ALL-FERRITE RHIC INJECTION KICKER*

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Abstract

Ion beams are transferred from the AGS into RHIC in boxcar fashion as single bunches. The nominal design assumes 60 bunches per ring but increasing the number of bunches to gain luminosity is possible, thereby requiring injection kickers with a shorter rise time. The original injection system consists of traveling-wave dielectric loaded kicker magnets and a Blumlein pulser with a rise time adequate for the present operation. Voltage breakdown in the dielectric kickers suggested the use of all-ferrite magnets. In order to minimize the conversion cost, the design of the all-ferrite kicker uses the same components as the dielectric loaded units. The all-ferrite kickers showed in bench measured good breakdown properties and a current rise time of < 50 ns. A prototype kicker has been installed in the blue ring and was tested with beam. Beam measurements indicate suitability of all-ferrite kicker magnets for upgraded operation.

1 RATIONALE

In the quest for higher luminosity, increasing the number of bunches is one of the simpler steps to take. The only limit is set by the need to avoid spurious collisions, which for zero angle collisions in RHIC allows nominally 120 bunches. Beam transfer from the AGS to RHIC is performed in box-car fashion. For the present operation, bunches created in the AGS are transferred individually in order to form a 60-bunch pattern to yield collisions at the six interaction points. The revolution frequency in RHIC is 78.196 kHz and the rf harmonic of the acceleration system is 360, so that every sixth bucket can be filled. The bunch spacing is 213 ns and the bunch length at transfer is ~20 ns, thus requiring an injection kicker rise time of 190 ns, well within the capabilities of the original system [1]. Doubling the number of bunches will require injection kickers with rise time improved to 85 ns.

The RHIC injection system consists of traveling wave kicker magnets and a Blumlein pulser. The kicker is constructed as a "C" cross section magnet in which ferrite and high-permittivity dielectric sections alternate [2]. The dielectric blocks provide the capacity necessary for the nominally 25 Ω characteristic impedance of the traveling wave structure. Matched operation of the kicker requires ~38 kV, a value which was exceeded in the laboratory but could not be reliably maintained over million of pulses. Long-term operation without breakdown was achieved by mismatched operation with a 16 Ω termination thereby reducing the voltage to 30.5 kV. However, this is accompanied by an increase in the rise by ~50 ns due to the doubled current filling time.

* Work performed under the auspices of the U. S. Department of Energy

Voltage breakdown of the kicker typically occurred at the corners of the dielectric blocks, presumably as a result of significant field enhancements. Elimination of the dielectric blocks, thereby minimizing breakdown, provided the initial impetus for studying all-ferrite magnets. However, in order to minimize the conversion costs, their design had to retain the use of all original components.

Replacing the dielectric blocks with ferrite, but maintaining the overall geometry and in particular the metal frame has the consequence of only changing the characteristic impedance of the magnet from 25 to ~50 Ω and decreasing the filling time to ~25 ns, resulting in an overall reduction of the kicker rise time.

The all-ferrite kicker must still be considered a traveling wave structure rather than a lumped unit. Thus the kickers will be operated mismatched, and reflections resulting potentially in after-pulse are a concern. In the 2001 run of RHIC, the all-ferrite kickers were terminated with 16 Ω. The first after pulse falls into the abort gap of ~1 μs created by omission of four bunches. Subsequent pulses are expected to be below the tolerance level or to arrive between bunches.

2 MAGNET FABRICATION

The injection kicker is constructed in two functional components, the core and the frame. The core represents and determines the magnet properties and the frame supports the magnet and provides the connection to the terminating resistor and the pulsed power supply. This concept was chosen to allow rapid replacement of damaged cores. During the six month run in 2000, replacement of one magnet was required - interrupting the operation for only a few hours.

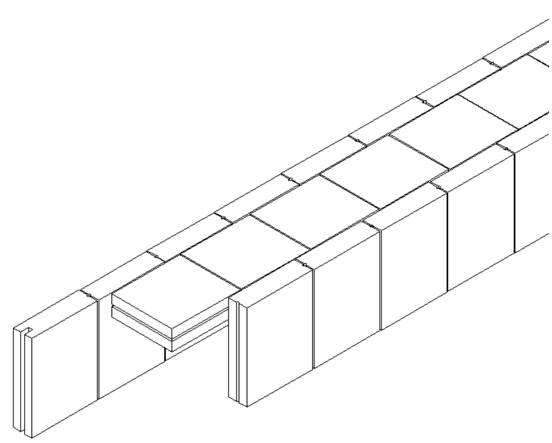

Figure 1: Isometric view. of all-ferrite core

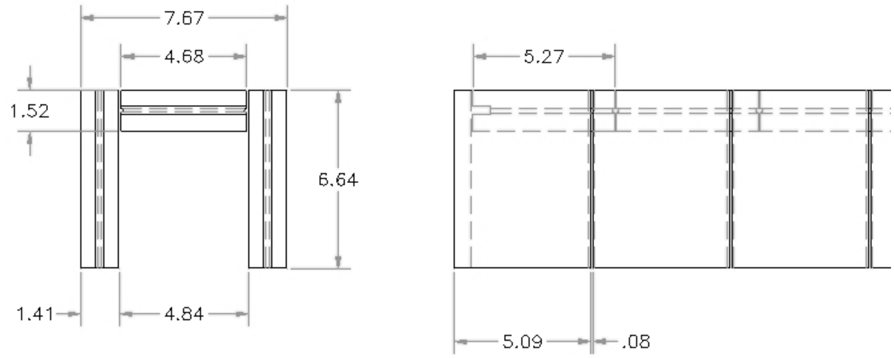

Figure 2: Ferrite blocks of injection kicker (dimensions in cm)

An isometric view of the all-ferrite core but without the buss bar is shown in Fig. 1. The core cross section and the dimensions of the ferrite blocks are shown in Fig. 2. The magnet core is a structure of ferrite blocks and buss bar, solidly held together with epoxy. The CMD5005 ferrite blocks are produced by the vendor, Ceramic Magnetics, to 50 μm accuracy. Prior to their incorporation into the core, the top ferrite blocks are high voltage tested for 2 ms to 50 kV and the side blocks to 40 kV. The blocks are Al_2O_3 bead blasted to roughen the surface for better epoxy adhesion and cleaned with ethanol and Zero-Tri. The sides of the blocks are primed with Conap-Primer AD1147 and baked to 70°C for 30 min. When ready for assembly, a 0.1 mm thick indium layer is attached with 3M Repositionable Adhesive 75 on the surface which will contact the buss bar. Proper spacing of blocks is achieved by ~1mm thick, 2 mm ∅, insulating spacers, which are attached with a minimal amount of Loctite 454 Superglue.

The blocks are assembled together with the bus bar in a fixture and impregnated with epoxy. The high voltage capabilities depend completely on full contact between epoxy and ferrite surface and greatest care during the preparatory stages is mandatory. To assure separation of core and core-casting fixture, the latter is prepared by covering it with a thin layer of beeswax at 75°C. The core is formed with the epoxy, Conap RN-1000 and a EA-87 hardener in a 100:37 ratio by weight. The thoroughly mixed epoxy is slowly transferred into the fixture under vacuum, better than 1 Torr, to avoid the formation of bubbles. After allowing the escape of gases formed during the solidification of epoxy, the fixture is pressurized and remains at 10 psig, typically till the next day.

Surface epoxy and other irregularities are ground off using diamond wheels on a flat milling machine. Prior to the final assembly of the core into the frame, a 0.1 mm thick indium layer is put on the top of the core. Good contact with the frame in order to avoid gaps and local field enhancements is achieved by assembly under mechanical pressure and voids are filled with Dow-Corning Sylgard Silicone elastomere 184 mixed with hardener in a 10:1 ratio.

3 ELECTRICAL MEASUREMENTS

Before the injection kickers are sent to the rings, each unit is tested in a stand fully equivalent to the operational conditions. The dielectric loaded kickers were terminated with 16 Ω for reasons discussed above, and have been subject to ~100,000 pulses at 35 kV. The current in the load resistor is monitored with a transformer (Fig. 3).

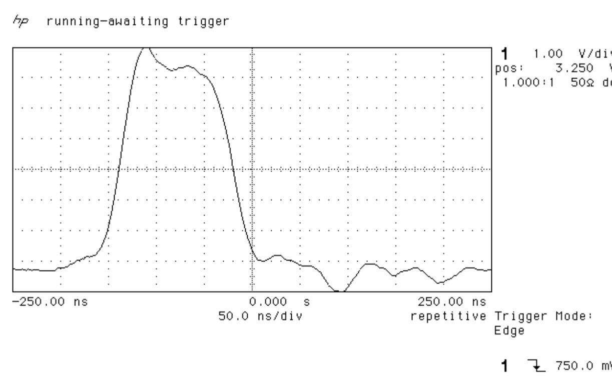

Figure 3: Current in the load of a dielectric kicker (30 kV into 16 Ω; scale 200A/V).

The current rise time of the dielectric loaded kicker would satisfy the 85 ns requirement, but the added delay due to the ~50 ns filling time prevents its use for the future upgraded luminosity operation.

The current pulse in the terminating resistor of the all-ferrite magnet is shown in Fig. 4. The magnet is terminated with 16 Ω and ready for installation in the ring. One sees that the current rise time <50 ns and essentially the same as in the dielectric kicker, so that an improvement in the kick rise time must come from the reduced filling time.

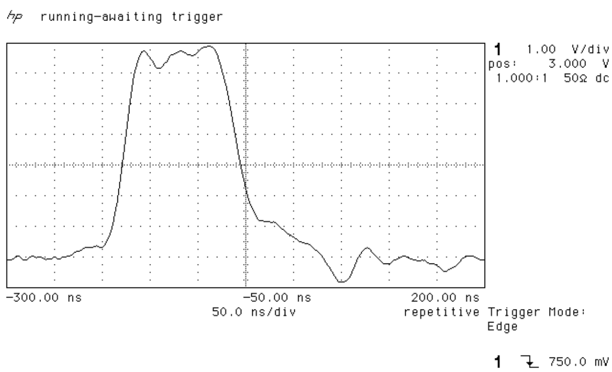

Figure 4: Current in the all-ferrite magnet (32 kV and 16Ω)

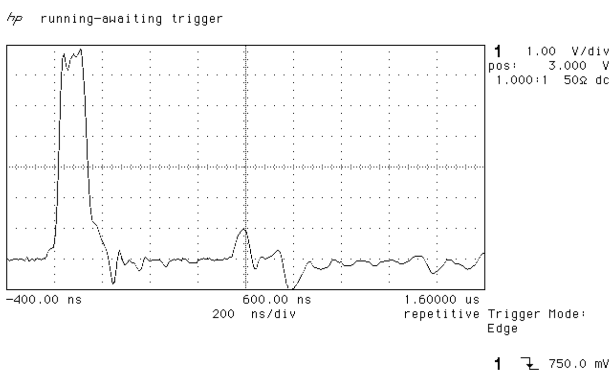

Figure 5: Current in the all-ferrite magnet (32 kV and 16 Ω)

The current pulse in the termination of the all-ferrite magnet is shown with expanded time scale in Fig. 5. One observes the first after-pulse which falls into the abort gap and a small second pulse. The second pulse can be reduced by terminating the magnet with 25 Ω at the expense of increased voltage to 38 kV, as seen in Fig.6.

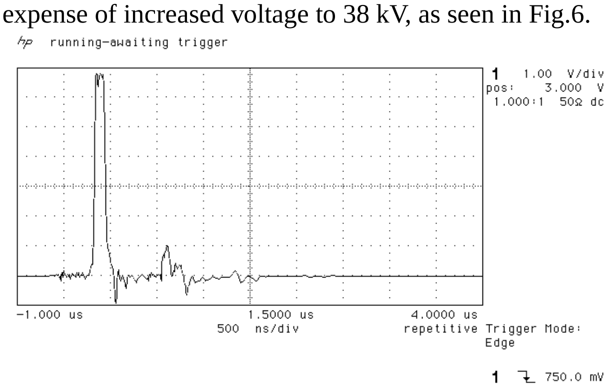

Figure 6: All-ferrite magnet with 25 Ω load @ 38 kV

4 BEAM BASED MEASUREMENTS

The kicker rise time and flattop were measured with beam for both the dielectric loaded and the all-ferrite kickers. In RHIC four modules are operated in each ring. For the measurement beam was injected and the kicker timing was shifted.

The flat top (× in Figs. 7 and 8) was obtained by shifting the kicker timing and observing the beam location at a downstream vertical position monitor. Note that due to the beam length, the flat top in this measurement is different from the flat top in the current measurement. To find the location of the rising edge (•in Figs), beam was injected using a vertical corrector instead of the kicker. The kicker timing was then moved until an effect on the beam became visible

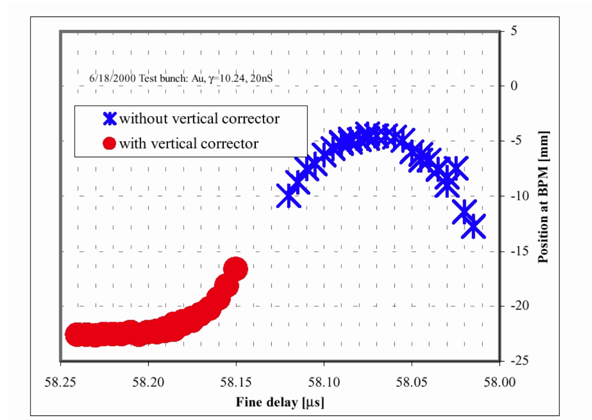

Figure 7: Beam based rise time and flat top measurement of the dielectric loaded kickers.

In Fig. 7 the dielectric loaded kicker measurement is shown. Fig. 8 gives the corresponding results for the blue ring with one all-ferrite kicker.

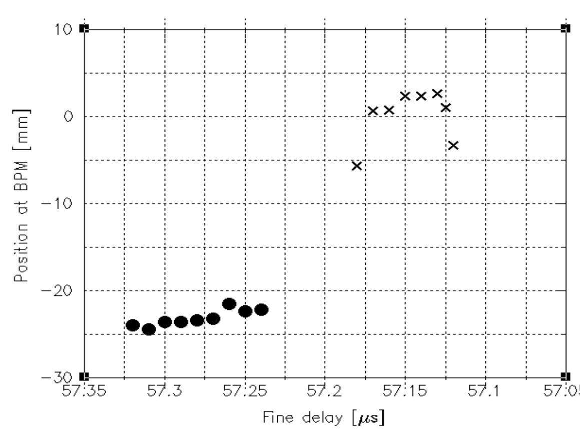

Figure 8: Beam based rise time measurement of the blue ring with one all-ferrite kicker magnet.

5 ACKNOWLEDGEMENTS

The authors would like to acknowledge the support provided by the technicians in the Beam Components and Pulsed Power Groups, especially Ch. Trabocchi during the kicker fabrication and K. Hartmann and D. Warburton during kicker testing.

6 REFERENCES

[1] W. Fischer et al., PAC '97, Vancouver, BC, p. 210.
[2] H. Hahn, N. Tsoupas and J.E. Tuozzolo, ref.1, p.213