OPERATIONAL EXPERIENCE WITH THE FERMILAB 150 GeV INJECTION KICKER

R.C. Trendler
Fermi National Accelerator Laboratory*
P.O. Box 500
Batavia, IL 60510

Abstract

The Fermilab E17 injection kicker has been in operation for more than 12000 filament hours and has logged almost 350,000 pulses since commissioning without major failure. The kicker system uses EEV 1193B and 1193C double-ended thyratrons in the MAIN, CLIP and DUMP configuration. In typical operation, the pulser produces 4800 A, 20 μs pulses at a charging voltage of 60kV and is capable of operating at a 80kV charging voltage. Any failure of the injection process can cause the Tevatron cryogenic magnets to quench. This includes any misfires of the injection kicker. Considerable effort was made to maximize reliability and provide interlocks to limit the problems that could happen from injection kicker misfires. The operating experience and reliability of the EEV thyratron will be discussed. Also, the use of the fiberoptics, unique charging power supplies, and unusual digital interlocks and the role they play in improved reliability will be discussed.

General Design

Figure 1 shows the simplified schematic of the injection kicker pulser. The 6.25 ohm PFN consists of 22 cells; each cell having a 4.3 μH inductor and a 0.08 μF capacitor. The MAIN and DUMP deuterium filled thyratron tubes are EEV 1193B, whereas the CLIP tube is an EEV 1193C. The 1193 C is essentially identical to the 1193B except for the addition of a screen grid. The pulser drives two 12.5 ohm transmission line magnets in parallel, via four RG 220 coaxial cables in parallel per magnet. The entire pulser ensemble; thyratrons, PFN, isolation transformers, tube bias and diagnostic circuitry, etc., reside in a single oil filled tank (see Figure 2).

The need for high reliability, both in terms of component lifetime and avoidance of injection kicker misfires was clear from the very beginning of the design. In particular, special attention was paid to the choice of thyratrons, capacitors, charging power supply, and system controls. Experience at Fermilab and elsewhere has shown the importance of maintaining careful isolation of the three independently triggered thyratrons. Failure to isolate the tubes and failure to control circuit impedances can lead to erratic tube firings or high voltage breakdown. In the case of the injection kicker, this could lead to quenching of the superconducting Tevatron magnets. Special attention was paid to the design of the thyratron tube mounts and enclosures (see figure 2). Additionally, electrostatically shielded high voltage transformers were used for power delivery to the thyratron heaters and reservoirs.

Some of the most important design considerations in high voltage systems are to minimize potential sources of high voltage sparking and to control system impedances to reduce uncontrolled voltage transitions. Examining Figure 1 shows that locating the CLIP tube on the cathode side of the MAIN would improve the fall time of the clipped pulse; however, the dv/dt appearing of the anode of the CLIP when the MAIN fires would contribute strongly to spontaneous firing of the CLIP. The capacitance associated with the CLIP gradient grid voltage divider would couple significant energy to the CLIP grid. These considerations led to locating the CLIP as shown. It can be observed, however, that this location for the CLIP now introduces a new problem that is not readily controlled in systems of this physical size. Note that when the MAIN tube fires, stray inductances in the PFN can and do cause the voltage at the MAIN tube anode to drop precipitiously. Figure 3 shows this effect. This rapid voltage change will fire the CLIP tube. To minimize this voltage change, an RC network was added from the MAIN/CLIP anodes to circuit common. The values chosen are a 10 ohm resistor in series with a 0.08 μF capacitor. This addition has largely eliminated the early CLIP fire problem and, because our rise time requirements are not too stringent, it has not significantly affected the pulse shape.

It should be noted that the CLIP tube is different from the MAIN and DUMP tubes in that it has a screen grid designed in by EEV to help shield the grid from voltage changes on the anode. The screen is directly coupled to the cathode. There has not been the opportunity to verify the need for the screen, but based upon the experience at CERN, it is probably essential for minimal CLIP voltage breakdowns.

Operating Experience

The injection kicker, as pointed out in the abstract, has operated almost 13000 filament hours and has logged almost 350000 pulses. The most serious problems occurred shortly after commissioning and have been associated with the failure of the commercially designed load resistors. These were replaced with resistors of our own design which have operated without problems. Other problems were associated with a commercially produced ± 15 VDC power supply used in the thyratron bias monitoring circuitry. These have been eliminated by using a unit of different manufacture.

Thyratron Experience

The EEV 1193B/C thyratron tubes (see Figure 4) are provided by English Electric Valve Company Limited of Chelmsford, Essex, England. The tubes are deuterium-filled four-gap double-ended thyratrons. Their general tube parameters are as follows:

Maximums

Peak forward anode voltage	140	kV max
Peak anode current	6000	A max
Average anode current	6.0	A max
Peak output power	350	MW max

* Operated by Universities Research Association, Inc. under contract with the U.S. Department of Energy.

Electrical

Cathode heater voltage(each end)	6.3+5%	V
Cathode heater current(each end)	40	A
Reservoir heater voltage(each end) (nominal)	5.0	V
Reservoir heater current(each end)	10	A

Mechanical

Seated height (flange to flange)	21.130 inches
Clearance required below flanges	2.500 inches
Overall diameter	6.000 inches
Net weight	27.5 pounds

The CLIP tube typically carries 9600A at a 60kV PFN charging voltage. This is well beyond the specified peak anode current; but within the crow-bar service specification. The tubes have functioned flawlessly since installation. We have found, however, that the CLIP reservoir voltage had to be run at a lower voltage (nominally 25% lower) than specified on the tube for consistant operation. The effect is quite sharp. A mere 0.1 volt increase from nominal will cause the CLIP to fire simultaneously with the MAIN.

Fiberoptics

Fiberoptic components have been used throughout for thyratron tube triggering and monitoring. The MAIN tube, in particular, has the most stringent requirements. An examination of Figure 1 shows that the MAIN cathode is charged to 60 kV. When the MAIN is fired, the cathode drops to 30 kV and, the anode rises to 30 kV for the duration of the 20 µs pulse. To avoid one possible source of coupling to the CLIP or DUMP tubes, the MAIN cathode trigger and monitoring circuitry and the main anode monitoring circuitry are physically located at the tubes ends in attached aluminum enclosures (see Figure 2). All connections to these boxes are either wires from the secondaries of the elecrostatically shielded high voltage transformers, or light pipes for triggering and monitoring. Figure 5 shows a simplified schematic of the circuitry in these boxes.

There was considerable concern about the effect of transformer oil on the fiberoptic transmitters, receivers, cable, and connections. The Hewlett Packard HFBR-0500 series was the system finally selected. It was tested in oil for about six months before final selection. This system was one of the first available to allow reasonably simple and easy field connection. All fiberoptic components have performed without problems and reliable fiberoptic connections have been maintained in the oil.

System Control and Monitoring

Besides the normal function of keeping track of typical system parameters, temperature, on/off status, interlocks, etc., the injection kicker control system was further designed to provide measurements of system readiness right up to the moment of firing. In the eventuality of any indication of injection kicker system problems, the Tevatron abort line is pulled down and the beam is aborted. The way this final state of readiness is determined is by comparing the actual PFN voltage to the high voltage charging power supply command voltage. This comparison signal is sampled about 500 µs before the MAIN tube is fired. If the two signals do not agree the Tevatron beam is aborted.

The control system additionally digitizes the waveforms from each of the current transformers that sample the current through the magnet and load resistors (see Figure 1). These digitized values are compared with values stored from previously digitized kicker pulses. In the original plan, any incorrect comparison would shutdown the system and alarm in the control room. However, it has been difficult to reach a compromise between sensitivity and noise, so the signals are used primarly for diagnostic purposes. Other signals that are regularly monitored are the waveforms from current transformers that are located to sample the CLIP current, the DUMP current, and the sum of the MAIN and CLIP currents.

Ramping the PFN to high voltage just before MAIN tube firing is essential to minimizing system misfires. In our system, the Spellman RHP 100kV high voltage power supply is used for system prefire charging. It has worked very well and has proven to be very reliable. We are, however, considering a resonant changing power supply for even shorter PFN charge tubes.

Summary

The Fermilab injection kicker has been proven to be reliable and has met the needs of the Tevatron. As the $\bar{p}$ source commissioning begins, the kicker will be required to produce a nominal 1µs pulse. For short tests, simple adjustments to the DUMP and CLIP thyratron firing times will be made to shorten the pulse. It is expected that for long term $\bar{p}$ operation, we will reduce the number of PFN cells. This will reduce the power that the CLIP tube conducts and that the DUMP resistor must disipate.

Acknowledgements

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References

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2. H. Kuhn and G.H. Schroder, "High Power Pulse Generators for Fast Pulsed Magnets, Developments and Operational Experience", 14th Modulator Symposium, June 3-5, 1980.

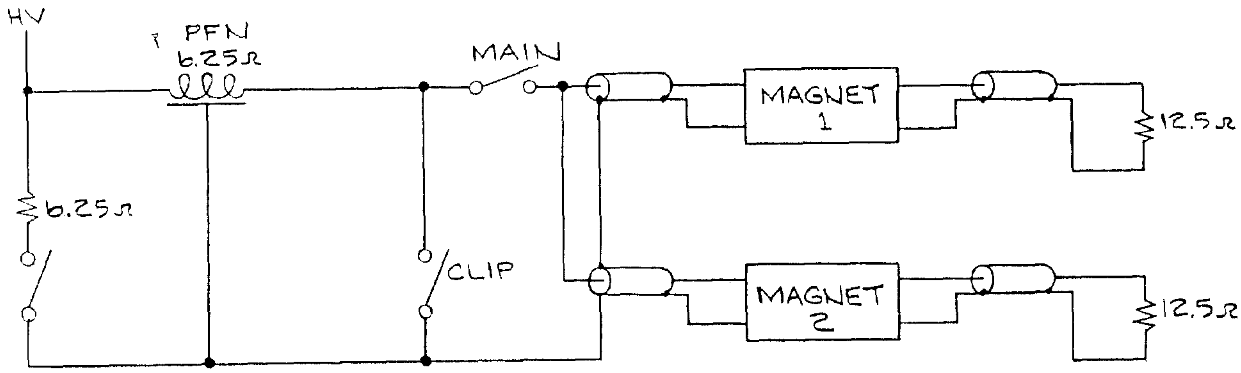

FIGURE 1

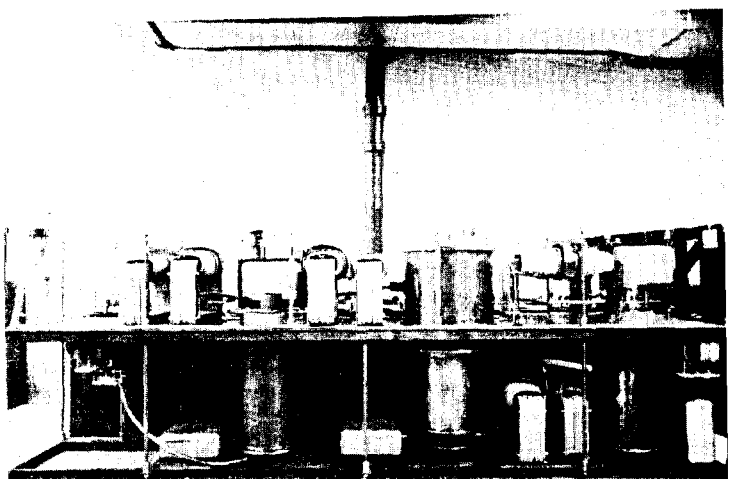

FIGURE 2

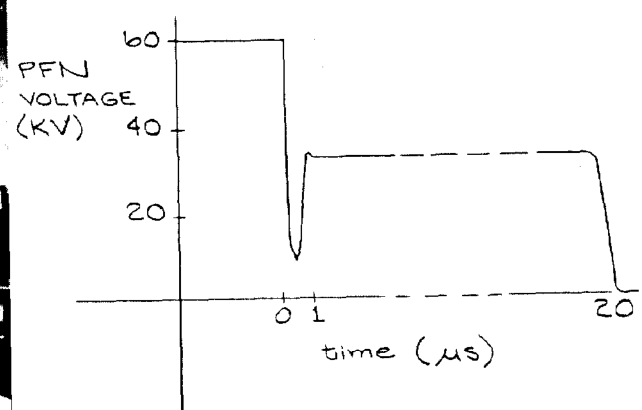

FIGURE 3

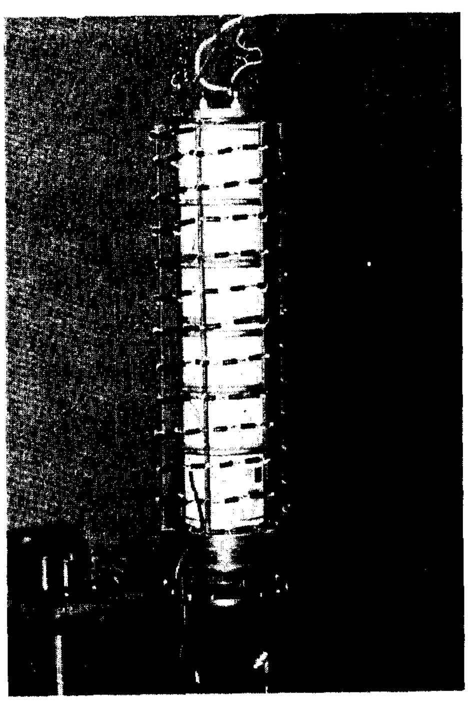

FIGURE 4

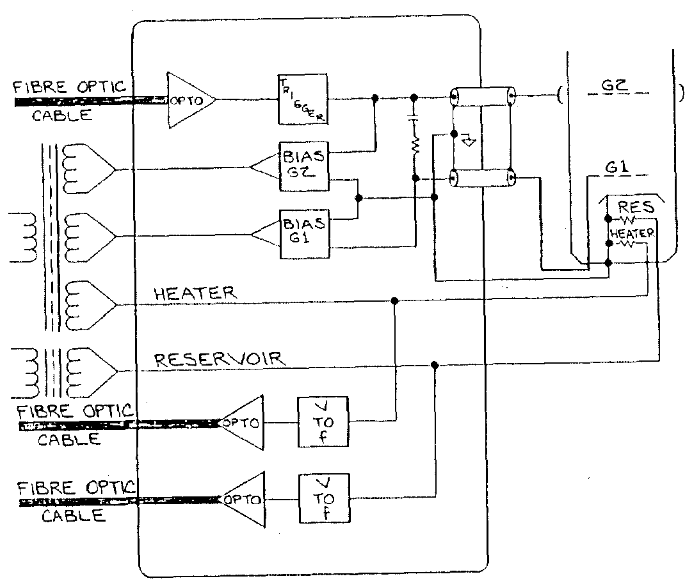

FIGURE 5