UP-GRADED RHIC INJECTION KICKER SYSTEM*

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Abstract

The design of the RHIC injection systems anticipated the possibility of filling and operating the rings with a 120 bunch pattern, corresponding to 110 bunches after allowing for the abort gap. Beam measurements during the 2002 run confirmed the possibility, although at the expense of severe transverse emittance growth and thus not on an operational basis. An improvement program was initiated with the goal of reducing the kicker rise time from 110 to ~95 ns and of minimizing pulse timing jitter and drift. The major components of the injection system are 4 kicker magnets and Blumlein pulsers using thyratron switches. The kicker terminating resistor and operating voltage was increased to reduce the rise time. Timing has been stabilized by using commercial trigger units and extremely stable dc supplies for the thyratron reservoir. A fiber optical connection between control room and the thyratron trigger unit has been provided, thereby allowing the operator to adjust timing individually for each kicker unit. The changes were successfully implemented for use in the RHIC operation.

INTRODUCTION

Beam injection into the RHIC is done vertically by means of four kicker systems per ring, each consisting of a magnet connected to a Blumlein pulser using thyratron switches [1,2]. The pulsers are located outside the RHIC tunnel and are connected to the magnets by ~75 m of high voltage cables. The Blumlein pulser [3,4] consists of rigid, oil-filled transmission lines in a folded triaxial configuration. The magnet was originally conceived as a transmission line magnet with 25 Ω characteristic impedance to match the two parallel 50 Ω feeding cables. Using a conceptual SLAC design [5], the first version of the magnet was build with a "C" cross section formed of interspersed ferrite and high-dielectric constant bricks [6]. The kicker operates in air and thus requires a ceramic beam tube with the dimensions of 47.6 mm o.d. and 41.3 mm i.d., presenting the smallest aperture at injection. Voltage breakdown in the dielectric loaded kickers suggested their replacement by the present all-ferrite magnets [7].

Beam transfer from the AGS into RHIC is done in box-car fashion. The bunches created in the AGS are transferred individually in order to form a nominal 60-bunch pattern to yield collisions at the six interaction points, implying 55×55 bunches after allowing for the dump gap. 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 injection system. Increasing the luminosity by doubling the bunch pattern to 120 corresponding to 110×110 injected bunches was part of the original design but requires a kicker system rise time of better than 95 ns [8]. Beam based measurements of the dielectric-loaded kickers showed a rise time clearly below this value [9], whereas the operational all-ferrite magnets during the 2002 run had a ~110 ns rise time [7]. Injection of 110 bunches was possible although with severe transverse emittance growth. Based on this experience, a system rise time of 95 ns without timing jitter or drift became the goal of the up-grade program discussed in the present paper.

SYSTEM UPGRADES

The original concept of the injection system with a transmission line kicker magnet is in principle capable of satisfying these requirements. However voltage breakdown problems forced the mismatched termination of the kicker magnet. Nevertheless, the following hardware modifications achieved 110 bunch operation in the 2003 run:

- the injection kicker magnets are terminated with 25 Ω instead of the previous 16 Ω, thereby raising the operating voltage from 31 to ~38 kV.
- the home-grown thyratron trigger system consisting of a DC power supply and two hard tube trigger units are replaced by a commercial solid state trigger unit. The new unit eliminates the sensitivity to ac power fluctuations and reduces the short term pulse jitter to ~3 ns peak-to-peak.
- the thyratron reservoir ac supply is replaced by a dc power supply, highly regulated to better than 0.01 V, thereby minimizing drift.
- a fiber optical connection between control station and the thyratron trigger unit allows the operator to adjust slow drifts due to temperature changes affecting the system immediately before injection.

ALL-FERRITE KICKER MAGNET

In the conversion of the dielectric-loaded into the all-ferrite magnet the ceramic bricks were replaced by ferrite, but in order to minimize the cost, the overall geometry and in particular the magnet frame was retained [7]. The magnet length is 1.12 m and the core cross section is shown in Fig.1.

It is not obvious that the converted all-ferrite magnet would retain transmission line characteristics rather than adopt those of a lumped magnet. However, a direct measurement of the magnetic field confirmed the transmission line properties. The time dependent magnetic

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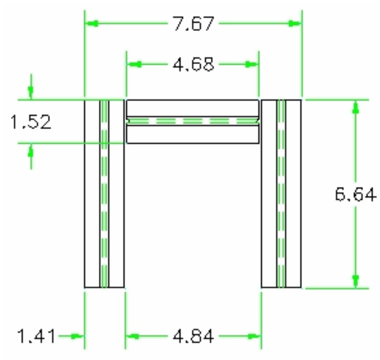

Figure 1: Kicker magnet core cross section (in cm)

field of the all-ferrite kicker was measured using the Faraday effect (1846), which describes the phenomenon that the polarization of a light beam traversing a crystal is changed by an applied magnetic field. In the present setup, a green Ar laser light was used together with an artificially grown TGG crystal which has a large Verdet constant.

The rise time of the magnetic field, measured at two positions in the magnet, ~ 80 cm apart, with one ~20 cm down-stream from the input and the second ~20 cm up-stream from the 25 Ω terminating resistor is shown in Fig. 2. The incoming pulse from the pulser has a rise time of ~33 ns. The transit time to cover the 80 cm is 24 ± 2 ns in both cases. Since the propagation velocity equals the light velocity times the ratio of characteristic impedance / Z_0, one finds a characteristic impedance of ~40 Ω. The effective rise time of the all-ferrite kicker with matched termination would be <50 ns.

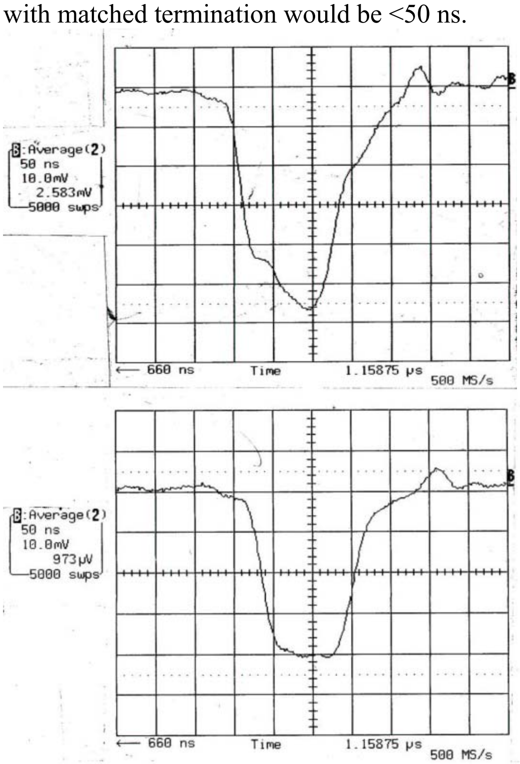

Figure 2: Magnetic field pulse at input (top) and output (bottom) of kicker magnet

The response of the kicker to a step function was also measured with the network analyzer in the time domain mode. The time dependent current or magnetic field at the kicker for different terminations is shown in Fig. 3. Note that the smaller mismatch between instrument, 50 Ω and the magnet yields only a qualitative comparison.

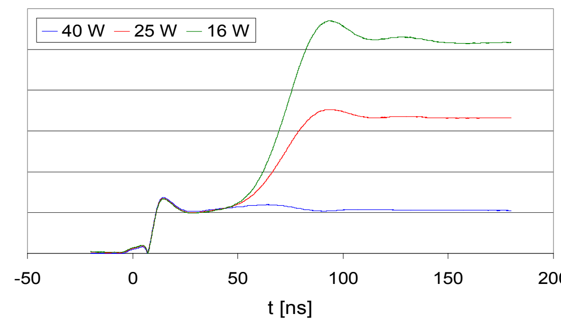

Figure 3: Kicker response to step function

The effective rise time of a mis-matched transmission line magnet consists of the rise time of the incoming pulse plus twice the transit time in the kicker. For RHIC operation, the magnet is mismatched with a low impedance to gain current and magnetic field at a lower voltage. The voltage required to achieve the necessary current is given by

$$U_B = \left[\frac{2}{Z_K + Z_0} \left(1 + \frac{Z_K - Z_L}{Z_K + Z_L} \right) \right]^{-1} I_K$$

where U_B represent the Blumlein source voltage and Z_0, Z_K, Z_L is the impedance of the source, of the kicker, and of the terminating load respectively. The total deflecting current is required to be ~1.15 kA at the reduced injection energy of 8.86 GeV/u for gold. During the 2002 run, the magnets were terminated with 16 Ω requiring ~31 kV. The voltage requirement with a matched termination of 40 Ω becomes ~46 kV, a level not yet tested. In the 2003 run, the kicker with 25 Ω termination runs conservatively at ~38 kV.

BLUMLEIN PULSER

Beam injection in the 2002 run was hampered by timing jitter and drifts of the pulser units. The switch tube in the Blumlein Pulser is a two-gap deuterium-filled thyratron, EEV 1168C (70 kV, 4 kA specs).

Trigger Unit

Proper operation of the thyratron requires triggers, 500 V on G1 and 1.5 kV on G2, as well as a negative 150 V to hold-off the anode voltage, which are now provided by a commercial trigger unit EEV MA2709A (a.k.a. "black box). The timing jitter of the thyratron is quoted as 1 ns typical, with 5 ns maximum. The trigger timing shift of the commercial trigger unit was tested to be less than 1 ns against line changes of 10 % (i.e.105 - 120 V) Implementation of the changes reduced the jitter to ~3 ns peak to peak.

Reservoir Voltage Power Supply

The reservoir voltage is the most critical parameter in the quest for trigger stability, both jitter and drift. The dependence of current timing on the dc reservoir voltage is shown in Fig. 4. The data sheet recommends that the reservoir voltage be stabilized to ± 0.05 V, which according to our measurements corresponds to typically ± 3 ns. New DC power supplies (Mid Eastern Ind. HWD 10-15B) 10 V & 10 A with 0.01 V regulation will be used

Achieving the full anode current rise time determines the minimum reservoir voltage. Operation at the highest level compatible with maintenance of the anode voltage hold-off is recommended. The kicker system runs at a low voltage, well below its design, so that the reservoir voltage can go to the manufacturer's limit of 6.5 V.

Changing the heater voltage by 10 % has no short term effect on the trigger time, but may contribute to a temperature induced drift. The heater is stabilized by a Solatron transformer.

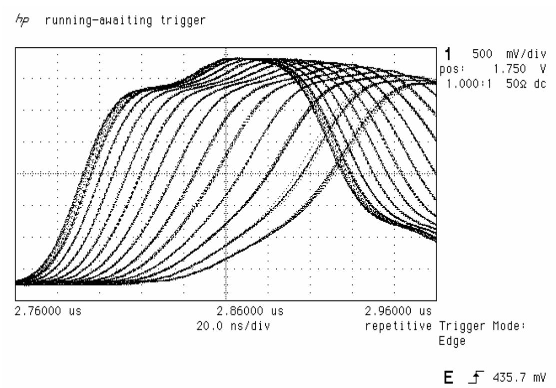

Figure 4: Anode Current change with reservoir voltage from 5.0 to 6.3 V

Anode Current Rise Time

The thyratron data sheet gives a nominal rate of rise of anode current of better than 150 A/ns but the actual value depends on the external circuit. The rate of rise in the Blumlein pulser as measured by the magnetic field in Fig. 2 is ~38 A/ns at operating conditions. However, the full rate of current rise is only reached after the anode delay time, defined as 0 to 25 %, which is typically ~100 ns. Allowing a 2% of full current delay adds ~65 ns to the time between the G2 trigger and bunch arrival. Since predictable, the effective pulse rise time is not affective by these delays. Simultaneous triggering of the four pulsers takes advantage of these delays and minimizes the overall kicker rise time.

Fiberoptic Controls

To accommodate the individual turn-on delays and time drift of the four thyratrons the bunch synchronized trigger drives a Stanford Research Systems DG535 4 channel delay generator with each channel remotely variable to 5ps resolution through an IEEE buss controller. Each of the 4 output channels is connected to an Agilent 1404 fiberoptic transmitter and then through a 30M light cable to the E2V MA2709A trigger unit input. This system was found to contribute <1 ns jitter to the system.

BEAM BASED MEASUREMENTS

The kicker rise time and flattop were measured with beam for the all-ferrite kickers with 16 and 25 Ω terminations. For the measurement beam was injected and the kicker timing was shifted. The rise time with 25 Ω was reduced from ~110 to ~95 ns as seen in Fig. 5.

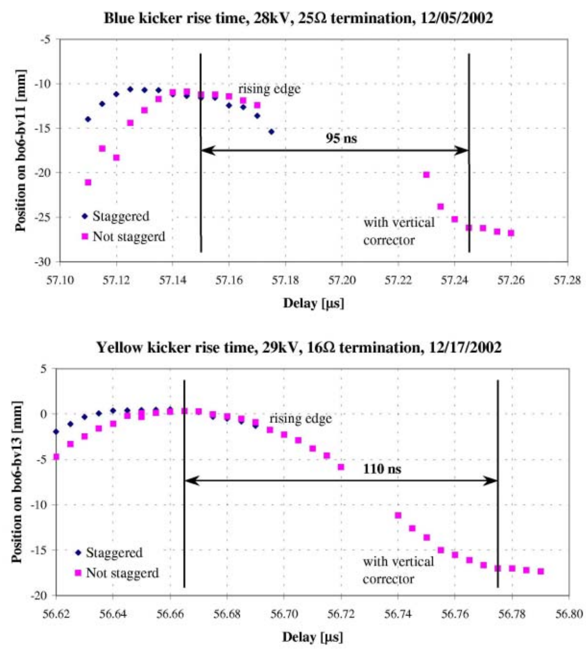

Figure 5: Beam based rise time measurements

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