USING FERRITE AS A FAST SWITCH FOR IMPROVING RISE TIME OF IPNS EXTRACTION KICKER *

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Abstract

The Kicker system [1-2] is used to extract beam from the Rapid Cycling Synchrotron (RCS). The Kicker consists of four identical pulse circuits, each providing over 3.8 kA to each magnet winding. The magnet length is restricted to the space between vacuum bellows attached to the ring magnets. This leaves 0.89m for the magnet. To keep the voltage low the magnet conductor is broke up into 4, ¼-turn magnet windings. Each pulse circuit consists of a Pulse Forming Network (PFN) that is charged to 50 KV. The PFN is discharged through a thyratron into a 6.3-ohm transmission line to one of the magnet windings. Our system has always had marginal rise time of around 100 ns. Although the thyratron switching time is much faster than this, losses in the transmission lines cause the slower response. By using ferrite to make a fast switch between the transmission lines and the magnet, the rise time in the magnet can be reduced. To make a fast ferrite switch, the saturation point must carefully be chosen. Parameters related to choosing the proper ferrite to provide fast saturation, at the correct current will be discussed.

INTRODUCTION

The Intense Pulsed Neutron Source [3] RCS delivers 450-MeV protons in a 70 ns pulse at 30Hz to a heavy-metal target to produce spallation neutrons for material science research. The average current is 15 μA with a peak intensity of 10 Amps. The kicker system is used for single turn extraction from the RCS. The RCS extraction kicker current has always had a slower rise time than desired; historically, it has been greater than 100 ns. Up to now, the rise time has not presented a problem other than to restrict the tuning range available to the operators. At extraction, the cycle time of the h=1 bunch is 194 ns of which 70 ns contains 98 percent of the beam. Therefore a 100 ns rise time leaves a 20-25 ns window for manual tuning. However, with the installation of a third cavity [4-5] operating at the second-harmonic to raise the current limit, the kicker tuning window will be consumed. A shorter rise time will be necessary to take full advantage of second harmonic operation.

Operationally, the previous coaxial cable used in the PFNs and transmission lines to the magnets failed frequently. When our supply of cable ran low, we decided to purchase a different type of line. The new line is much more robust, but pulse rise time is slower. The rise time for the new cable was initially measured at 115-120ns. This caused beam loss to go up in the RCS. We needed to improve the kicker rise time, but due to the radiation levels in the RCS tunnel, the project needed to be done with minimal time in the tunnel. Also, limited space is available in the RCS tunnel by the kicker magnets for additional components.

TEST SETUP AND RESULTS

We are in the process of developing a new kicker system that will use CX-1725 thyratrons, replacing the CX-1175 devices currently in use. The new thyratrons offer longer lifetime and cheaper replacement cost. A test stand has been constructed to evaluate a new switch circuit using the CX-1725. With the exception of the magnet, a prototype system is presently operating as it will be used in the RCS. The transmission lines for the prototype are terminated in a 6.5-Ω load. The kicker test stand provides an excellent place to test ideas that might improve the overall extraction system.

Employing the nonlinear saturation effect of ferrite, [6-8] the rise-time of the current in the kicker magnets can be lowered. Ferrite toroids are placed on the conductor between the end of the transmission line and the load. The square cross section toroid dimensions are 2.9-in. (7.37 cm) O.D. by 1.5-in.(3.81 cm) I.D. with a thickness of 0.5-in. (1.27 cm). The ferrite toroids used here are composed of Ni-Zn and are commercially available (Fair-Rite Products, Corp., Type 43, PN: 5943011101). The initial permeability of the Type 43 material is 850. Figure 1 shows the double exposure of a pair of oscilloscope waveforms. The signal displayed on channel 1 comes from one turn on a single ferrite toroid. Channel 3 monitors the current using a current transformer (CT). The "A" traces are the result of having only one toroid on the conductor; whereas, the "B" waveforms are with 14 toroids on the same conductor. Fig. 1 shows that the current pulse through the CT has an 18 percent shorter rise-time using the 14 toroids.

Voltage across the toroid stack can be estimated by multiplying the voltage across one toroid by the total number of ferrite pieces. The voltage across one toroid is greater than 2000 V at the peak and drops to less than 500 volts in 18 ns, a 1500 V change. The

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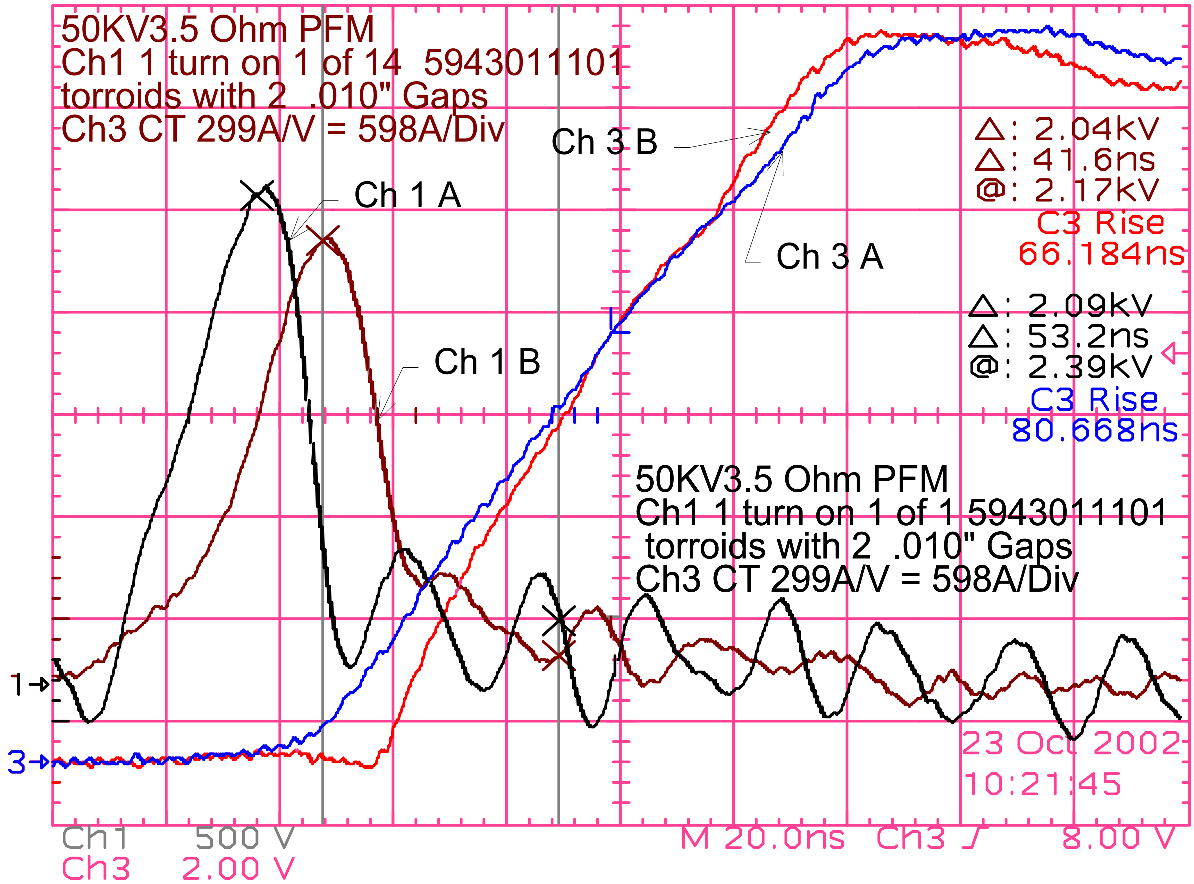

Figure 1 Scope trace from test stand. Ch 3 A is with only one toroid and Ch 3 B is with 14 toroids.

total voltage exceeds 20 KV in less than 20 ns for the 14-toroid stack. Because of the low quality factor for the coax cable transmission line, much of this voltage rise is not seen by the load and is instead dropped across lossy components in the transmission line. Magnet load termination is also an important factor in determining kicker current rise time. Load termination will be discussed in the next section.

The ability of the toroids to improve rise time is a function of their ability to store energy. In this application they will be operated with current passing through them in only one direction. Under this condition, the ferrite tends to become a permanent magnet. The field that remains at the beginning of the pulse, decreases the amount of field change the ferrite can accept before the it goes into saturation. By gapping the ferrite, the residual magnetic field can be reduced. This increases the energy that can be stored each pulse. Figure 2 shows effect of adding a gap to the Ni-Zn toroids mentioned above. Several factors must be considered when choosing a toroid and gap thickness. The ferrite must have a frequency response capable of handling the pulse rise-time being sought. Under high bias conditions, the upper frequency limit of ferrite can be increased slightly. Frequency response requirements limit the permeability of the ferrite to less than 1000. The rise-time of the current is limited by the inductance of the toroids until saturation is reached. This requires the ferrite to go into saturation at a current low enough not have a significant effect on the circuit. The assumption is made that if the saturation current is below 5% of the peak current, the added inductive loading would not cause a problem for the beam for the one pass through the magnet before extraction. This requires the toroids to saturate at less than 200 A. Figure 2 plots Volt-seconds verses Amps for gapped and ungapped Type 43 toroids. Figure 2 shows that saturation of the gapped toroids occurs between 100 and 200 amperes.

Reading from the graph, each toroid can block the current from rapid rise for about 55 V-µs before going into saturation. During the time before the toroids saturate, the current is being limited by the ferrite and the transmission line voltage is approaching its full voltage. When the toroids saturate their inductance will drop to near zero and the transmission line voltage will be applied to the magnet load system.

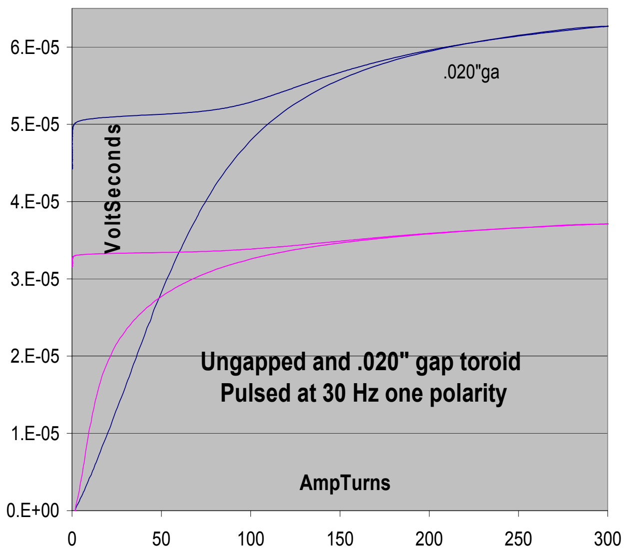

Figure 2 Measurements on 5943011101 toroid shows how many volt seconds can be applied before the toroid saturates.

RCS KICKER SYSTEM

A block diagram of the kicker transmission line, magnet and load shows the new components and where they are installed. The capacitance, C_{Trans}, at the end of the transmission line is 800 pF and C_{Load} is 7500 pF. Five toroids are present on the load capacitor line and nine are placed on the lead between the transmission line and the magnet. In the block diagram all of the circuitry before the feed end of the transmission line has been omitted because of space.

CONCLUSION

It is harder to evaluate the effect on the system that is in operation because of radiation levels and the time required to make changes and take data but improvements have been seen. Initially all of the toroids were between the end of the transmission line and the magnet. Tests showed better results with some of the toroids on the capacitor lead. When considering how many toroids to put on the capacitor lead both the current in the load and the toroid current go through the magnet. Magnet current should be less than 5% of flat top when the toroids go into saturation. By putting a loop of high voltage wire through one of the toroids the voltage can be measured. The voltage across the toroids on the capacitor lead is lower than the other toroids. There was some overshoot of the current pulse but the rise time of the pulse is faster and the top is flatter after some load tuning. More time will be spent when the new CX1725 system is installed.

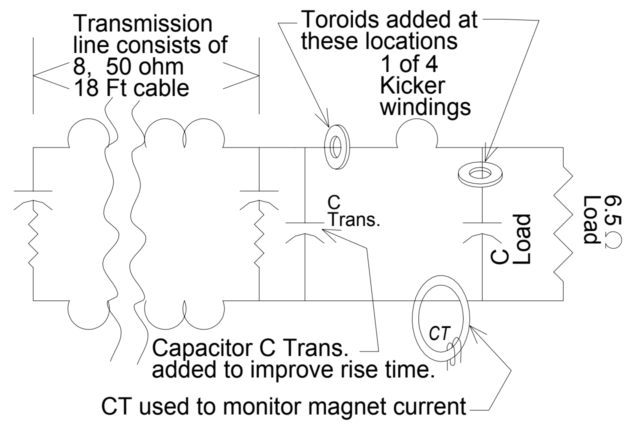

Figure 3 Block diagram of Kicker system including only components from transmission line through load.

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