KICKER SYSTEM FOR 8 GEV PROTON INJECTION

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Abstract

This kicker functions to inject 6 batches of 8 GeV beam vertically into the Fermilab Main Injector from the Booster. The trajectory of this beam must be bent 1.05 mr to place it onto equilibrium orbit. This kicker system produces a nominal integrated field kick of 0.309 kG-m. Specifications require a 1.6 microsecond pulse with a 50 ns risetime (1%-99%) and a 150 ns falltime (99%-5%). The system is comprised of three magnets and power supplies. Each is composed of a resonant charger, a 25Ω PFL, a thyratron-based pulsed power supply, a ferrite "C" magnet, and a Fluorinert™-cooled resistive load. Design details and measurements are presented.

1 INTRODUCTION

This system is being developed to replace the existing kicker that injects protons from the Booster to the Main Ring. The existing system does not provide a fast enough risetime. First, the current risetime of the thyratron is slow because the dc charging system requires a low reservoir level to avoid prefires. Second, the parasitic inductance of the thyratron housing limits the risetime of the circuit. Also, the control system is being upgraded to use components common throughout Main Injector and newer TeV kickers. Power supplies of this type will be also used in the Fermilab Recycler and future Booster upgrades. In addition to meeting design specifications, this kicker was also developed to meet reliability, serviceability and cost objectives.

Prefires and fail-to-fires must be kept less than one per every million shots. Lifetime is also important; over 10^8 shots are necessary to achieve 5 years of service. While this is most applicable to the thyratron, the magnet and resonant charging unit must also last a similar amount of time without any high voltage breakdown or other failure modes.

Serviceability was another major concern. Unlike previous power supplies which were large forced air or oil cooled tanks, this design is a compact Fluorinert™ cooled system. Replacement of a complete power supply takes less than an hour, while even the replacement of a thyratron is a fairly simple task requiring less than four hours. In general, an effort was made during the design to improve the ease of servicing all system components.

Of course, cost was another design consideration. The systems had to adhere to project budgets and schedules throughout the design and development phase.

Initial system specifications [1] are tabulated in Table 1. Some preliminary measurements are also included. These specifications are subject to revision.

$\int$ Bdl	0.309 kG-m
Kick Angle	1.05 mr vertical
Horizontal Aperture	101.6 mm
Vertical Aperture	50.8 mm
Magnets Required	3
Field Rise Time (1%-99%)	<50 nsec
Flattop	1600 nsec
Field Fall Time (99%-5%)	<150 nsec
Flattop Stability	±1%
Post Flattop Stability	±1% of full field
Magnetic Length	0.83 m
Gap Height	111.1 mm
Gap Width	63.5 mm
Nominal Field	0.136 kG
Characteristic Impedance	25 Ω
Number of Cells	26
Measured Magnet Fill Time	26 nsec
Measured Inductance per Cell	~29 nH
Measured Capacitance per Cell	~45 pF

Table 1: Specifications and Measurements

2 DESIGN

2.1 Power Supply

The power supply consists of a PFL, a thyratron pulser and a resonant charging system, as shown in Figure 1. This system must produce a 1.6 microsecond pulse with fast rise and fall times. It must operate at a 15 Hz repetition rate, producing 6 pulse "bursts" every few seconds. Minimization of prefires and fail-to-fires is a major design consideration. A lifetime of over 10^8 shots is required.

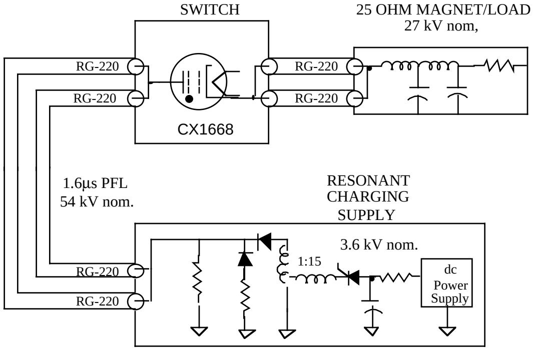

Figure 1: Diagram of Kicker System

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Each PFL consists of two lengths of RG-220 type cable. The cable itself is AA-5966, manufactured by Times Microwave Systems under a custom Fermilab specification. It is similar to standard RG-220 cable except that it has the addition of a foil shield bonded to the polyethylene. The two 50 Ω cables are installed in parallel to make a 25 Ω system. These cables are cut to nominal 160m lengths to determine the 1.6 μs pulse width. Cables delivered to Fermilab from Times passed a 500,000 pulse acceptance test at 66 kV. The falltime of the system is dominated by the skin-effect of the cable.

The pulsed power supply shown in Figure 2 consists of a thyratron switch, a trigger system, and associated filament/reservoir power supplies. These components are mounted in a Tin-plated Aluminum housing. This housing is compact to minimize parasitics that adversely affect the system risetime. The thyratron is cooled by 3M Fluorinert™ FC-40 liquid. This also provides the necessary high-voltage insulation. Connections to the PFL and load cables are made with custom connectors designed by Isolation Designs, Inc [2].

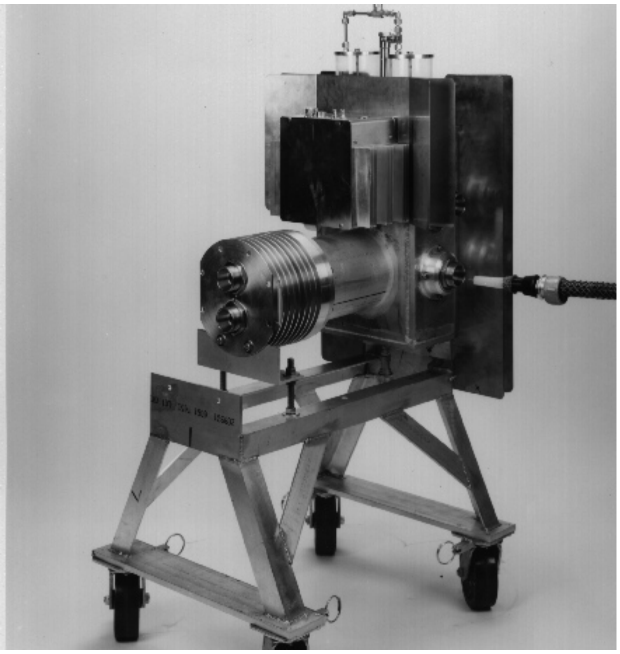

Figure 2: 25 Ω Pulsed Power Supply

Fermilab tested various 2-gap and 3-gap thyratrons. The best results were obtained with a hollow anode EEV CX1668 using a “cross-connection” bias scheme [3]. This decreases the overall system delay, and effectively reduces the risetime by minimizing the time between the breakdown of the two gaps. Biasing is accomplished with 4 MΩ resistors on the gradient grids; no capacitors were used in the bias network. An adjustable DC power supply and a 20 kHz DC-AC converter are used to power the filament and reservoir. This minimized the size of the transformer which provides isolation between high and low voltage components. Also in the thyratron housing is a fast thyratron trigger system [4].

A resonant charging supply is used in this system, primarily to allow the thyratron to operate at a higher reservoir power level than would be possible with a direct charging DC system. The higher reservoir power level improves the current risetime in the magnet significantly. In addition, the resonant charging system operates in about 300 μs, allowing fast repetition rates.

The resonant charging system is comprised of a 5 kV DC power supply which charges a capacitor. The capacitor size can be varied depending on the length of the PFL being resonantly charged. On command, an SCR switch discharges the capacitor into a step up transformer. The transformer assembly, made by Stangenes Industries, has a nominal 1:15 step up ratio. In addition, it incorporates the charging diodes, a 25 Ω resistor/diode back-termination network, and a 500 kΩ discharge resistor in its oil-filled housing. The discharge resistor will discharge the PFLs between pulses at the 15 Hz rep rate to prevent accidental overcharges, should a fail-to-fire occur. The PFLs connect directly to the transformer assembly via Isolation Designs connectors.

2.2 Magnet

Like the power supply, a new 25 Ω magnet has been developed to replace the existing Main Ring injection magnet. A “C” magnet design is used, incorporating 26 cells with inductance and capacitance tuned to provide a matched 25 Ω system. Vector Fields OPERA-2d software was used in analyzing and optimizing the field linearity in the beam tube gap.

Each cell is comprised of a high frequency Nickel-Zinc ferrite block. The ferrite is CMD 5005, made by Ceramic Magnetics [5]. The ferrites are 2.54 cm thick, and have a 0.635 cm spacing. Adjacent ferrites are cross-coupled with a single turn of copper strap and a series 10 Ω ceramic composition resistor [6]. Finally, each cell has a small parallel plate capacitor that forms a matched 25 Ω system with the magnet inductance. Standard high-voltage ceramic capacitors were determined to have too much stray inductance for this application. This capacitor is simply a small metallic plate connected to the busbar that forms a small capacitance with the top of the magnet case. The top of the case can be machined such that the distance between the capacitor electrodes can be varied to allow for precise matching of the impedance. OPERA-2d software was used to design the capacitor. An impedance analyzer will be used to ensure the production magnets are properly trimmed.

The magnet is potted in Grace Stycast 5952 Silicon Rubber. This is a high dielectric constant material which is used to achieve the proper capacitance between the parallel-plate capacitors. Most kicker magnets at Fermilab have used a transparent RTV material. While this allows for simple inspection of failures, it did not provide the high dielectric constant necessary in this design. The Stycast material does have the disadvantage that is it opaque, and will make locating repairs difficult. The potting material also provides high voltage insulation in the magnet. Since repairs are likely to be difficult, peak field stresses in the magnet were universally kept below half of the dielectric strength of the material.

Like the power supply and resonant charging unit, Isolation Designs connectors are incorporated into the magnet to facilitate connection to the RG-220 type cable that runs between the magnet and power supply. Capacitive pickup probes at the input and output are used to monitor the magnet voltage. In addition, the magnet may incorporate a saturable reactor and a speed up network to improve performance [7]. Preliminary tests have shown that a small saturable reactor at the input of the magnet does improve the risetime. Acceptable results were obtained using 3.23 cm^2 of CMD 5005 ferrite with no air gap. This ferrite had an ID of 1.27 cm and an OD of 3.81 cm. The ferrite was mounted directly over a 1.27 cm conductor inside the magnet. Larger amounts of ferrite improve the 10%-90% risetime significantly, but also cause unacceptable reflections later in the pulse. Further tests will determine if a small “speedup” capacitor on the output of the magnet can improve the risetime.

2.3 Resistive Load

Attached directly to the magnet is a 25 Ω load, comprised of ten disc resistors manufactured by HVR. These resistors are mounted in a low inductance, tapered housing. They are individually selected to be matched to the proper resistance at nominal operating temperatures and voltages. The resistors are cooled by a passive, evaporative cooling system using Fluorinert™ FC-72 liquid. Heat is transferred by copper plates between resistors to the Fluorinert™ in the center hole. Dow Corning Sylgard® 184 RTV provides high voltage insulation. A current viewing resistor is included for monitoring the current waveform.

3 MEASUREMENTS

Initially, we compared measurements from a printed circuit field coil and the difference of the two capacitive pickup probes. More recently, we have started some preliminary measurements on the prototype magnet with a novel ferrite probe [8]. All these measurements show reasonable agreement. A measurement of the rising edge of the magnet field using the new ferrite probe is shown in Figure 3. As the load was not at nominal operating temperature, there is a slight impedance mismatch in the system for these measurements. This mismatch is a partial cause of the small oscillation on the flattop. The parasitic inductance and capacitance of the thyratron housing are other factors. These measurements were taken at 20% over nominal field ratings. This is about 66 kV, and is the upper limit due to reliability of the PFLs and the thyratron. Typical observed jitter at these levels is about 1.5 ns. No saturable reactor or “speed-up” capacitor is installed for these measurements.

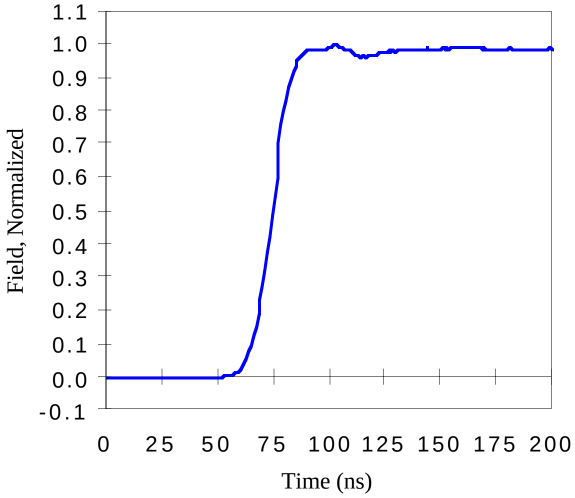

Figure 3: Magnet Field vs. Time

4 CONCLUSION

Preliminary field measurements on the prototype kicker system show that the system meets specifications except for flattop stability, which is better than ±2%. Final system components are being procured and assembled for installation in 1998. We intend to measure the first production magnet later this year using an 8 GEV proton beam. Based on those measurements, we may include a saturating ferrite and capacitive speed up network to improve performance over measurements presented here.

5 ACKNOWLEDGMENTS

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REFERENCES

[1] The Fermilab Main Injector Technical Design Handbook, November, 1995.
[2] A. Donaldson , et al., "High Voltage Pulse Cable and Connector Experience in the Kicker Systems at SLAC," IEEE Particle Accelerator Conference , Vol. 5, pp3159-3161 , May 1991.
[3] Ron Sheldrake, EEV Corportation, Private communication
[4] C. Jensen, D. Qunell, “A Thyratron Trigger with Low Jitter,” These Proceedings.
[5] C. Jensen, J. Dinkel, "Comparison of Ferrite Materials for Pulse Applications," IEEE Transactions On Magnetics, Vol. 31, No. 1, January 1995.
[6] B. Hanna, J. Dinkel, C. Jensen, D. Qunell, R. Reilly, D. Tinsley, J. Walton, “A New Fast Rise Time Kicker System For Antiproton Injection Into The Tevatron,” IEEE Particle Accelerator Conference Proceedings, Vol. 3, pp 1900-1902, May 1995.
[7] M.J. Barnes, G.D. Wait, “Effect of Saturating Ferrite on the Field in a Prototype Kicker Magnet”, EPAC94, London, pp2544-2546.
[8] W. Pellico, P. Colestock, “Pulsed Magnetic Field Measurement System,” These Proceedings.