AN OVERVIEW OF THE FAST INJECTION-EXTRACTION KICKER SYSTEMS OF THE BROOKHAVEN AGS-BOOSTER COMPLEX*

W. Zhang, R. Sanders, A. Soukas and J. Tuozzolo
AGS Department, Brookhaven National Laboratory, Upton, NY 11973-5000

Abstract

The expansion of the Brookhaven accelerator facilities, and the on-going efforts to raise the AGS beam intensity, have been a driving force for the addition of new kickers and the upgrading of older ones to meet this challenge. All kicker power supply systems are running above their design specifications to provide wider operating ranges. The newly upgraded Booster fast extraction kicker power supply was commissioned in September 1997. Its compact high voltage modulator structure offers a pulse length almost three times longer than the preceding package within the confines of the same physical space. The AGS A5 injection kicker and the AGS G10 extraction kickers are also discussed. In order to expedite design, assembly, and commissioning, and to facilitate interchangeability, standardized modules have been adopted where possible. This paper gives an overview of the AGS and Booster fast injection and extraction kicker systems including their parameters, structure and status.

1 THE AGS FAST KICKER SYSTEMS OVERVIEW

Through a decade of research and development effort, we have built up a series of fast kicker power supply systems to serve the AGS accelerator complex. A unique feature of these fast kicker systems is that they are all lumped magnet type. The main advantage is the cost savings in materials and manpower. The budgets of the AGS kicker systems are typically a small fraction of the comparable transmission line type kicker systems. The reliability of our fast kicker power supply systems have been very high, especially when we take into account that all injection/extraction fast kicker modulators are located inside of the AGS and Booster rings and have been subjected to a high level of radiation over many years. However, continually increasing intensities of the particle beams, and in turn radiation levels, has made the maintenance of the high voltage modulators difficult. Hence, consideration is being given to the development of future fast kicker systems that are transmission line type, minimizing the amount of equipment in the accelerator ring enclosure.

The AGS Department has undertaken, under restrained budget conditions, an expansion of its high energy/nuclear energy facilities. Thus, most of our electronic equipment has been designed with strong considerations to economy while trying not to sacrifice performance. We try, whenever possible, to use low-cost components and make effective use of innovative industrial developments in the integration of our kicker systems. In some cases we have spurred on these industrial developments to enhance our technical advances.

2 SYSTEMS SUMMARY

The AGS accelerator complex has a number of injection and extraction kickers. With the consideration of building systems in the most expeditious manner, interchangeability of equipment and components, and similarity of operation, standardization is stressed. The Pulsed Power Group and other AGS systems groups all use Allen-Bradley Programmable Logic Controller (PLC) based systems for control of command and status in new and upgraded equipment. Stanford Research DG535 delay generators are used to time, synchronize and trigger charging power supplies and high level thyratron trigger pulse generators. Finally, standard in-house designs are used for auxiliary power supplies and thyratron trigger pulse generators. The high voltage charging power supplies are usually located in the nearby ring service buildings. The charging cable feeds into the ring use a commercially available 3-conductor, 15 kV, ac cable and terminations.

Reliability, simplification, costs, compatibility with other systems, and safety is paramount factors in all new system designs. Because the AGS accelerators are synchronized to the power line, unregulated power supplies are used in trigger circuits and thyratron auxiliary power supplies without the risk of unwanted jitter. Where possible, reconstituted mica dielectric instead of oil filled capacitors are used in high radiation areas. High voltage circuitry is high potential tested to levels as high as twice the anticipated operating level where possible. Careful system grounding (star configuration) is used for both safety and noise reduction (as much as 20db lower than previous systems).

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

The magnets of the existing AGS kickers are single turn lumped inductance type ferrite magnet. They are inside of vacuum chambers. The beam image current related phenomena have been observed on all kicker power supply systems.

2.1 The Upgraded AGS Booster Extraction Fast Kicker System

The Booster fast extraction kicker is located in the F3 section of the accelerator. It consists of four full aperture picture frame lumped ferrite magnets with their adjacent modulators, and remotely located power supplies, controls, timing and other system equipment.

This system underwent a major upgrade in 1997. System specifications were changed. Kicker strength was raised a few percent for protons. The PFN was modified to provide a pulse length of at least 1800 Ns for a full-turn extraction capability for heavy ions. The previous maximum pulse length was 800 Ns.

A simplified schematic diagram is shown in Figure 1.

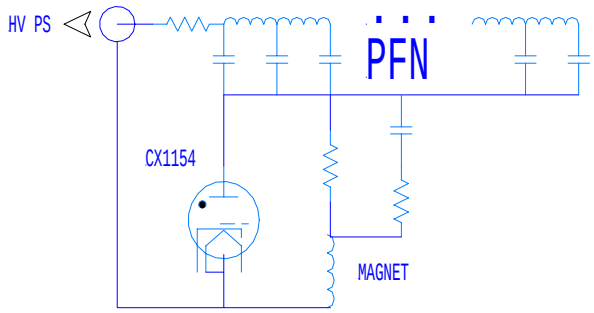

Figure 1. The Booster Extraction Fast Kicker

The equipment changes were extensive but the available space in the accelerator was limited to the mechanical package outline of the previous modulators. Because of volume constraints, it was necessary to simplify the circuits and to select components with tighter margins. The need for a higher stored energy would have required a larger volume for the PFN. The previous PFN capacitors were rated 50 kV with 100% reversal. The new capacitors were rated 40 kV with 50% reversal thus giving a comparable volume for a longer pulse length.

In anticipation of future dust build-up and moisture, high voltage surfaces were properly rounded and smooth. Careful thought was given to component placement, creepage length and spacing. Each modulator was hi-potted to 60 kV before installation. The design operating voltage was 28.6 kV. The floating common deck was hi-potted to 50 kV because of transient voltages.

These PFN's are now operating successfully above their design specifications. The PFN voltage has been raised to 35 kV and the magnet current has increased accordingly. It should be noted that with seven pulses per AGS cycle, they are operating at 200% of their original power rating. Table 1 lists the system parameters.

Table 1: Booster F3 Extraction Fast Kicker Parameters

	Proton	**Heavy Ion**
Rigidity	**(9.5 T-m)**	7.7 T-m
Deflection Angle	5.0 mrad	3.8 mrad
Magnetic Field Strength	**(206 Gauss)**	127.44 Gauss
Pulse Current	**(1095 A)**	683 A
Pulse Rise Time (3% - 97%)	≤ 140 nS	≤ 140 nS
Pulse Flat Top	**(2250 nS)**	**(2250 nS)**
Flat top Ripple	≤ ± 3 %	≤ ± 2 %
PFN Voltage	28.30 kV **(35 kV)**	20.49 kV
Maximum Number of Pulses per AGS Cycle (2.0 second or longer)	**(7)**	5
Pulse Repetition Rate inside Burst	≤ 7.5 Hz	≤ 7.5 Hz

Bold letter parameters indicate actual operating values.

2.2 The AGS Injection Fast Kicker System

The AGS injection fast kicker is located at the A5 section of the ring. It consists of three full aperture picture frame lumped magnets and their associated PFN modulators, similar to the aforementioned F3 system. It features an innovative tail-biting circuit design, which has proved to be successful and reliable. This systems has been operating for almost eight years.

In 1995, the modulator circuit was modified. The original design used a double ended thyratron, which was replaced by a single ended type. The unidirectional conducting property of single ended thyratron blocks reverse current reflection from the PFN and inductive load. This current is forced to flow through a tail-biting circuit that is parallel with the magnet. This circuit has helped to improve injection stability. Table 2 summarises the system parameters.

Table 2: AGS A5 Injection Fast Kicker Parameters

	Proton	**Heavy Ion**
Rigidity	**(8.1 T-m)**	**(8.1 T-m)**
Deflection Angle	2.85 mrad	2.85 mrad
Magnetic Field Strength	**(242 Gauss)**	**(242 Gauss)**
Pulse Current	**(1100 A)**	**(1100 A)**
Pulse Rise Time (3% - 97%)	≤ 140 nS	≤ 160 nS
Pulse Flat Top Length	360 nS	> 1100 nS

Pulse Fall Time	(~ 140 nS)	~ 500 nS
Flat top Ripple	≤ ± 3 %	≤ ± 2 %
PFN Voltage	**(32.5 kV)**	**(32.5 kV)**
Maximum Number of Pulses per AGS Cycle	**(7)**	5
Pulse Repetition Rate inside Burst	≤ 7.5 Hz	≤ 7.5 Hz

Bold letter parameters indicate actual operating values.

Figure 2 is a simplified schematic diagram of the AGS injection fast kicker modulator.

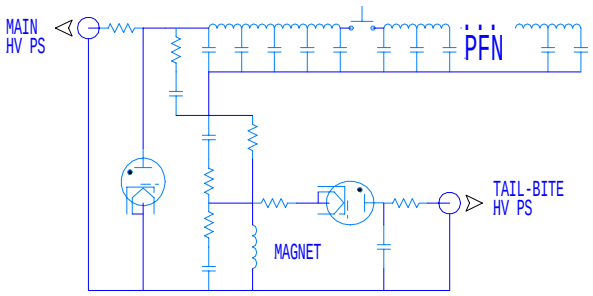

Figure 2. The AGS Injection Fast Kicker

2.3 The AGS Extraction Fast Kicker System

The G10 fast extraction kicker was another recent addition to the AGS. It was installed in 1995 and has been running successfully. It serves the AGS fast extract beam (FEB) program, the g-2 experiment and RHIC. These kickers allow extraction of a series of individual beam bunches (the number depends on the AGS harmonic number) at the peak of the magnet cycle. FEB differs from slow extracted beam (SEB) which smears the bunches and extracts it more slowly.

The system concept is similar to others in that it uses a multiple of magnets and modulators. It uses small aperture C-type ferrite magnets. As with the other kickers, each magnet is driven by a separate modulator.

Table 3 is a tabulation of the system parameters. Figure 3 is a simplified schematic diagram.

Table 3: AGS G10 Extraction Fast Kicker Parameters

	RHIC	**G-2**
Extraction Momentum	30 Gev	(24 – 30) Gev
Deflection Angle	2.0 mrad	2.0 mrad
Magnetic Field Strength	830 Gauss **(955 Gauss)**	830 Gauss **(955 Gauss)**
Pulse Current	1650 A **(1900A)**	1650 A **(1900A)**
Pulse Waveform	Half Sine	Half Sine
Pulse Rise Time	≤ 180 nS	≤ 180 nS
Pulse Flat Top	≥ 20 nS **(40nS)**	≥ 40 nS **(>100nS)**
Flat top Ripple	≤ ± 1 %	≤ ± 5 %
Stability and Reproducibility	1 % **(±0.12 %)**	1 % **(±0.12 %)**
Pulse Base Width	380 nS	380 nS
Capacitor Voltage	28.7 kV **(35 kV)**	28.7 kV **(35 kV)**
Max. Number of Pulses per AGS Cycle	12	12
Pulse Repetition Rate inside Burst	≤ 30 Hz	≤ 30 Hz

Bold letter parameters indicate actual operating values..

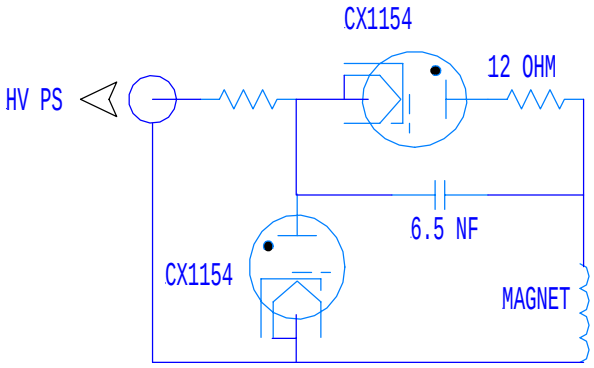

Figure 3. The AGS G10 Extraction Fast Kicker

3 ACKNOWLEDGEMENTS

We would like to thank Mr. J. Addessi, Mr. P. Benjamin, Mr. C. Eld, Mr. K. Hartmann, Mr. S. Perlstein, Mr. D. Warburton, and Mr. R. Zapasek of pulsed power group for their technical support.

4 REFERENCES

[1] M. Tanaka, Y.Y. Lee, "The AGS-Booster Complex for g-2 experiment and RHIC injection", Proceeding, IEEE Particle Accelerator Conference, 1993.

[2] W. Zhang, J. Bunicci, A.V. Soukas, S. Y. Zhang, "The Booster to AGS Beam Transfer Fast Kicker Systems", Conference Record, IEEE 20th Power Modulator Symposium, 1992.

[3] W. Zhang, J. Bunicci, W.W. Frey, A.V. Soukas, S. Y. Zhang, "The Booster-to-AGS Beam Transfer Fast Kicker Modulators", Proceeding, IEEE Particle Accelerator Conference, 1991.

[4] M. Tanaka, Y.Y. Lee, "The AGS new fast extraction system for g-2 experiment and RHIC injection", Proceeding, IEEE Particle Accelerator Conference, 1991.

[5] W. Zhang, W.W. Frey, A.V. Soukas, S. Y. Zhang, J. Bunicci, "Test Modulator of AGS Injection Fast Kicker", Conference Record, IEEE 19th Power Modulator Symposium, 1990.