RESEARCH AND DEVELOPMENT TOWARD THE RHIC INJECTION KICKER UPGRADE*

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Abstract

A research and development work is ongoing toward the upgrade of the RHIC Injection Fast Kicker System. We report here the proposed nano-second pulse generator, the initial test result, options of the deflector design, injection pattern, and the benefit to the future RHIC programs.

INTRODUCTION

The present RHIC injection kicker provides a 1.86 mrad vertical deflection to the incoming beam. Two identical injection systems, one in yellow and one in Blue, have a total of eight kickers, four in each ring. Its architecture is based on oil filled high voltage Blumlein Pulse-Forming-Line with thyratron switch, transmission cables, kicker magnet and a pulse termination resistor stack. The system injects up to 111 bunches of beam in each ring in a 120 bunch pattern. Therefore, the field rise time of kicker must be within the beam bunch gap of 95 ns, including magnet filling time.

The kicker rise time is marginal, especially for polarized proton operation where intentionally long bunches are injected into 9 MHz buckets, and where mistimed injection kicker can quench Siberian snakes. In addition, to reach the high luminosity goal in eRHIC, more beam bunches will be required, for instance a 180 bunch pattern, or ultimately a 360 bunch pattern. This implies a much faster kicker field rise time under 56 ns which is beyond the capability of the present injection kicker system. Hence, we have started a research and development effort for the future upgrade of the injection kicker system.

THE RESEARCH AND DEVELOPMENT PLAN

Main Parameters

We list the main parameters of RHIC injection kicker upgrade in Table 1.

Scanning the technology landscape of high voltage kicker system design, we see that the switching technology and deflector design are the critical elements for RHIC injection kicker upgrade. Thyratron has been the dominant switching choice for high power fast kickers. It is challenged by the solid state technology in recent years. Several solid state fast pulse generator topologies have caught people's attention. They have becoming the trend in a variety of new designs. Among them, the FID high voltage pulse generator is in the range of our application and commercially available.

Table 1: Main Parameters

Deflection Angle	1.86	m-radian
Machine Magnetic Rigidity	80.0	T-M
Deflection Strength	0.14880	T-M
Total Effective Magnetic Length	4.48	M
Magnetic Field Strength	0.03321	Tesla
Window Height and Width	0.048	M
Magnet Current	1.28	kA
Revolution time	12800	nS
Number of Bucket	180 -360	
beam bunch length	15	nS
Kicker Field Rise Time	56 - 21	nS
Field Flat-top Duration	> 15	nS

The high strength deflector design favours magnetic kicker for its high deflection efficiency. However, the lumped magnet has a large inductance value, and the transmission line magnet requires "magnetic field filling" time or transmission time.

The parallel-plates deflector is a popular choice among fast kickers in low and medium voltage range. In high voltage range above 50 kV, it has been used in advanced system designs. The physical dimension of the deflector and the high voltage hold-off of the deflector to reach the required deflection are the design factors have to be evaluated. The combination of nanosecond rise time high voltage generator and the parallel-plates deflector shall be considered in any new design feasibility study.

Other factors such as pulse lifetime, pulse repetition rate, pulse repeatability, and system reliability as well as device availability in long range are also considered.

We plan to conduct the research and development in multiple steps or phases. Our phase one effort is to acquire the high voltage solid state pulse generator for evaluation with existing RHIC injection kicker magnet. Table 2 lists the planned operation and testing mode of pulse generator.

Table 2: Operation and Testing Mode

Operation and testing mode	Mode 1	Mode 2	Mode 3	Mode 4
Transmission cable impedance (ohm)	50	50	50	50
Transmission cable length (feet)	225 - 260	225 - 260	10 - 260	10 - 260
Load deflector	RI magnet	RI magnet	parallel plates	none
Load termination resistor (ohm)	50	25	50	50

Next, we will investigate deflector options and best combination of pulse generator and deflector.

PROGRESS IN PHASE ONE EFFORT

We are in the procurement process of a FID high voltage pulse generator. A preliminary test was conducted at factory witnessed by Brookhaven representative. The test result is encouraging, although there are some areas

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that need improvements. We observed some characteristics of the pulse generator during the test.

The Pulse Rise Time and Settle Time

The pulse rise time is faster at lower voltage. An overshoot is present at the leading edge. However, the rise time plus settle time is within 10 ns. At higher voltage, the rise time slows down and the overshoot disappears. At 50 kV, the leading edge is somewhat round.

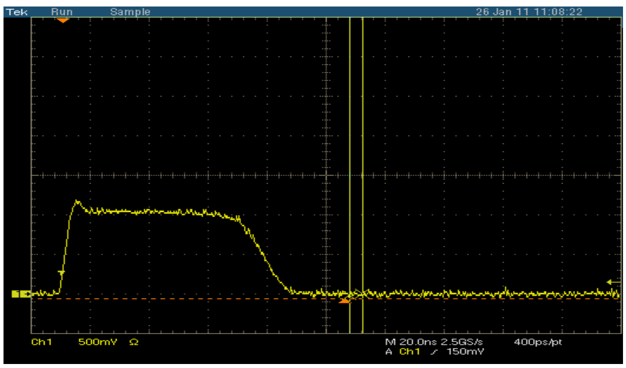

Figure 1: The output voltage waveform of FID Pulse Generator at 20kV. Vertical scale: 1:20,000, 0.5Vper division; Horizontal scale: 20 ns per division. (Photo courtesy of FID GmbH)

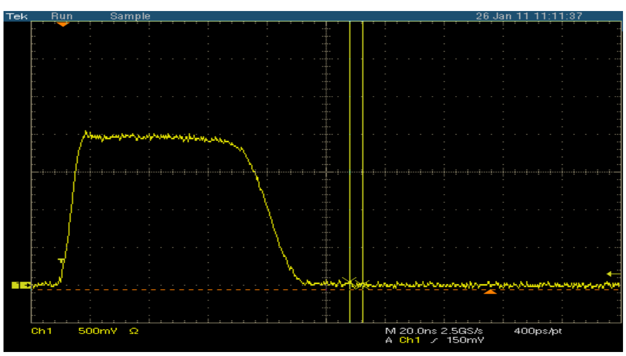

Figure 2: The output voltage waveform of FID Pulse Generator at 40kV. Vertical scale: 1:20,000, 0.5Vper division; Horizontal scale: 20 ns per division. (Photo courtesy of FID GmbH)

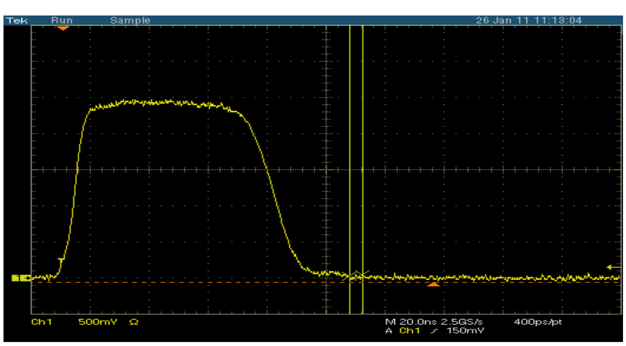

Figure 3: The output voltage waveform of FID Pulse Generator at 50kV. Vertical scale: 1:20,000, 0.5Vper division; Horizontal scale: 20 ns per division. (Photo courtesy of FID GmbH)

The Voltage Dependency of Waveform

The output waveform is voltage dependent. The pulse flat top is better at voltage range 30 to 45 kV. There is a slight after pulse at higher voltage above 40kV.

The Reflection Absorption Test

The existing RHIC injection kicker magnets are semi-transmission and semi-lumped all ferrite potted magnets. It has a characteristic impedance of 39 ohm. The Blumlein pulse generator is a 25 ohm system and two parallel 50 ohm high voltage pulse cables transport the pulse into the kicker magnet then terminated into a 25 ohm resistor stack as shown in Figure 4.

Figure 4: A simplified schematics of a single RHIC injection kicker module.

There are pulse reflections due to impedance discontinuity. The reflection after main pulse could affect early injected beam bunches in the ring. Therefore, we require the solid state pulse generator to have the capability of absorbing reflected waves without further reflection under mismatched load condition.

We observed a test with positive and negative mismatched loads from 18 ohm to 100 ohm. The test results are shown in Figure 5 to Figure 9.

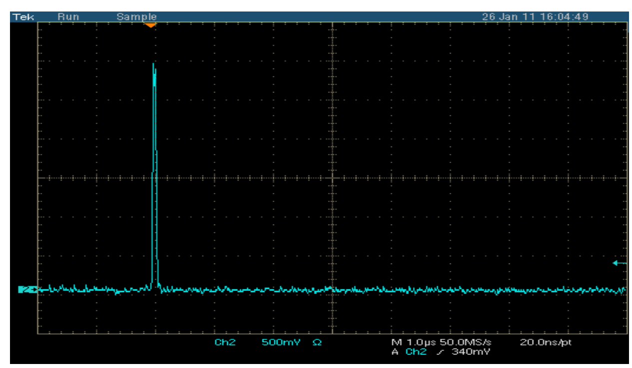

Figure 5: A reflection test with 18 ohm termination. 1.0 µs per division. (Photo courtesy of FID GmbH)

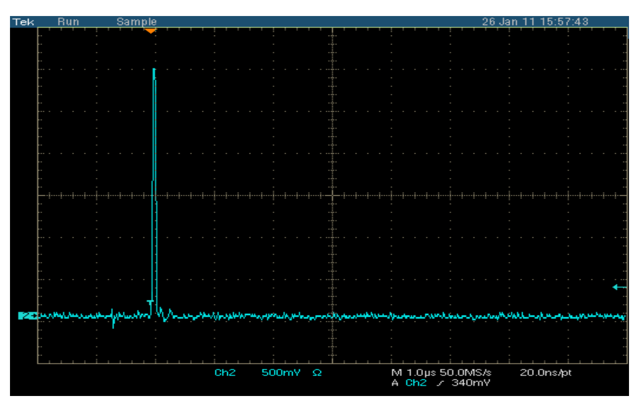

Figure 6: A reflection test with 27 ohm termination. 1.0 µs per division. (Photo courtesy of FID GmbH)

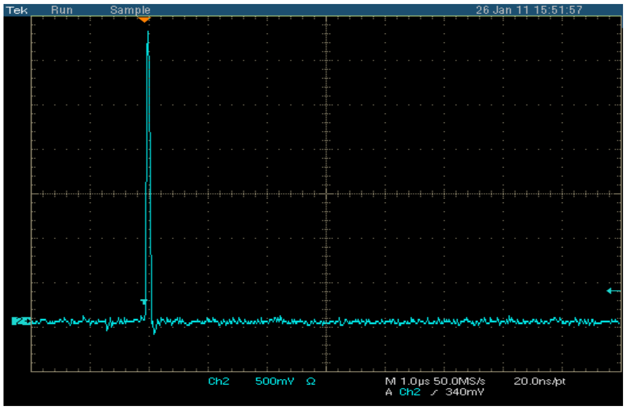

Figure 7: A reflection test with 50 ohm termination. 1.0 µs per division. (Photo courtesy of FID GmbH)

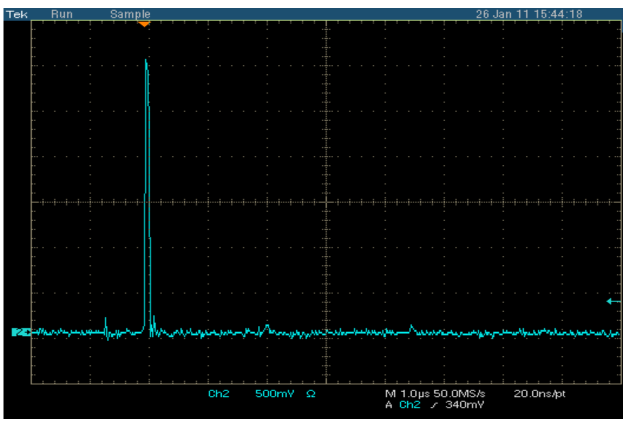

Figure 8: A reflection test with 75 ohm termination. 1.0 µs per division. (Photo courtesy of FID GmbH)

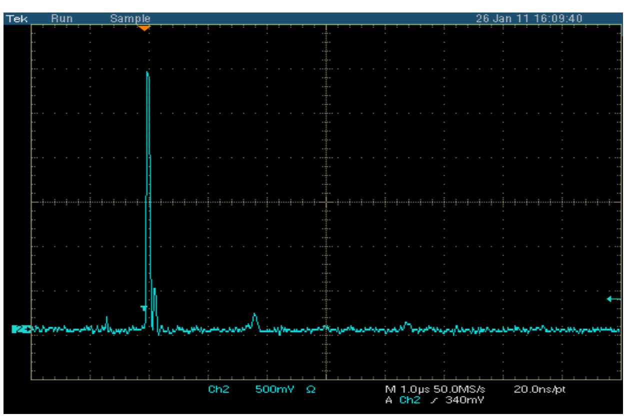

Figure 9: A reflection test with 100 ohm termination. 1.0 µs per division. (Photo courtesy of FID GmbH)

The pulse generator was able to absorb the reflected waves. The result indicates the unit works better with negative mismatched load.

In the present RHIC injection kicker system, the magnetic field deflection is the main force. Therefore, using negative mismatched load increases load current and magnetic field by adding reflected wave on top of the forward propagating wave.

DEFLECTOR DESIGN OPTIONS

As we have discussed earlier, the kicker field rise time is a combination of electrical pulse rise time and the pulse propagation time through the deflector. With mismatched system, the reflected wave propagation time contributing to the field rise time as well.

In the upgrade design, we will investigate several deflector design options to meet the faster field rise time requirement. One option is to use more sections, i.e. an increase from 4 sections to 6, with a shorter magnet length in each section. This will reduce the magnet filling time due to wave propagation.

The second option is to use parallel plates with ceramic supports, especially when considering a 360 bunch pattern. Waves travel through parallel plates in near light speed. This would significantly reduce the field rise time by reducing wave travelling time. For example, the pulse propagates through a 2.4 meter parallel-plates deflector in 7.2 ns. This would make the 21 ns field rise time achievable combined with a 10 ns rise time pulse generator.

However, the 50 ohm parallel-plates push-pull deflector requires much higher voltage, about ±65 kV, to generate sufficient electromagnetic force to kick the beam. Indeed, the electrical force contributes only a few percent for this beam energy, therefore the magnetic force deflection is the main source. The width of the parallel-plates is much wider than the existing magnet and requires a large vacuum chamber. Our preliminary study suggests it is possible.

CONCLUSIONS

We are glad to see the promising progress of FID pulse generator development. The technology has a great future. However, the generator can be improved with better components and circuit protection design.

We are concerned of its reliability. There are several reports by FID users indicating pulse lifetime issues.

REFERENCES

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