ANALYSIS OF BEAM LOSS INDUCED ABORT KICKER INSTABILITY*

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Abstract

Through more than a decade of operation, we have noticed the phenomena of beam loss induced kicker instability in the RHIC beam abort systems. In this study, we analyze the short term beam loss before abort kicker pre-fire events and operation conditions before capacitor failures. Beam loss has caused capacitor failures and elevated radiation level concentrated at failed end of capacitor has been observed. We are interested in beam loss induced radiation and heat dissipation in large oil filled capacitors and beam triggered thyratron conduction. We hope the analysis result would lead to better protection of the abort systems and improved stability of the RHIC operation.

ISSUE DESCRIPTION

RHIC beam abort kicker high voltage modulators are inside RHIC beam tunnel directly connected to kicker magnets. These modulators contain large quantity of oil filled high voltage capacitors as energy storage pulse forming networks. The discharge devices are deuterium filled thyratrons. Thyratron cathodes are connected to magnets and floating up during pulse discharge. Thyratrons are right in front of the beam chambers and most capacitors are underneath the beam pipes. They are subjected to high level beam induced radiation.

The charging power supplies, auxiliaries, and main trigger systems are in the service building outside the beam tunnel. However, the redundant trigger systems and diode adders of trigger pulses have been moved into the tune near the high voltage modulators a few years ago. The purpose is to shorten the cable delays and speed up discharge of other modulators in case that one of the modulator discharged unintentionally. Doing so could minimize the beam loss during unintended discharge events. The high voltage trigger modules have MOSFET devices and diode adders are solid state devices as well. They are along the tunnel wall or above the cable tray, just a few feet away from beam pipes.

The RHIC beam ranges from polarized proton, ion, and copper, gold, and uranium particles. They produce gamma, beta, and neutron radiations. First, according to literatures [1-8] the gamma ray and the high energy electrons are capable to trigger thyratrons. Second, the ionized radiation can damage capacitors and cause micro-discharge or arcing. The third issue is that radiation upset of solid state devices, such as MOSFET, could make redundant trigger failure. These would then cause thyratron to discharge and result in unintended beam abort. These beam aborting events are usually unsynchronized to beam gap and produce significant beam loss that could quench superconducting magnets. In addition, part of the uncontrollable beam might circle back to the abort kicker area generating more ionized radiation and cause further damage to modulators.

Over the past twelve years, we have significantly improved the abort kicker system reliability through a series of engineering efforts. During investigation of unintentional beam abort events, we noticed there seem to be some association of beam loss and kicker pre-fire events. This means the abort kicker system could have been the victim of the beam loss caused by other systems or operations in some situation. Our intention is to understand the link behind phenomenon and to further improve the beam abort kicker system reliability. We summarize the main factors contributing to unintended beam abort in Figure 1.

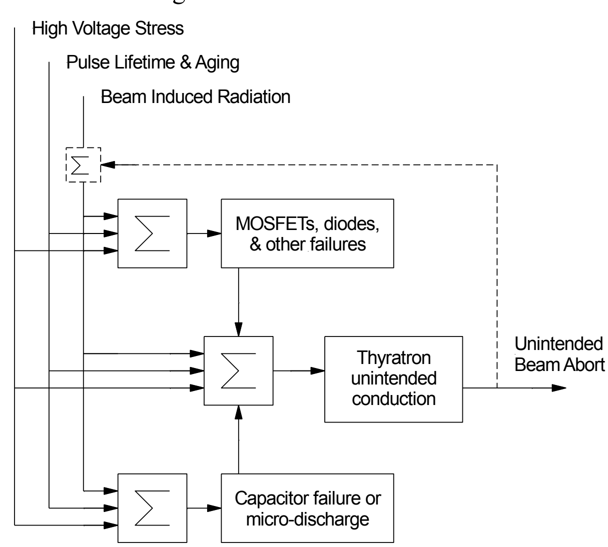

Figure 1: Main factors contributing to unintended beam abort in RHIC beam abort systems.

EFFECT ON THYRATRON

Several factors could cause thyratron misbehave. With careful conditioning and monitoring, we have been able to keep them much more stable than before. In last few years, all thyratrons have been reconditioned and then placed back to service. We have not found any thyratron failures in recent years, although they may reach device lifetime in next few years. Thyratrons are normally triggered by electrical pulses. The high energy electron beam could also cause the field breakdown of the thyratron internal gap. With up to 255GeV high intensity proton beam or up to 100 GeV heavy ion beams

* Work supported by U.S. DOE under contract No DE-AC02-98CH10886 with the U.S. Department of Energy.
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ISBN 978-3-95450-115-1

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circulating in the machine, secondary beam caused thyratron conduction is always a possibility. This type of pre-fire occurs immediately or within a few micro-second after secondary beam hitting the thyratron, such as during high intensity beam loss or beam scrubbing.

High voltage over stress is another factor contributing to thyratron pre-fire. This is usually treated with high voltage preconditioning of modulator to a slightly higher voltage and adjustment of reservoir and grid potentials.

In general, thyratron aging would make it difficult to trigger rather than self-conducting. But, the internal metallization of thyratron ceramic wall due to reverse arcing could cause high voltage degradation. The main conduction current of RHIC beam abort kicker is near 20 kA, and its reversed current is about -4 kA.

EFFECT ON CAPACITOR

The capacitors used in the high voltage modulators are manufactured by the Condenser Products. Each PFN consists of twelve KN series capacitors and one 5 uF KC series capacitor. The KN capacitor is mineral oil filled Kraft tissue and polypropylene construction with thermal plastic tubing enclosure. The KC is also mineral oil filled Kraft tissue and polypropylene construction contained in metal can.

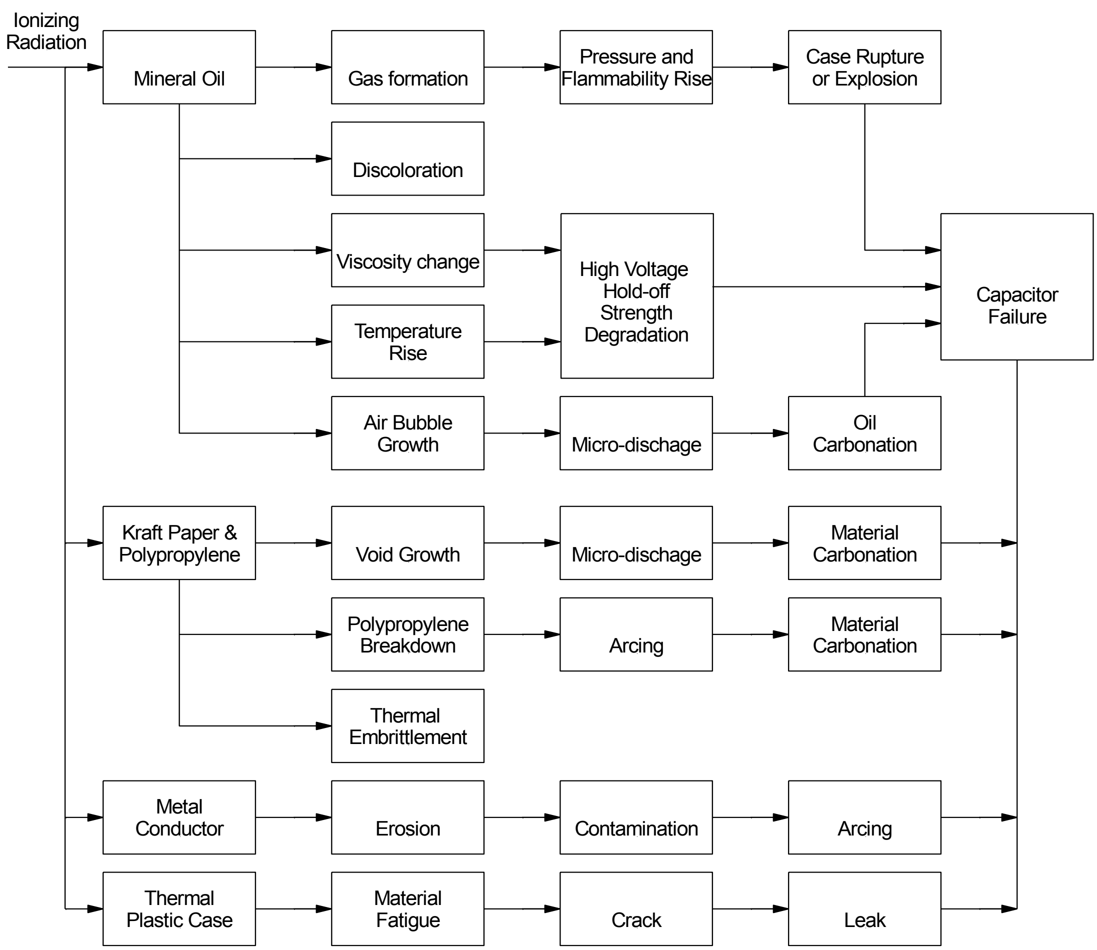

Figure 2: A diagram of possible radiation effects on oil filled capacitors.

According to various literatures [1-8], the ionized beam radiation could lead to many adverse effects of oil filled capacitors. These effects may have delayed reaction in capacitors hours or even days after beam irradiation. This is distinctly different than the thyratron reaction, which is almost instantaneously.

Typical ionizing radiation phenomenon of mineral oil [1-2,4,6-8] includes oil gassing and pressure rise, air bubble formation and micro-discharge, discoloration, viscosity change [2], gel formation [1], temperature rise [1-3,5] due to energy deposition, etc. The micro-discharge of air bubble or arcing will lead to oil contamination and degradation of high voltage hold-off strength. The gas formation could cause pressure rise and explosion. This gas inside capacitor is dangerous due to its high flammability. It is known that the dielectric strength of insulation liquid has temperature dependency [1,2].

The radiation damage to Kraft tissue [1,2] and polypropylene [3] is mainly the void growth, polypropylene breakdown, and paper embrittleness [1]. These also lead to micro-discharge [7], carbonation, arcing, and high voltage degradation [1].

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The metal erosion under beam radiation [1,4] has also been reported. We illustrate the effects on capacitor in Figure 2.

In the RHIC beam abort kicker systems, observed capacitor failures include capacitor section explosion, case rupture, oil leaking, plastic case discoloration, carbonization of oil and capacitor sections, melted wires, etc. Most often is the hearing of popping or crackling sounds from inside of capacitors during high voltage hold-off. A few plastic capsulated capacitors had continued making popping sounds shortly after being removed from modulators. A total of 78 capacitors have been changed, including 11 large metal enclosed ones and 67 thermal plastic case capacitors.

Elevated radiation levels have been measured at failed capacitors. Radiation technician reported the finds in more than one case, that measured radiation level is much higher at failed end of the capacitor than the background while the other end measured almost nothing. In one case, the failed end is the grounding side.

In many situations, we noticed that the kicker pre-fire occurred minutes or hours after heavy beam loss due to other system failures or beam manipulations. Thyratron usually recovers fairly fast after beam induced conduction. Its temperature could stabilise in 20 to 30 minutes due to forced air cooling. Most of the time, the quench recovery of superconducting magnets would take much longer time than the thyratron recovery, but we observed that the kicker could still be unstable or unable to withstand the operating voltage during operation recovery. However, it would regain the strength later. This seems to be a link to the oil filled capacitor radiation effect.

For example, the pre-fire events often happen multiple times in series. In Run 7, among 36 logged pre-fire events, there were 22 events fit the sequential pattern. Also, 7 events linked to BBQ setup, such as tune feedback, tune wiggling, etc. Some pre-fire events had clear association to beam loss or beam manipulation such as during APEX, beam scrubbing, and after quench events caused by other systems.

EFFECT ON SOLID-STATE DEVICES AND OTHER AUXILIARIES

The solid state devices are vulnerable to beam radiation. We placed most solid state electronics in service building outside of beam tunnel. Only the redundant trigger systems and diode adder boxes are placed inside tunnel. Occasionally, radiation induced single event upset occurs in these devices and cause abort kicker pre-fire and trigger module damage. Diode adders have been able to survive in the ring, and need to be replaced once in a while.

Other factors such as noise through loss connections, improper auxiliary settings, high voltage arcing, etc. could also induce unintentional beam abort. However, they are occurring much less frequent then before.

In the polarized proton Run 2012, the only pre-fire event was the result of a MOSFET damage of a redundant high voltage trigger module.

CONCLUSION

We believe that the beam abort kicker pre-fire events need to be investigated more thoroughly to uncover underline causes. This would help us to build better systems and operate machine with higher efficiency.

ACKNOWLEDGMENT

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

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ISBN 978-3-95450-115-1