time for a half length magnet, time scale 50 ns per division.

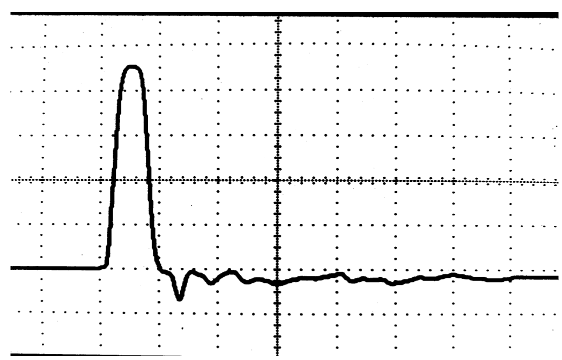

Fig. 2b. Same waveform as Figure 2a. except 200 ns per division showing field at ~ 800 ns after injected bunch.

V. REFERENCES

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