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THE ABORT KICKER SYSTEM FOR THE PEP-II STORAGE RINGS AT SLAC*

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Abstract

The PEP-II project has two storage rings. The HER (High Energy Ring) has up to 1.48 A of election beam at 9 GeV, and the LER (Low Energy Ring) has up to 2.14 A of positron beam at 3.1 GeV. To protect the HER and LER beam lines in the event of a ring component failure, each ring has an abort kicker system which directs the beam into a dump when a failure is detected. Due to the high current of the beams, the beam kick is tapered from 100% to 80% in 7.33 μS (the beam transit time around the ring). This taper distributes the energy evenly across the window which separates the ring from the beam dump such that the window is not damaged. The abort kicker trigger is synchronized with the ion clearing gap of the beam allowing for the kicker field to rise from 0-80% while there is no beam in the kicker magnet. Originally the kicker system was designed for a rise time of 370nS [1], but because the ion clearing gap was reduced in half, so was the rise time requirement for the kicker. This report discusses the design of the system interlocks, diagnostics, and modulator with the modifications necessary to accommodate an ion clearing gap of 185nS.

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The PEP-II project has two storage rings. The HER (High Energy Ring) has up to 1.48 A of election beam at 9 GeV, and the LER (Low Energy Ring) has up to 2.14 A of positron beam at 3.1 GeV. To protect the HER and LER beam lines in the event of a ring component failure, each ring has an abort kicker system which directs the beam into a dump when a failure is detected. Due to the high current of the beams, the beam kick is tapered from 100% to 80% in 7.33 µS (the beam transit time around the ring). This taper distributes the energy evenly across the window which separates the ring from the beam dump such that the window is not damaged. The abort kicker trigger is synchronized with the ion clearing gap of the beam allowing for the kicker field to rise from 0-80% while there is no beam in the kicker magnet. Originally the kicker system was designed for a rise time of 370nS [1], but because the ion clearing gap was reduced in half, so was the rise time requirement for the kicker. This report discusses the design of the system interlocks, diagnostics, and modulator with the modifications necessary to accommodate an ion clearing gap of 185nS.

I. INTRODUCTION

The PEP-II beam abort kicker system is designed to divert the stored beam of the HER and LER rings into a beam dump in the event of beam based trigger or an equipment failure trigger. The HER and LER abort systems operate independently, and their operating parameters are listed in Table 1. The rings have been operating approximately 275 days per calendar year since July 1998. On average, the abort kicker is triggered fifteen times per day due to a failure in one of the ring's subsystems.

From the beginning of PEP-II operation, the rings have had an ion clearing gap of 370ns. An ion clearing gap of this duration has caused instability for the RF system, therefore a shorter ion clearing gap (half) is desirable. Because the existing abort system was designed to minimize the inductance of the modulator and its connection to the magnet, the abort kicker magnet dominates the system inductance. In order to reduce the rise-time of the kicker pulse in half, either the circuit inductance needs to be reduced by half, the voltage of the modulator doubled, or some combination of the two. None of these options were viable, thus a two magnet solution has been chosen. To minimize upgrade costs and reduce the impact on maintenance part inventories and personnel training, a plan was devised to use the existing magnet design and modified modulator design. The reduction of the modulator's high voltage capacitor value by a factor of four will reduce the peak current and the rise-time by a factor of two for the same voltage. Two modulators that generate pulses of half the current rise-time and half the current of the previous design into independent abort kicker magnets were manufactured for each ring and have been in operation since November 2002. The two abort kicker modulators for a ring are designated as Systems 1 and 2.

Table 1. Abort Kicker Operating Parameters.

	HER (9.0 GeV)	**LER (3.1 GeV)**
Max. Bend Angle (Sum of the bend from two magnets)	1.7 m-rad	2.1 m-rad
Magnetic Field per Abort Kicker Magnet	300 G	197 G
Kick Direction	Down	Down
Magnet Current Amplitude (without overshoot)	2400 A	1578 A
Magnet Current Rise-Time (0-80%)	185ns Max.	185ns Max.
Magnet Current Droop (in 7.33µs)	20%	20%
Max. Pulse Rep. Frequency	0.5 Hz	0.5 Hz
Typical Pulse Rep. Time	2 hr.	2 hr.

II. ABORT KICKER MODULATOR

The modulator generates the high current pulse for the abort kicker magnet. The modulator circuitry is housed in a 53cm x 54.5cm x 56cm cabinet which is mounted directly beneath the abort kicker magnet for the HER or above the magnet for the LER. Figure 1 is a photograph of the modulator connected to the magnet in a test area before their installation. When mounted in the ring, the magnet connections are made with 5 cm wide aluminum bus, approximately 20cm long, and spaced 3.8cm apart. The modulator is air cooled and uses an air filter to limit the dust intake. The ambient air temperature of the ring tunnel is approximately 40°C, thus the modulator components are rated appropriately.

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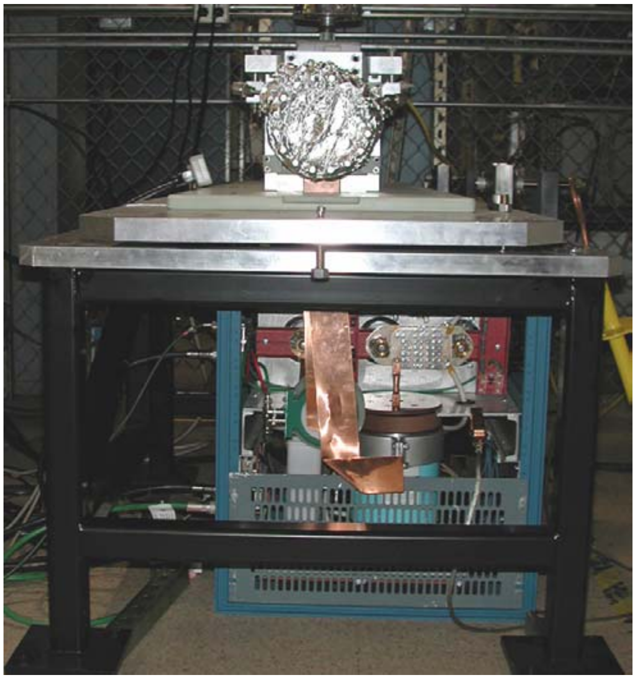

Figure 1. Kicker magnet and modulator test assembly.

The modulator consists of three CX1622 thyratrons, two pulse capacitors, a damping resistor, and many other supporting components. Figure 2 shows the simplified modulator circuit. Because of the shape of the pulse, the circuit design is such that it has two parts: a high voltage part and a low voltage part. The high voltage part is made up of one CX1622S thyratron and a 0.0375µF, 50kV low inductance pulse capacitor. The capacitor charges through the magnet, and likewise discharges through the magnet when the thyratron is triggered. The resulting pulse generates a voltage on the magnet of -28kV. The low voltage part of the circuit consists of two parallel CX1622RS thyratrons, a 100µF, 4kV low inductance pulse capacitor, and a 0.2Ω damping resistor made from 50 parallel 2W carbon composition resistors. Each thyratron is supported in a slotted cylindrical housing which acts as the current return path for low inductance. Because stray inductance in the low voltage circuit contributes to the current overshoot, the inductance of all circuit connections is minimized.

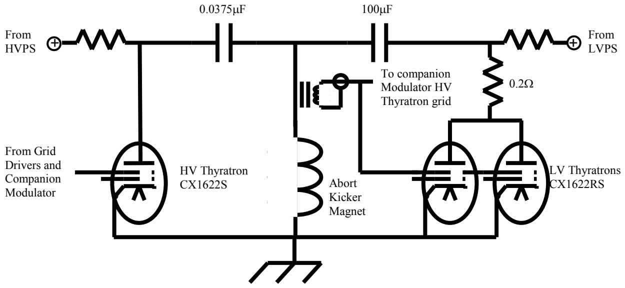

Figure 2. Simplified Modulator Schematic

The high voltage thyratron is triggered by redundant grid drivers or its companion modulator in the ring. Upon triggering, the voltage at the magnet and the low voltage circuit changes to -28kV, and a half sine current pulse is initiated in the magnet, with the high voltage circuit capacitance and inductance determining the current rise-time. The low voltage thyratrons are triggered in parallel with a pulse formed by a current transformer positioned on the connection from the modulator to the magnet. Therefore, the low voltage thyratrons will always be triggered when the high voltage thyratron conducts whether by command or self triggering. The same pulse transformer has been modified to drive the grid of the high voltage thyratron in the companion modulator in the ring. This cross triggering is essential, since it takes the operation of both modulators to properly dump the beam.

As the magnet voltage swings through zero, the low voltage thyratrons become positively biased, and conduction begins. Initially, the magnet forces current through the low voltage circuit up to the point where the R-C network of the circuit gives the wave-shape an exponentially decaying tail. The pulse overshoots because of the stray inductance in the low voltage circuit which limits the circuit's current rise-time and allows for the high voltage circuit current to swing past its peak.

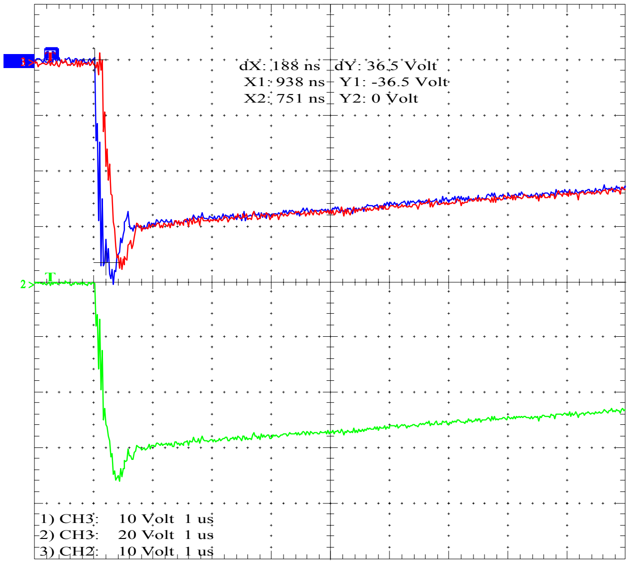

Figure 3. Abort kicker current test results.

III. TEST RESULTS

The abort kicker modulators were modified as described above, and they were tested up to the maximum voltage of the high voltage power supply (30kV). Two modulators were connected to loads and pulsed at a rate of 0.3Hz. Then the grid triggers for one of the modulators was disabled so as to test the cross triggering. Each modulator was able to trigger the other. The oscillogram of Figure 3 shows the currents of the magnets and their summation. Notice that the summed pulse is the desired wave shape for sweeping the beam out of the rings. Figure 4 shows the same wave shapes with an expanded scale to more clearly show the current rise times. Notice how the current of the modulator with the inhibited grid triggers is delayed by 120ns, yet the sum of the currents has a 0-80% rise-time of less that 180ns.

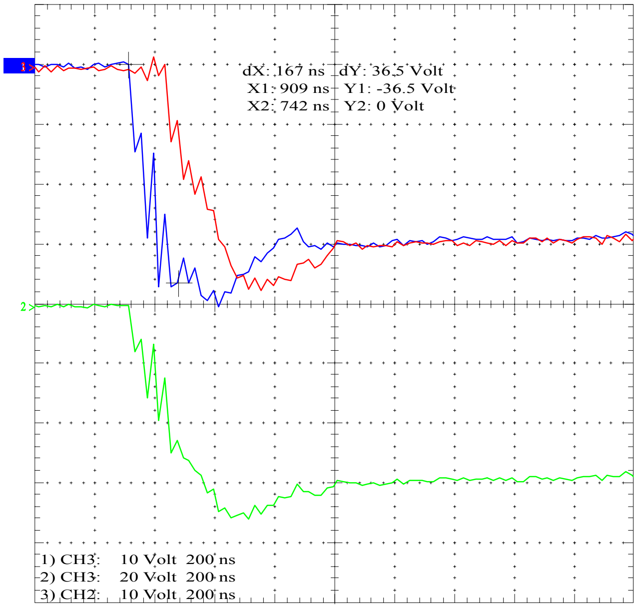

Figure 4. Expanded abort kicker current test results.

IV. SYSTEM OPERATION

A. Diagnostics

There are a number of status bits reporting system functionality. Particularly important are the trigger statuses. The trigger sequence begins with the redundant Beam Abort Trigger System (BATS). Each BATS pulse triggers its own Grid Driver chassis, and either the redundant Grid Drivers or the modulator cross trigger pulses the grid of the High Voltage thyratron resulting in a voltage across the kicker magnet. This voltage is recorded as a Magnet Voltage Pulse, and it is a part of the trigger sequence monitored by the control system. These diagnostics are useful to determine whether a trigger module needs repair or when self triggering occurs.

There is analog read-back data that is stored in history buffers. These include: thyratron heater and reservoir current, thyratron keep alive current, thyratron bias voltage, pulse capacitor voltages, magnet current, and interlock trip levels. Some additional analog read-backs were recently added to monitor thyratron performance. A portion of the magnet current signals from each system is split off into the control system for monitoring. The magnet current's peak, integral, falling edge, and rising edge are monitored for diagnostic purposes. A running history of all analog read-backs is recorded in the control system's main frame computer.

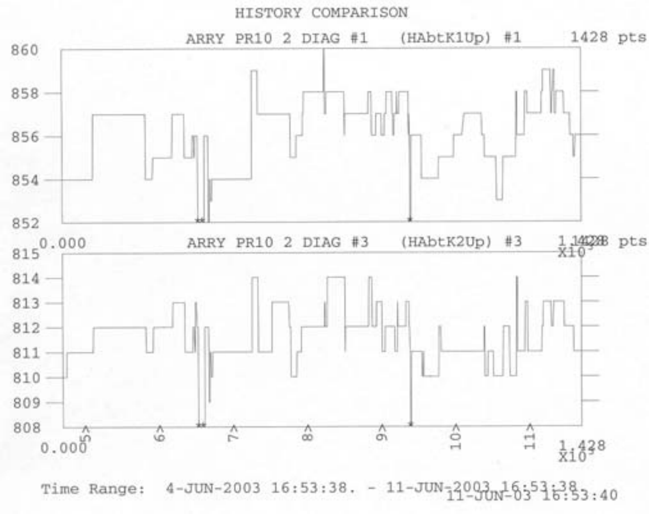

Figure 5. HER magnet current pulse rising edge data.

Thyratron diagnostics have become more important with the two modulator abort system. If there is an abort system problem, it is vital to know which of the two systems is failing. As the thyratrons age, their anode delay time and jitter will worsen; this in turn will deteriorate the pulse rise-time or unsynchronize the pulse with the ion clearing gap. The thyratron rising edge data may be used to better synchronize the kicker pulse with the ion clearing gap as the anode delay changes or assist with thyratron reservoir adjustment. Some magnet current rising edge data for the HER abort kicker systems 1 and 2 is given in Figure 5. The vertical scale is nanoseconds, and the horizontal scale is the date (one week in total). Between systems 1 and 2 there is a difference in delay of 45ns, and there is a small difference in the thyratron jitter. Overall the anode delay difference is 45 ± 8ns. This difference is clear in the magnet current data taken from the same systems and displayed in Figure 6. The difference in delay is presumably from the difference in the age of the High Voltage thyratrons in the two systems.

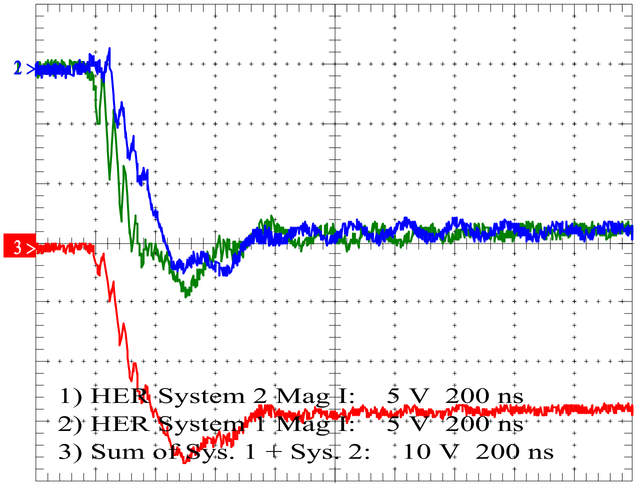

Figure 6. HER magnet current data.

Table 2. Abort Kicker Interlocks and their system status.

Description	System 1	System 2	Status	Response
HV or LV Fail High ($V > 103\%$)	High Trip	OK	Not OK	Alarm
	OK	High Trip	Not OK	Alarm
	OK	OK	OK	Ready
HV or LV Falling ($0 > \text{Slope} \geq -2\%/\text{ms}$) {Slope measured between voltage levels of 97% to 95% of normal operating voltage}	Slope Trip	OK	Failing	Abort
	OK	Slope Trip	Failing	Abort
	OK	OK	OK	Ready
HV or LV Fail Low ($V < 95\%$) or ($\text{Slope} < -2\%/\text{ms}$)	Low Trip	OK	Not OK	Alarm
	OK	Low Trip	Not OK	Alarm
	OK	OK	OK	Ready
HV or LV Low Trip Set to Slope Trip Set Ratio (Low Trip Set/Slope Trip Set $\leq 98\%$) [Software Interlock]	Ratio High	OK	Not OK	Alarm
	OK	Ratio High	Not OK	Alarm
	OK	OK	OK	Ready
HV, LV1, or LV2 Keep Alive Current	High or Low Trip	OK	Failing	Abort
	OK	High or Low Trip	Failing	Abort
	OK	OK	OK	Ready
HV or LV Bias Voltage	Low Trip	OK	Failing	Abort
	OK	Low Trip	Failing	Abort
	OK	OK	OK	Ready
HV or LV Htr./Res. Current	Hi or Low Trip	OK	Failing	Abort
	OK	Hi or Low Trip	Failing	Abort
	OK	OK	OK	Ready
Htr./Res. Time-Out	Not Ready	Ready	Not OK	Alarm
	Ready	Not Ready	Not OK	Alarm
	Ready	Ready	OK	Ready
Controller Control Power Voltage	Low Trip	Ready	Failing	Abort
	Ready	Low Trip	Failing	Abort
	Ready	Ready	OK	Ready
Modulator Temperature	High Trip	OK	Failing	Abort
	OK	High Trip	Failing	Abort
	OK	OK	OK	Ready
Grid Driver AC Input Voltage	Low Trip	OK	Failing	Abort
	OK	Low Trip	Failing	Abort
	OK	OK	OK	Ready
Grid Driver Fault (No output pulse when triggered)	Fault	OK	Not OK	Alarm
	OK	Fault	Not OK	Alarm
	OK	OK	OK	Ready

B. Interlocks

The overall abort system is designed such that it is self monitoring and able to determine whether it is abort ready. Each system has a controller that monitors its components. The controllers send two statuses which are summed and sent to the BATS--System OK and System Failing. If the systems are OK, then they are ready for a command trigger; the BATS triggers for the two systems are paralleled. If a system is not ready, then the status is Not OK, and an alarm is sounded warning the accelerator operators that the abort system cannot be triggered. When a system is failing, then the kicker is triggered by the BATS before the system is completely disabled. A list of the interlocks and the resulting system status is given in Table 2.

V. ACKNOWLEDGEMENTS

Artem Kulikov has initiated much of this work, and he has contributed greatly to the success of this project. Alan Fisher has designed and installed the analog read-back system to monitor the modulators' performance. His work is providing useful information for the maintenance of the system, and I thank him for his efforts. I also thank Hank Gray for assembling and installing the modulators and Joe Olszewski for the design and fabrication of many of their parts and subsystems.

VI. REFERENCES

[1] J. E. de Lamare, et al, "The PEP-II Abort Kicker System", Proceedings of the 1997 Particle Accelerator Conference (PAC 97), 1997, pp. 1316-1318.