RESEARCH AND DEVELOPMENT OF RHIC INJECTION KICKER UPGRADE WITH NANO SECOND FID PULSE GENERATOR*

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Abstract

Our recent effort to test a 50 kV, 1 kA, 50 ns pulse width, 10 ns pulse rise time FID pulse generator with a 250 ft transmission cable, resistive load, and existing RHIC injection kicker magnet has produced unparalleled results. This is the very first attempt to drive a high strength fast kicker magnet with a nano second high pulsed power (50 MVA) generator for large accelerator and colliders. The technology is impressive. We report here the result and future plan of RHIC Injection kicker upgrade.

UPGRADE PLAN

RHIC injection kicker systems inject beam into one of every three RF buckets. There are 360 RF buckets, so the present 120 bunch pattern could fill at most one third of the buckets ignoring the beam gap. The current rise time is marginal, in particular for the long proton bunches, and for eRHIC an increase in the number of hadron bunches is planned, such as to fill every other RF buckets, for a 180 bunch pattern. We plan to use the same kicker location with the same overall length of magnet or deflector. This demands a faster kicker system. Figure 1 is the existing RHIC injection kicker Blumlein pulse generators.

Figure 1: RHIC injection kicker Blumlein triaxial pulse generators.

To inject a 24 GeV beam into RHIC or eRHIC to fill a 180 bunch pattern, the rise time of the kicker electromagnetic field must be less than the adjacent beam bunch space. To determine the kicker field rise time, we have to consider the beam bunch magnet transit time, the electrical pulse rise time, and the magnet filling time. Both the kicker magnet filling time and the beam transit time depend on the kicker magnet or deflector length. Maintaining the same overall strength, six kicker modules, instead of four, will be used with shorter individual kicker magnets or deflector length. This reduces the electrical pulse rise time constraint.

To position the upgrade project on the path to success, we want to be forward looking with advanced technology that is challenging yet with certain assurance of meeting the technical requirement. This early stage research and development effort is to identify the potential candidate technologies. FID is one of the advanced technologies that may fulfil the RHIC upgrade requirements. Figure 2 is the FID nano-second pulse generator under test.

Figure 2: FID pulse generator under 50 kV, 1 kA, and 100 Hz test.

The primary choice of kicker deflector is a 25 Ω impedance travelling wave magnet. The CERN type vacuum plate capacitor and ferrite plate inductor interleaved design is being considered at this time. This would lead to a 32 kV kicker voltage at 1.28 kA output current, the required peak current to inject 24 GeV beam into RHIC.

To fill a 180 bunch injection pattern, the bunch center-to-center time would be 71 ns. We expect the RHIC beam bunch length to be 21 ns or shorter. If using six kicker magnet modules in each ring, each one would have a mechanical length of 0.747 m. For a 25 Ω travelling wave magnet with a fill time of 37.5ns, the available electrical pulse rise time is less than 12.5ns. The time required for a single particle beam to travel through each magnet is 2.5 ns. Hence the electromagnetic field flat top must be longer than 23.5 ns. The electrical pulse flat top has to be longer than 61 ns.

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We believe a 60 kV, 2.4 kA, 80 ns pulse width, 10 ns rise time, and 30 ns fall time fast pulse generator shall give sufficient design and operation safety margin.

PROGRESS

Brookhaven National Laboratory entered a purchasing contract with FID technologies and received the pulse generator last year. We performed the factory test at FID site in Germany, then the acceptance tests at Brookhaven. Although we have identified some deficiencies during the test, we are impressed with the FID technology. It has been a learning process for both sides.

This pulse generator is rated for 50 kV and 1.0 kA peak current at 100 Hz repetition rate. The pulse shape is 10 ns rise time, 50 ns flat top duration, and 30 ns fall time. Additional requirements include adaptation to the existing RHIC injection kicker high voltage pulse cable connector and absorption of pulse reflection, etc.

As we have discussed with Dr. Efanov, the founder of FID and inventor of its technology, the critical challenge would be the pulse lifetime and device reliability. The heat dissipation handling capability in bulk solid state switching device is a well know issue. Another one is the repetitive energy extraction capability with ultra high current slew rate from storage components, which is a typical lifetime limitation factor in pulsed power devices.

We have reported the initial factory test result at FID in an earlier article [1]. We performed the initial acceptance test at Brookhaven upon receiving the pulse generator. The output pulse waveform was satisfactory. We discovered a few deficiencies during test. One deficiency was caused by a failed surface mounted diode and another one was the amplitude variation developed during the acceptance test. The unit was repaired by FID. The second acceptance test went well with the exception of pulse reflection absorption capability which we believe is partially due to long cable delays. In this process Dr. Efanov offered us his expert advice and we appreciate his help.

SELECTED TEST RESULTS

In this section, we present a few select test pictures to highlight the test results. The major components in the test setup include the FID generator, a reel of 250 feet high voltage pulse transmission cable, the high power load resistor with or without the injection kicker magnet. The waveform in Fig. 3 is the voltage monitoring output of the FID pulse generator. During these tests, we faced challenges due to instrument limitations. Most of our kicker systems are designed and operated in the tens to hundreds of nanosecond rise time range, and our instruments are sufficient to support existing systems. For this new FID pulse generator, we discovered the upgrade needs of our test laboratory.

The first obstacle we faced was the saturation of pulse attenuators. Our standard instrumentation or microwave attenuators worked well at a voltage below 25 kV and slow repetition rate. They became saturated at higher voltage and higher repetition rate.

Figure 3: FID voltage monitoring output waveform at 50 kV.

The second obstacle is the pulse current transformer response time and power handling capability. All commercial current transformers are either limited by response time, peak current rating, or RMS current rating.

The third one is the bandwidth limitation of the test fixtures, such as the stray inductance of high power load, cables, etc.

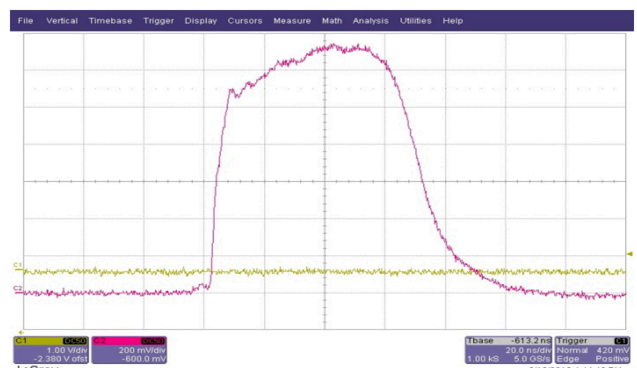

Figure 4: Load current waveform with 50 Ω air cooled resistor stack and 250 feet of high voltage pulse transmission cable.

Figure 5: Load current waveform with 50 Ω oil cooled resistor stack and 250 feet of high voltage pulse transmission cable.

The waveforms in Fig. 4 and Fig. 5 are the current waveforms with the air cooled resistive load and the oil

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cooled resistive load, respectively. The oil cooled resistor stack is a cylindrical structure similar to the one used at RHIC injection magnet output end. The current pulse waveform in Fig. 5 is much flatter at top than the one in Fig. 4, and the pulse fall time is faster as well. The significant waveform improvement indicates that the stray inductance of the load fixture is responsible for the waveform distortion and it must be reduced further. A half-length resistor stack with modified cable adaptor structure might be helpful.

The voltage monitoring output and load current have showed baseline noise due to the FID internal device conduction, as shown in Fig. 6. At 50 kV, the baseline noise to main pulse current ratio is ± 0.38 %.

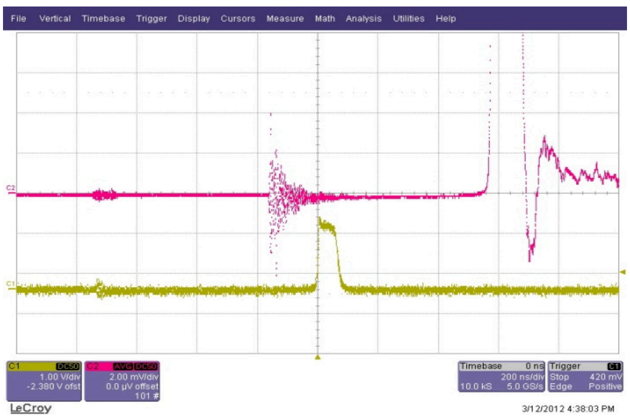

Figure 6: Baseline noise at 50kV.

We observed two types of reflections after the main pulse. One is due to mismatched load resistance to source and cable, which has a plateau section on the reflected signal. The other one is a transient reflection due to stray inductance or capacitance of the load or connectors, which is sharp and narrow. With a short cable length, the FID pulse generator had demonstrated the capability to absorb reflections at least in one direction. With 250 feet long cable, the reflections were bounced back to the load.

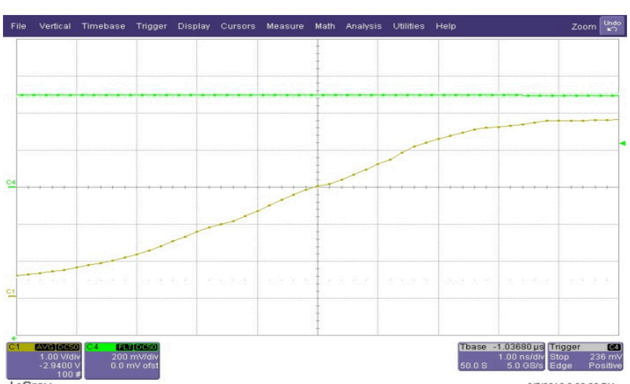

Figure 7: Jitter measurement at 50 kV, 1 Hz repetition rate.

The timing jitter is a critical parameter for the injection kickers. Figure 7 is the jitter measurement of 100 pulses at 50 kV, 1 Hz repetition rate, using scope average mode. The short-term timing stability is very good even when displayed at 1 ns per division.

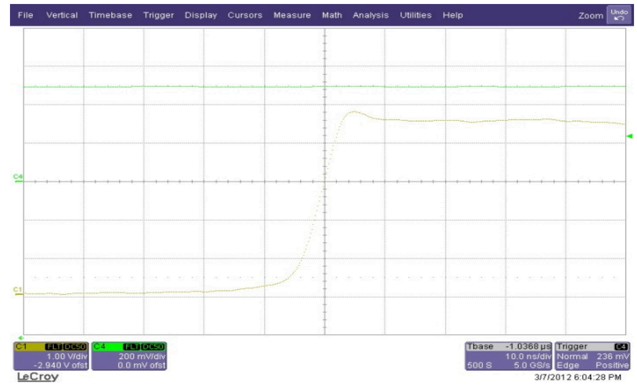

Figure 8: Jitter measurement at 50 kV, 100 Hz repetition rate.

Figure 8 shows the jitter measurement result in scope persistence mode with 50 kV, 100 Hz continuous operation for more than 1000 pulses. Again, the short-term stability is very good. The display was set to 10 ns per division.

The field waveform of the existing RHIC injection kicker was measured with matched and mismatched load. Figure 9 shows the integrated field measurement of kicker magnet with 25 ohm load at 40kV.

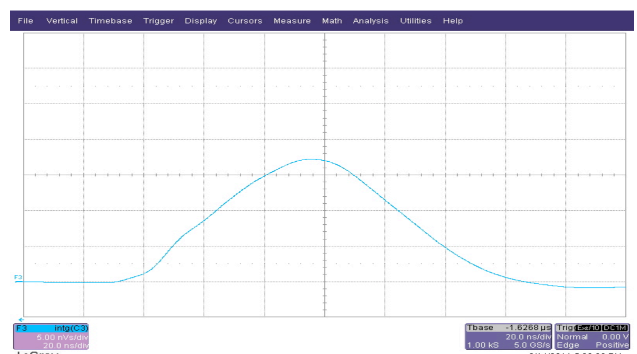

Figure 9: The integrated field measurement of kicker magnet with 25 ohm load at 40kV.

However, we need an upgrade of longer pulse length or a short length magnet for better measurement accuracy.

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[1] W. Zhang, W. Fischer, H. Hahn, C. Pai, J. Sandberg, and J. Tuozzolo, "Research and Development Toward The RHIC Injection Kicker Upgrade", Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA, pp. 1211-1213.