ANALYSIS OF KICKER NOISE INDUCED BEAM EMITTANCE GROWTH*

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Abstract

Over the last few years, physicists have occasionally observed the presence of noise acting on the RHIC beams leading to emittance growth at high beam energies. While the noise was sporadic in the past, it became persistent during the Run-11 setup period. An investigation diagnosed the source as originating from the RHIC dump kicker system. Once identified the issue was quickly resolved. We report in this paper the investigation result, circuit analysis, measured and simulated waveforms, solutions, and future plans.

INTRODUCTION

This was an interesting lesson of how a tiny leakage current, usually less than a billionth of the pulsed current level, through an imperfect connector affected the circulating beam and what we had learnt from it.

RHIC beam dump kicker high voltage modulators are located inside beam tunnel directly connected to the kicker magnets.

There are five high voltage modulators serving each ring, and ten in total. One of the Blue ring modulators developed metal erosion on one high current output lead over the years, which was hiding inside a wiring lug beneath the thyratron mounting plate. It did not affect kicker operation, but induced intolerable beam emittance growth during the RHIC Run 2011 machine setup period.

This noise had been observed since 2007 and eventually became more persistent in 2011. The investigation was rather difficult and time consuming, but the fix was easy and quick. Here, we explain the phenomena and provide some analysis.

THE NOISE HUNT

The Blue ring beam emittance growth was intermittent at first, and then became persistent. The figure below shows that the emittances were blown up in both planes. In about three hours, the beam emittance would approximately double as shown in Figure 1, which prevented operation. It suggests as a possibility that the source has high power and is generated by a magnetic dipole field with a random component or impulse excitation. Beam diagnostics clearly identified the source as being in the horizontal plane with excitations present also at injection energy.

On February 8th, 2011, it was narrowed down to Blue dump kicker. Later that evening, we confirmed that the beam dump kicker was the source.

At RHIC, the beam revolution time is 12.8 µs during injection. In 3 hours, the circulating beam passes the kicker more than 843 million times. Therefore, the accumulative effect of a little noise kick could be large enough to affect the beam.

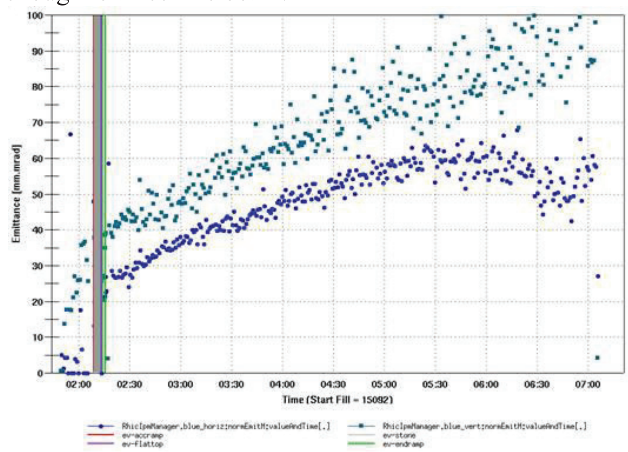

Figure 1: RHIC Blue beam emittance growth measure by IPM in fill #15092.

The blue traces in Figure 2 and Figure 3 show the noisy Blue beam waveforms measured by base-band tune meter (BBQ) system. In comparison, the yellow trace is the Yellow beam signal.

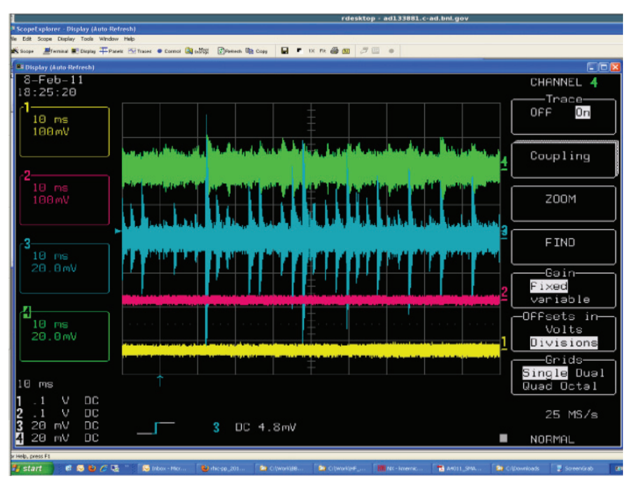

Figure 2: The blue trace is the Blue difference signals of the base-band tune meter; and the yellow trace is the Yellow difference signals of the base-band tune meter. The horizontal scale is 10 ms per division.

At the kicker, the nominal pulse current signal from the pulse current transformer is 180 V. It has to be attenuated before connecting to a scope. In order to detect the tiny

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noise signal, we removed all attenuators and adjusted the scope to near maximal signal resolution. It enabled us to find the noise current in one of the pulse modulators, Blue module B. The noise signals on module B PFN voltage and charging current waveforms are shown in Figure 4.

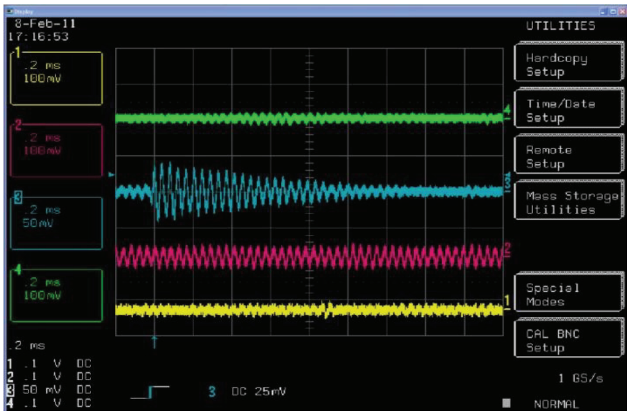

Figure 3: The blue trace is the Blue difference signals of the base-band tune meter; and the yellow trace is the Yellow difference signals of the base-band tune meter. The horizontal scale is 0.2 ms per division, much more expanded than in Figure 2.

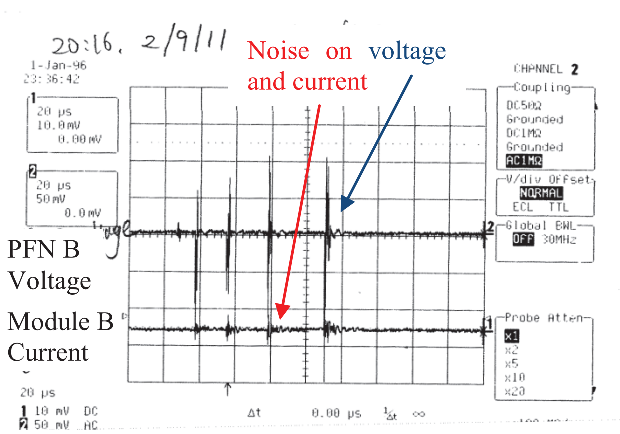

Figure 4: Noise on PFN voltage monitoring signal and magnet current monitoring signal.

Since the high voltage modulators are inside the tunnel, they are inaccessible during beam operation. Each entry into the tunnel would cause significant operational interruption, which also hindered the investigation.

Initially the thyratron and charging power supply were replaced. However, this did not solve the problem.

In the following days, we observed that the noise signature was random and intermittent. It behaved like a dynamic spark gap discharging at random voltage level. Its damped oscillation waveform with random oscillating frequency suggested a parallel circuit of varying capacitor and resistor. The channel 1 in Figure 4 was the noise current detected by the current transformer without attenuators. The vertical scale is 10 mV per division and 0.01 V per ampere. From the picture, the noise current was of order 10 mA. The noise current oscillation usually damped out in several 10s of ms.

Eventually, an eroded connector inside a wire lug was found. It was mounted beneath the thyratron base plate and not visible from the front, as shown in Figure 5. The repair was easy and fast, although the investigation took days.

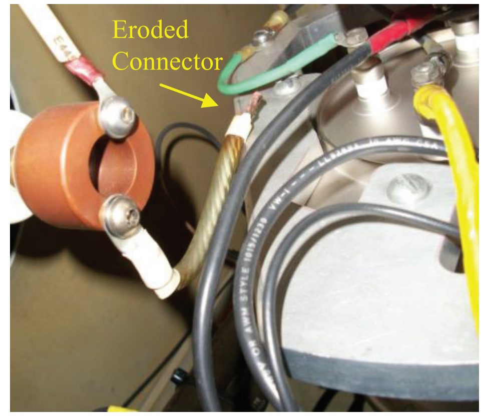

Figure 5: The eroded connector being placed on the thyratron base plate.

CIRCUIT ANALYSIS

There are five kicker modulators in each ring, and they are commonly charged by a single high voltage power supply with a maximum output current of 360 mA. Each modulator has a nominal charging current of 72 mA. Since the thyratron stays open during beam injection, acceleration, and store, it isolates the charging current from the kicker magnet. Therefore it was puzzling to us, how the dump kicker could affect the beam before the discharge. After the discovery of the connector problem we conducted an analysis to understand the circuit behaviour.

Each of the beam dump kicker modulators is capable of discharging up to 22 kA of pulsed current to deflect the beam. Its PFN voltage tracks the main dipole field from injection to full energy at store. In normal operation, it is charged to 27 kV, and the discharge current is 18 kA. Figure 6 shows the simulated current waveform.

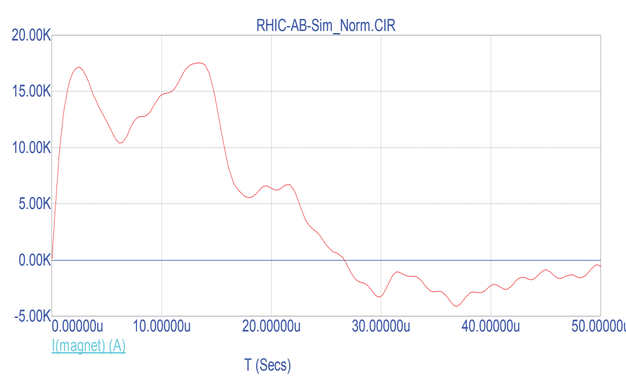

Figure 6: Simulated kicker current waveform at 27 kV charging voltage.

Ideally, an open thyratron should be an open circuit. In reality, it has a capacitance between the anode and cathode, the parallel capacitance and resistance in its gap

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voltage equalization circuit, the grid auxiliaries, etc. The circuit model of a thyratron in open position is usually represented by a small capacitor in the pF range. We bring this model into the dump kicker modulator circuit for the noise analysis. Under normal conditions, the leakage current through the thyratron and its auxiliary components is of the order of hundreds of nA, which is less than a billionth of the discharging current and therefore not a threat to the beam.

We enhanced the simulation circuit model of the beam dump kicker as shown in Figure 7. In this circuit, the eroded connector was in between the thyratron cathode and the magnet high voltage lead. There was a small bypass capacitor across the magnet feed-through. We modelled the eroded connector by a switch (SW1), a capacitor (C16), and a resistor (R10) in parallel. This was to simulate a connection with random air gap.

The capacitor slowly charged up during initial PFN charging and tracking, and suddenly discharged by the switch representing a spark gap. The simulated leakage current through the magnet is shown in Figure 8.

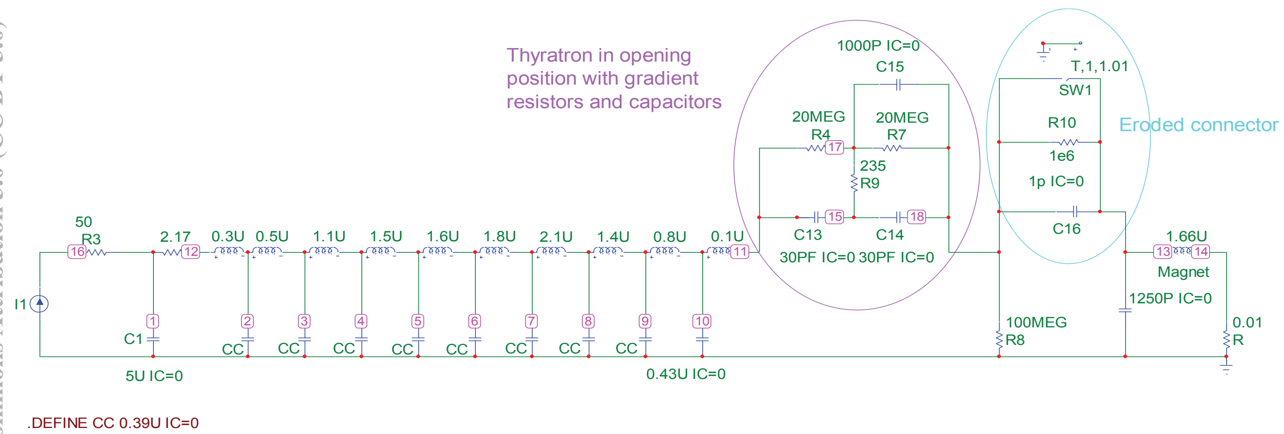

Figure 7: The enhanced circuit model of beam dump kicker for noise analysis.

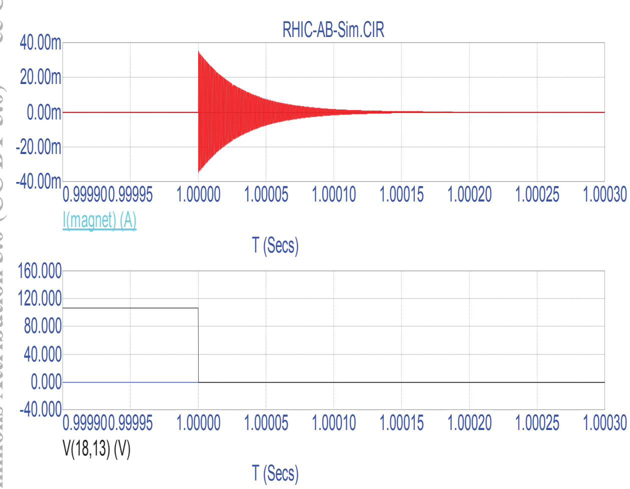

Figure 8: The upper trace is the leakage current of the kicker and the lower trace is the voltage across the nodes of the dynamic circuit model representing the eroded connector.

The simulated noise current is about 40 mA in amplitude with an oscillatory waveform similar to some of the measured noise signatures. This noise current is about a few millionths of the peak discharge current and well below the resolution of the normal monitoring capability.

Using this model, we performed some ac circuit analysis as well. The result indicates that the circuit is sensitive to ac signals in 400 kHz range.

CONCLUSIONS

The RHIC beam dump kicker systems have been routinely maintained during annual maintenance period. All high voltage thyratrons have been cleaned, reconditioned, and reinstalled before the start of the RHIC 2011 operation and their auxiliary settings were checked before start up as well.

The discovery of the eroded connector prompted us to replace similar connectors in all ten modulators. The erosion of the connector could be the result of a combination of several factors, such as improper construction technique, high current induced metallic migration, and radiation induced metal erosion, etc.

We plan to routinely check current signals during start up and replace high current connectors when necessary to ensure the operation reliability of the system.

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