TEST MODULATOR OF AGS INJECTION FAST
KICKER¹

W. Zhang, W.W. Frey, A.V. Soukas, S.Y. Zhang, and J. Bunicci

Brookhaven National Laboratory
Upton, New York 11973

Received by OSTI

AUG 20 1990

ABSTRACT

In this paper, a test modulator of the Brookhaven AGS injection fast kicker is described. The AGS injection kicker is the complementary system to the AGS Booster extraction fast kicker. During the fourth batch transfer of the proton beam from the Booster to AGS, the fall time of the AGS injection kicker has to be very fast (<140 ns), so that it does not appreciably deflect the first batch of injected protons that is circulating in the AGS. A test modulator was built, which consists of a PFN, a tail-biting section, and two thyatron switches. One thyatron switches the current to the load magnet, and another bites down the current at the end of the pulse. The load and circuit stray inductance is about $1.95 \mu\text{H}$ to $2.15 \mu\text{H}$, and the required peak current is about 1000 Amp. The current pulse waveform, tested at half current level (500 amp), has a fast fall time as well as a fast rise time. The test results will be presented, and some technical difficulties will be discussed.

INTRODUCTION

The Brookhaven AGS Booster, in its final phase of construction, will be completed this year. It will serve as a multi-function synchrotron injector for the AGS, capable of accelerating protons from 200 Mev, the Linac operating energy, to 1.5 Gev, at a repetition rate of 7.5 Hz (4 pulses/AGS pulse). The Booster is also capable of accelerating heavy ions to a magnetic rigidity equal to 17.52 tesla-meters, at a 1 Hz repetition rate (1 pulse/AGS pulse). Beam transfer from the Booster to the AGS will be bucket to bucket. There are 3 RF accelerating buckets in the Booster, and 12 in the AGS. During each pulse of proton beam transfer, 3 Booster proton bunches will be transferred to 3 of 12 AGS buckets. At the final transfer, the fall time of the AGS injection kicker has to be very fast (<140 ns), so that it will not appreciably deflect the first bunch of the first injected Booster pulse. This means that the AGS kicker modules must incorporate some form of tail-biting circuit to reduce the kicker current fall time to meet the above requirement.

The AGS injection fast kicker, consisting of 3 identical modules, will be located at the A5 straight section of the AGS ring. Its required strength is to deflect the 1.5 Gev (rigidity $B\rho$

$= 7.51$ T-m) proton beam by 3 mrad, and the 11 T-m rigidity heavy ion beam by 3 mrad. The kicker magnet is a lumped inductance picture frame type. The load magnet and loop stray inductance is estimated at $1.95 \mu\text{H}$ to $2.15 \mu\text{H}$ for each module. The pulser parameter specifications are listed in Table 1.

Table 1 - PULSER PARAMETER SPECIFICATION

	Proton	Heavy Ion
Rise time	120ns (0-97%)	160ns (0-98%)
Pulse length	600ns	1000ns
Fall time	120ns (97%-10%)	<2300 ns
Pulse overshoot	3%	2%
Flat top ripple	$<3\%$	$<2\%$
PFN voltage	~ 40 KV max	~ 40 KV max
Peak current	1006A	1473A

SYSTEM DESCRIPTION AND TEST RESULT

Since the AGS injection fast kicker is the complementary system to the AGS Booster extraction fast kicker, some requirements, such as the ability to operate for both proton

¹ Work performed under the auspices of the U.S. Department of Energy.

and heavy ion beam transfer with fast rise time and limited voltage for reliable operation in air, are the same for both kickers. Therefore, a similar pulse front shaping network is used for both kicker systems. To meet the different kicker current requirements of proton and heavy ion injection, a resistor is switched to match or mismatch the pulse forming network impedance. Two R-C compensators are used to obtain a fast pulse rise time, one in parallel with the matching resistor is a sink network, and another in parallel with the first PFN capacitor is an energy compensation network. Detailed discussion of the pulse front shaping is given in reference [2], and the current testing results of the B3 (Booster extraction fast kicker) prototype module are shown in photographs 1 and 2.

Photograph 1. Current Waveform

Photograph 2. Field Waveform

The main additional requirements of the AGS injection fast kicker are a fast fall time for proton beam injection, and a longer pulse width for heavy ion injection. This fast fall time specification is very stringent for a low cost high inductance lumped magnetic kicker. The decision to build this type magnet was made based on budgetary concerns, manpower availability, and project schedule etc., and after we studied and evaluated the schematics such as the CERN traveling wave kicker [3], HCTF EMD injection pulser [4] etc. A test circuit shown in Figure 1, improved from a schematic in [4], is chosen because of its structural simplicity and promising performance. A test pulser based on this circuit has been simulated, constructed, and tested. Photograph 3 shows this test pulser. The EEV CX1154 thyristors were used as the main switch as well as the tail-biting switch.

FIGURE 1. TEST PULSER

Photograph 3. Test Pulser

In the construction of this test unit, both thyatron assemblies have been carefully shielded and arranged on different sides of the PFN to eliminate pulse coupling. The compact package of the tail-biting thyatron auxiliary power supply kept the effects of the distributed inductance and capacitance as low as possible. This test unit has been powered up to 25 KV, and about 900 A including the tail-biting function.

To increase the current pulse tail-biting speed, a separate power supply is used to charge up the tail-biting section capacitors. With a higher tail-biting voltage, a trapezoidal current pulse is obtained. The fall time of the current pulse is comparable to the rise time. Due to the voltage rating of the CX1154 thyatron and power supply limitation, the pulser was tested at 500 A. For each PFN tested, there is a nearly optimum point of time to bite down the current. As the tail-biting point shifts, the results of the current fall time and percentages of undershoot could be very different. Some test results are shown in photographs 4 and 5.

Photograph 4. Pulse fall time with $t=600ns$

Photograph 5. pulse fall time with $t=616ns$

The design of the tail-biting function of the AGS injection fast kicker is based on the above mentioned test unit. Two gap thyatrons are used to hold-off higher voltages, and a double ended tube is placed as the main switch to allow bi-directional current flow for heavy ion injection. The prototype AGS injection fast kicker modulator has been constructed, as shown in Figure 2 and photograph 6. Two more modules are in the construction phase, making a total of 3 modules.

Photograph 6. AGS Injection Kicker Prototype Modulator

The main switch thyatron is triggered to start the pulse. Approximately 720 ns later, the tail-biting thyatron is triggered to cut off the current pulse. At the beginning of the rising part of the pulse, the current through the load magnet and the matching resistor is zero, so the voltage across the magnet inductance is about the full PFN voltage. Therefore, the tail-biting tube at this moment is holding off a high voltage equivalent to the summation of the tail-biting capacitor voltage and at least half of the voltage the PFN is charged to. The cathode plate of the tail-biting thyatron is connected to the high voltage end of the magnet (see Figure 2). During the pulse rise, the cathode plate and auxiliary grid power supplies of the tail-biting thyatron will float to a negative high voltage. The transient of this high voltage introduces noise to the triggering circuit that might cause the tail-biting thyatron to mis-trigger. At the late portion of the pulse flat top region, the tail-biting thyatron is triggered. The voltage to which the tail-biting capacitors are charged is then applied to the load

magnet to force a fast decrease of the current. The current fall rate is governed by $\frac{di(t)}{dt} = \frac{v(t)}{L}$, which is proportional to the voltage that the tail-biting capacitor is charged to. The function of the tail-biting voltage is to force a fast extraction of the inductive energy stored in the magnet and to dissipate in the resistors both the capacitive and inductive energies stored. During the pulse flat top, the voltage across the matching resistor is half of the PFN voltage. When tail-biting is applied, the voltage across the matching resistor jumps to the sum of half of the PFN voltage and the tail-biting voltage. The high current passing through the matching resistor dissipates most of the stored energies. The sink R-C compensator in parallel with the matching resistor bypasses a part of the current during the current pulse fall region and reduces the resistive loss. Although a higher tail-biting voltage will guarantee a faster current fall time, device limitations and other design considerations, such as thyatron forward and reverse voltage ratings and pulse undershoot etc., favor a lower tail-biting voltage at a comparable level of the PFN charging voltage. To reach a fast current fall time with limited tail-biting voltage, a multiple section R-C network will perform much better than a single section capacitor. Other benefits of the multiple section R-C network are the lower undershoot and a wider tail-biter triggering range at a non-optimal triggering time.

Although a diode has been placed in series with the load magnet, at present it is shorted out. It will be activated to attempt to clean up the pulse undershoot and the tail ripples, when a modified auxiliary power supply and triggering unit are ready. The major technical difficulty is the implementation of the auxiliary grid supplies and triggering circuit of the tail-biting thyatron. The device internal inductance, distributed inductance and capacitance have turned out to be crucial to the tail-biting circuit stability. Since the auxiliary circuit of the

tail-biting thyatron will float at negative high voltage during the current pulse rise, the transient noise coupled by device and distributed inductance and capacitance might prematurely trigger the thyatron or cause a tail-biting time jitter problem. The A-5 prototype module has been powered up to 25 KV for proton operation testing, and an unstable performance of the tail-biter triggering circuit has been observed above 20KV. The tail-biter was in a self trigger type mode. Meanwhile a tail-biting test has been performed successfully at half current level (500A) using this module. The modification of the triggering circuit is underway.

A floating deck trigger amplifier is used to pulse the tail-biting switch tube grid. Due to the fast rate of rise of current in the magnet load, it is necessary to isolate the tail-biting control grid circuit from transients and noise. A small hard tube modulator, utilizing a planar triode (6442 tube type) referenced to the tail-biting tube cathode is used. A 1:4 pulse transformer is used to trigger the tail-biting switch tube. The trigger is coupled up to the floating deck using a 1V/A Pearson current transformer with a 3 turn primary at ground reference. A 1500V trigger pulse into 50 ohms is developed as the tail-biting trigger. The 90V pulse on the current transformer output drives the grid of the 6442 well into the positive grid/emission limited region from the hard cut-off region. Stray capacitance of the trigger circuit is minimized to allow stable triggering.

Some test results of the A5 prototype module are shown in photographs 7 and 8. The PFN impedance is about 14 ohm. A 14KV charging voltage was applied to the PFN, and the tail-biting voltage used was 18KV. The photos show the load inductor current pulse of 500A peak with fast rise and fall time. The fall time from flat top level to 10% is about 120ns, and the tail ripple is about 5.8%. The comparison of the pulse with and without tail-biting are shown in photographs 8 and 9.

FIGURE 2. AGS INJECTION KICKER POWER SUPPLY SCHEMATIC

Photograph 7. Pulse Waveform

Photograph 9. Pulse Waveforms
with and without tail-biting

Photograph 8. Pulse fall times
with and without tail-biting

REFERENCES:

1. "Booster Design Manual", AGS Booster Project, AD Department, Brookhaven National Laboratory, 1988.
2. W. Zhang, et al., "Test Fast Kicker pulser", Proceedings of 7th Pulsed Power Conference, 1989.
3. E. Frick, et al., "Fast Pulsed Magnet Systems for Proton and Antiproton Injection into the CERN 400 GeV Proton Synchrotron", IEEE Conference Record of 1982 Fifteenth Power Modulator Symposium, 1982.
4. J. Pachner, Jr., "A Pulsed Ferrite Inflector for the Emitance Measuring Device of the Chalk River High Current Test Facility", Proceedings, 1973 Particle Accelerator Conference, 1973.
5. J. P. O'Loughlin and L. J. Sidler, "The End of Line Tail Biter", Proceedings of 6th Pulsed Power Conference, 1987.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.