BNL-94156-2011-CP

Analysis of RHIC beam dump pre-fires

**W. Zhang, L. Ahrens, W. Fischer, H. Hahn,
J. Mi, J. Sandberg, Y. Tan**

Presented at the 2011 Particle Accelerator Conference (PAC'11)
New York, N.Y.
March 28 – April 1, 2011

Collider-Accelerator Department

Brookhaven National Laboratory

**U.S. Department of Energy
Office of Science**

Notice: This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

DISCLAIMER

ANALYSIS OF RHIC BEAM DUMP PRE-FIRES*

W. Zhang, L. Ahrens, W. Fischer, H. Hahn, J. Mi, J. Sandberg, Y. Tan

Brookhaven National Laboratory, Upton, NY 11973-5000

Abstract

It has been speculated that the beam may cause instability of the RHIC Beam Abort Kickers. In this study, we explore the available data of past beam operations, the device history of key modulator components, and the radiation patterns to examine the correlations.

INTRODUCTION

The RHIC beam abort kicker system was designed and built in the 90's. Over last decade, we have made many improvements to bring the RHIC beam abort kicker system to a stable operational state. However, the challenge continues.

We present the analysis of the pre-fire, an unrequested discharge of kicker, issues which relates to the RHIC machine safety and operational stability.

SYSTEM LAYOUT AND IMPROVEMENT

There are two RHIC beam abort kicker systems; one serves the Yellow ring and other serves the Blue ring of RHIC. Each beam abort kicker system has five identical high voltage modulators and their related auxiliary subsystems. A total of ten high voltage modulators are in operation.

The controls, instrumentation, timing, high voltage charging power supplies, and main high voltage trigger systems are located in service buildings outside of the collider tunnel. The high voltage modulators and redundant high voltage trigger systems are located inside the RHIC collider tunnel. They directly connect to kicker magnet vacuum feed-through. The modulator outline is L-shaped. They are packaged to fit in front and beneath the beam chambers.

In each high voltage modulator, the thyratron is right in front of the beam chamber to reduce circuit loop inductance. It is floated in high voltage during the pulse.

The energy storage capacitors that form the pulse-forming-network are in the lower portion of the modulator, beneath the beam chambers, as shown in Figure 1.

Over the years, many improvements were made such as construction modifications, change of high voltage insulation materials, conductor shapes, low level circuits, etc.

In parallel with the high voltage structure improvement was the effort to improve the thyratron stability. The original version with a CX1575C thyratron had reverse arcing problems. It was evident by finger patterns of metallic painting inside thyratron ceramic wall. The CX3575C thyratrons replaced the CX1575C thyratrons for higher voltage ratings and pulse current conducting capacities.

Then capacitor safety issues became a focus. Two types of capacitors are used in the modulators. The 0.39 μF oil filled capacitors with plastic tube package and the 5 μF oil filled capacitors with steel case package. Two of the plastic packaged capacitors were damaged with partial blow up of case material. These plastic tube capacitors are rated at 40 kV and operated below 28.5 kV. After discussing with capacitor vendor failure mechanism, the proton and heavy ion beams and beam radiation became the suspected cause. The large 5 μF metal cased capacitors also had several failures associated with high current pulsing. Internal construction was modified by the capacitor vendor to improve reliability.

RHIC BEAM ABORT PRE-FIRE EVENT RECORDS

We looked into the RHIC beam abort kicker pre-fire history in the last few years, as shown in Table 1, to investigate issues. It is evident that highest likelihood of a pre-fire occurs with the highest beam energies, not the highest intensities.

Table 1. RHIC beam abort pre-fire history 2007 to 2010

Run	Mode	Beam		Energy			Length	Prefire
		Blue	Yellow	Blue	Yellow		Day	
RUN 2010	1A	Au	Au	100	100	GeV/u	101	19
	1B	Au	Au	31.2	31.2	GeV/u	21	0
	1C	Au	Au	19.5	19.5	GeV/u	14	0
	1D	Au	Au	3.85	3.85	GeV/u	34	0
	1E	Au	Au	5.75	5.75	GeV/u	9	0
	1F	Au	Au	2.5	2.5	GeV/u	1.21	0
RUN 2009	1A	pp	pp	250	250	GeV	67	10
	1B	pp	pp	100	100	GeV	74	1
	1C	pp	pp	100	100	GeV	5	0
RUN 2008	1	d	Au	101.9	100	GeV/u	80	5
	2	pp	pp	100	100	GeV	41	0
	3A	Au	Au	4.6	4.6	GeV/u	1.29	0
	3B	au	Au	2.5	2.5	GeV/u	0.625	0
RUN 2007	1A	Au	Au	100	100	GeV/u	125	30
	1B	Au	Au	4.6	4.6	GeV/u	1	0

BEAM ABORT PRE-FIRE AND CAUSES

Our current understanding of the possible causes includes:

1. Machine and system design deficiencies such as location of high voltage modulators in immediate beam areas and modulator high voltage design. The system is operating at its limit.

*Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.

#arling@bnl.gov

2. Thyratron self-conduct.
3. Secondary beam triggered thyratron conduct
4. Secondary beam induced capacitor high voltage breakdown.
5. Radiation damage caused capacitor insulation weakening.
6. AC power instability.
7. Loss connections, surface dust, components and material defects and aging, etc.
8. Human error.
9. Remote operation system error from noise, RF, or control, etc.

The common causes of beam abort pre-fires are the high voltage arcing or micro discharge which is voltage dependent. Another is unintended triggering due to control or operation error which is a misfire rather than pre-fire event.

The thyratron is known to have high voltage breakdown in random nature which causes pre-fires. These usually can be treated with pre-conditioning of the thyratron to reduce the number of pre-fires but cannot be entirely eliminated. Since the High voltage modulator is inside the tunnel and thyratrons are right in front of beam pipes they can be affected by beams. That thyratrons under high voltage tension can be triggered by charged particle beams is a known fact. The charged particle beam or secondary beam unintentionally passing through a thyratron could form a virtual electrode within the thyratron which has a much smaller electric field gap that can easily breakdown under high voltage. Another situation is the beam or secondary beam travel through thyratron disturbing the high tension electric field and forming electron stream to cause field breakdown. This type of problem happens more frequent during initial collider machine setup phase, physics program change, accelerator machine experiment, or beam scrapping, etc. In the last several years, since summer 2007, we have not replaced any thyratron. All thyratrons were reconditioned to 40 kV DC during 2010 summer maintenance and reinstalled for service before the RHIC RUN11.

An interesting phenomenon is the capacitor related beam abort kicker pre-fires. After the capacitor case rupture events, more attentions have been devoted to capacitor inspection and high voltage conditioning. The clicking sound from the high voltage capacitors during continuous DC hi-pot, the tiny oil marks on capacitor cases, the fine line crack, etc., are all signs of capacitor problems. In several instances, the series of pre-fire events were stopped after changing large 5 μF capacitors. Looking into the history of capacitor replacement, there seems to be correlations of the capacitor location and beam radiation.

RADIATION DAMAGE TO CAPACITORS

During last 12 years of operation, we observed several capacitor damages seem to be caused by radiation. For instance, at the end of one operation season some high voltage modules became unstable, but all capacitors seemed to be intact when inspected immediately after the operation season ended. However, after several months of power off during summer shutdown a bunch of capacitors developed minor leaks and fine cracks on capacitor cases. It suggests there were pressure build up inside of capacitors and the likely source is beam radiation.

Localized Radiation

A radiation technician and pulsed power group technicians alerted us of localized radiation phenomena. After replacement of a capacitor during 2009 operation, the radiation survey showed the concentration of radiation at the ground end of the damaged capacitor only, as shown in Figure 1. Coincidentally, the damage, a fine crack line on capacitor case caused a minor oil leak, was at the ground end with abnormal radiation reading. Since the internal arcing of the capacitor happens usually at the high voltage end, this damage at ground end raised alarm of possible radiation damage to capacitors.

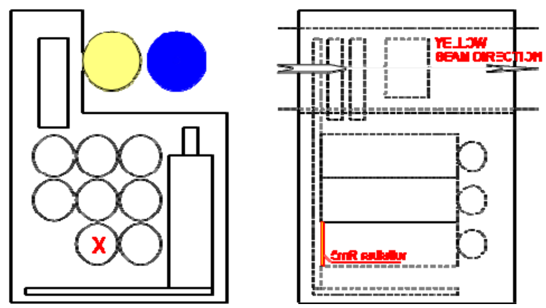

Figure 1: The yellow modulator 4 front view and side view and the location of the damaged capacitor.

Correlations of capacitor location and beam pipe position

To investigate further, we looked into capacitor replacement records and their location relative to beam pipes. Table 2 and table 3 list the capacitor replacement history of yellow and blue beam abort systems, respectively. Figure 2 shows the capacitor location and beam pipe location.

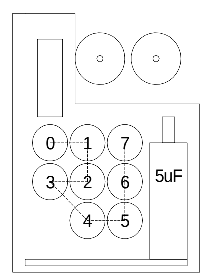

Figure 2: Side view of capacitor location inside modulator and beam pipe position.

From the statistics point of view, the number of replacement and location of the capacitor seems to be correlated. The location of the large 5 μF capacitors and the location of the № 7 capacitors are direct under the beam pipes as shown in figure 2. A total of 14 capacitor replacements happened on location № 7 since 2005, the highest among all capacitors. The second highest one is the 5 µF large metal case capacitors. The third in rank is № 2 capacitor, for which we have not found a clear reason.

Table 2. Yellow abort kicker capacitor replacement record

Location		0	1	2	3	4	5	6	7	Large 5uF		
YELLOW RING											Sub-total	Total
Modulator #1												
	8/1/2005								1		1	
	11/20/2009								1		1	
Sub-total												2
Modulator #2											0	
	8/19/2003									1	1	
	8/1/2005								1		1	
	12/19/2007									1	1	
	3/10/2010									1	1	
Sub-total												4
Modulator #3											0	
	12/23/2003									1	1	
	8/1/2005								1		1	
	11/20/2009			1				1			2	
	12/17/2010									1	1	
Sub-total											0	5
Modulator #4											0	
	8/1/2005								1		1	
Sub-total												1
Modulator #5											0	
	7/20/2003								1		1	
	8/1/2005		1	1	1	1	1	1	1		7	
	4/15/2009					1					1	
	11/20/2009							1	1		2	
	11/29/2010		1								1	
	3/2/2011									1	1	
Sub-total												13
TOTAL		0	1	2	1	2	1	3	8	6	25	25

Table 3. Blue abort kicker capacitor replacement record

Location		0	1	2	3	4	5	6	7	Large 5uF	Sub-total	Total
BLUE RING												
Modulator #1												
	8/3/2005			1							1	
	9/25/2005		1								1	
Sub-total												2
Modulator #2												
	10/19/2005			1							1	
	9/17/2007	1	1	1	1	1	1	1	1		8	
	9/27/2007									1	1	
Sub-total												10
Modulator #3												
	10/12/2003				1						1	
	12/3/2004	1									1	
	10/5/2005								1		1	
	10/12/2005						1				1	
	9/17/2007	1	1	1	1	1	1	1	1		8	
Sub-total												12
Modulator #4												
	9/21/2005	1									1	
	7/13/2007									1	1	
	10/31/2007	1	1	1	1	1	1	1	1		8	
	12/19/2007									1	1	
	3/12/2009									1	1	
	8/27/2009			1	1		1	1	1		5	
	12/17/2010									1	1	
Sub-total												18
Modulator #5												
	11/15/2004									1	1	
	11/17/2004	1	1	1	1	1	1	1	1		8	
	9/16/2005		1	1							2	
Sub-total												11
Total		6	6	8	6	4	6	5	6	5	53	53

Uncertainty of modulator location and radiation survey

The correlation of the modulator location and the residual radiation in blue seems clear, but not in yellow. The blue module 4 had the highest number of capacitor replacement and the highest residual radiation in survey. However, the yellow module 5 that had a total of 13 capacitors replaced had low reading in radiation survey.

The Figure 3 and Figure 4 are the pictures of yellow and blue abort kicker modulators' rear view and radiation survey results.

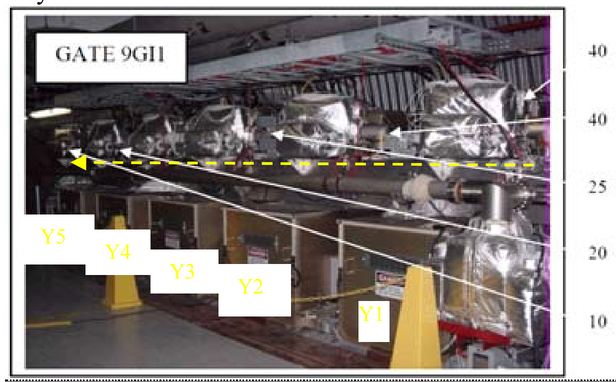

Figure 3: The yellow abort kicker modulators rear view and radiation survey result in µRem. The dashed yellow line is the yellow beam direction.

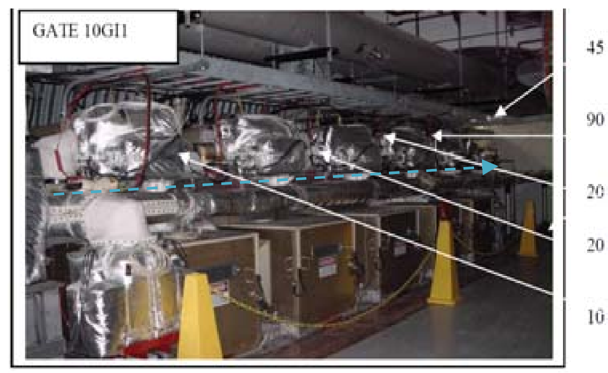

Figure 4: The blue abort kicker modulators rear view and radiation survey result in µRem. The dashed blue line is the blue beam direction.

CONCLUSIONS

We suspect that the instantaneous beam loss might cause more damage than low level background radiation. It also causes abort system instability. We notice that the beam loss is non-uniform throughout the beam abort kicker area.

There are scanty published literatures of radiation effects in liquid dielectrics. The beam induced damage to oil filled capacitor requires more in-depth study. The development of radiation resistant and fire resistant high voltage, 40 kV, and high current, 20kA, pulsed capacitors are critical for RHIC operation.

A new research and development of abort kicker system is necessary for the future RHIC upgrade.

We would like to thank K. Hartmann, J. Addessi, W. Dartiguenave, S. Perlstein, R. Zapasek, P. Bergh, and J. Williams for their assistance.

REFERENCES

[1] H. Hahn, et. Al., "THE RHIC BEAM ABORT KICKER SYSTEM", Proceedings of the IEEE 1999 Particle Accelerator Conference, pp. 1100-1102.