

OBSERVATION OF BEAM-INDUCED ABORT KICKER FERRITE HEATING IN RHIC *

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Abstract

During the FY 2013 RHIC polarized proton run, deterioration of the abort kicker system was observed. The reduced kicks resulted in quenching the superconducting quadrupole Q4 downstream of the beam dump. Frequent re-tuning of the modulator wave form temporarily mitigated the effect, which worsened during the course of the run. Beam-induced heating of the kicker ferrites was eventually identified as the root cause of this behavior. We report our observations and discuss modifications to the kickers.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) consists of two superconducting storage rings. Fully stripped heavy ions or polarized protons can be accelerated up to rigidities of 831 Tm, which corresponds to 100 GeV/n gold or 250 GeV proton beam energies. To abort the beams, a dedicated beam dump system is installed in IR10. This system consists of five fast kicker magnets per ring that deflect the beam horizontally into the beam dump. These kicker magnets are located just downstream of the low- β triplet quadrupoles, while the beam dump is installed upstream of the next quadrupole, Q4.

EVIDENCE FOR KICKER HEATING

Several weeks into the FY2013 polarized proton run, beam aborts began to frequently result in quenches of the superconducting Q4 quadrupole downstream of the dump. As Figure 1 shows, the amplitude at the minimum of the kicker waveform had dropped by a few percent compared to the situation just three weeks earlier, resulting in an insufficient kick amplitude for some of the 109 bunches. As a preliminary measure one of the kicker modules was retuned by shorting individual windings in some of the inductance coils in that particular pulse forming network (PFN). The resulting waveform with its raised amplitude at the minimum is shown in Figure 2.

While this countermeasure was initially successful in preventing quenches of the Q4 magnet, these quenches recurred after a couple of days. Consequently, the retuning procedure was applied to other modules as well. However, this has the undesirable side effect that the waveform gets more and more flattened, so individual bunches end up very close to each other on the exit window. This may in turn

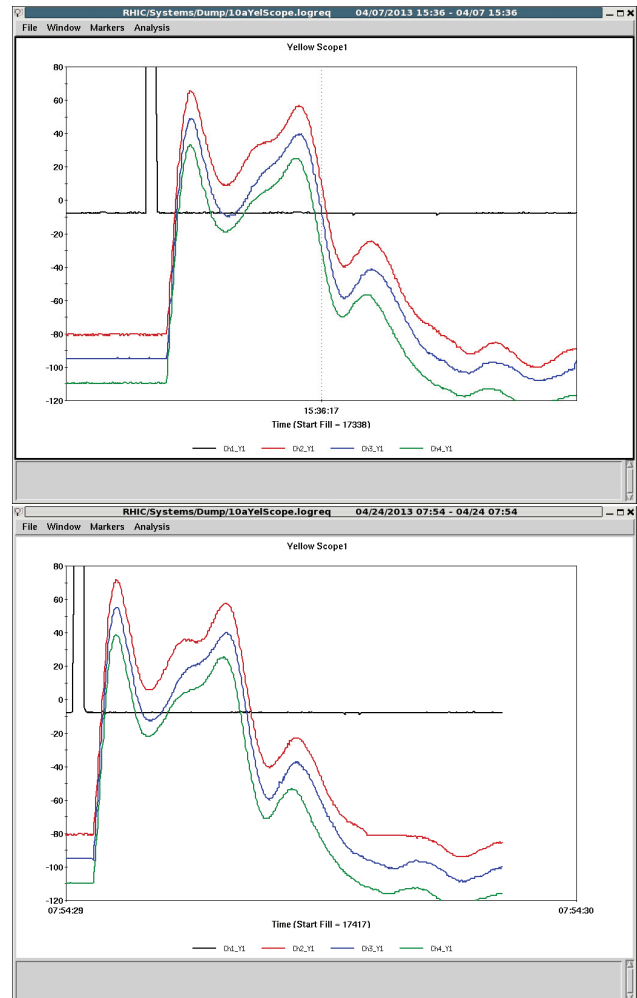


Figure 1: Abort kicker current waveforms at the beginning of Run-13 on April 3 (top), and several weeks into the run when the first Q4 quench occurred on April 24 (bottom). The red, blue, and green lines show the current waveforms of three individual abort kicker modules. The black line depicts the trigger pulse and serves as a reference to guide the eye here.

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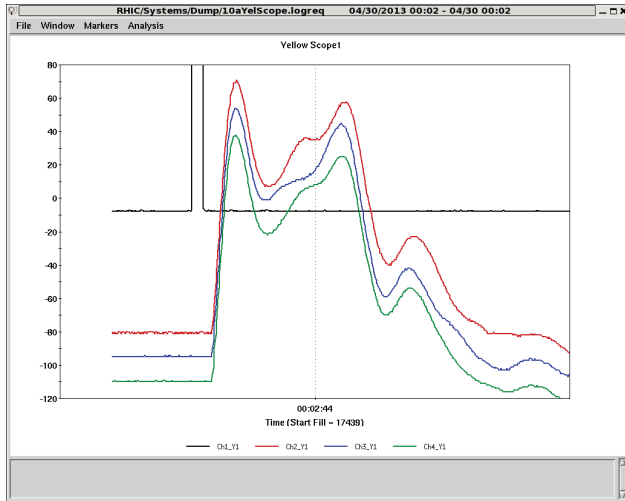


Figure 2: Kicker current waveforms after retuning the “blue” module.

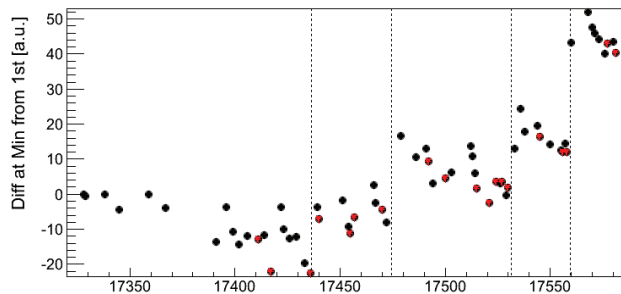


Figure 3: Minimum of the sum of all abort kicker currents in the Yellow ring vs. fill number. The red dots indicate fills that led to a quench of the downstream Q4 quadrupole upon dumping the beam. The vertical lines indicate when one or more PFNs were retuned to raise their minimum current.

result in mechanical failure of that window, and therefore several weeks of machine downtime during the subsequent repair.

Each retuning of an individual kicker module raises the current at the minimum of the wave form of that particular module, and therefore the sum of the currents of all five modules, as shown in Figure 3. However, there is clear indication that after each retuning of a module this minimum sum current slowly decreases over the course of several RHIC fills. Eventually, the minimum sum drops below a certain critical value, resulting in quenches of the Q4 magnet. It is also apparent that over the course of the run, this critical current value slowly rises, i.e. quenches occur at higher and higher minimum sum currents.

A comparison of individual bunch positions downstream of the abort kickers shows that later in the run individual bunches receive a smaller deflecting kick than several weeks earlier, despite the fact that retuning of individual modules has resulted in a higher kicker current, as shown

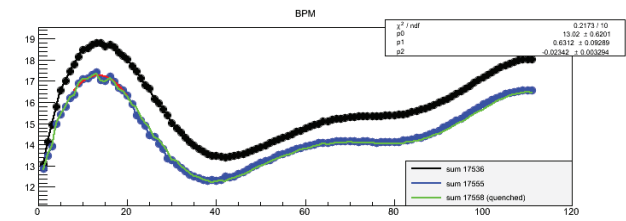


Figure 4: Positions of individual bunches as measured by a dedicated fast BPM between abort kickers and beam dump. PFNs were retuned after fill 17536 (black line). A few weeks later, the resulting effect on the bunch positions is smaller despite the higher kicker current (blue trace).

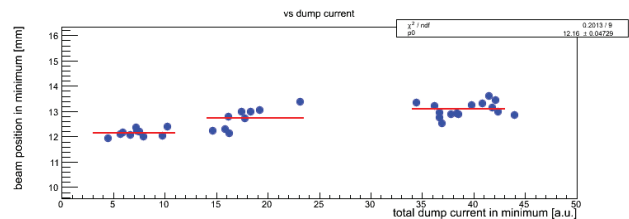


Figure 5: Minimum BPM position vs. total current in the waveform minimum.

in Figure 4. This indicates that not only does the kicker current in the waveform minimum decrease over the course of the run, but also the magnetic field resulting from the same current becomes lower and lower over time. This slow deterioration becomes even more apparent when plotting the bunch position in the waveform minimum vs. the sum of the abort kicker currents in that minimum, Figure 5. The three groups of data shown in that plot correspond to three distinct tuning states of the PFNs, while the red lines represent the average bunch position in the waveform minimum for each group.

Between the first group (on the left) and the second one (center), only one PFN had been retuned, while two PFNs were retuned between the second (center) and the third group (on the right). In both cases this retuning resulted in a significant increase of the total kick in the waveform minimum. However, despite the fact that the second retuning involved two PFN modules, the resulting kick increase is in fact smaller than in the first instance which involved only a single module being retuned. In conclusion, this indicates the the kicker properties, and not the PFNs, change during the course of the run.

Beam-induced heating of the kicker ferrite material has been identified as the root cause of the decreasing kicker strength during the course of the run. With the calculated power deposition in the ferrite being around 100 W, the poor thermal conductivity to the outside vacuum enclosure results in a gradual heating of the ferrites. While no direct temperature measurements exist, ferrite heating manifests itself indirectly as an increase of the vacuum pressure in

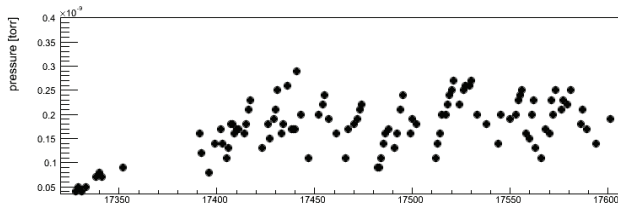


Figure 6: Vacuum pressure in the RHIC abort kicker region vs. fill number

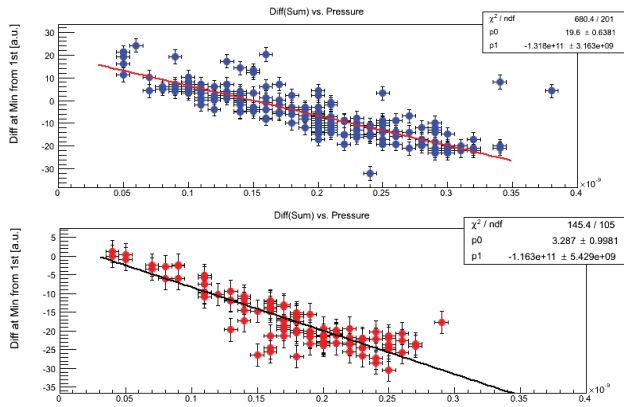


Figure 7: Kicker current minimum vs. vacuum pressure in the BLUE (top) and YELLOW (bottom) RHIC rings.

the abort kicker region, as shown in Figure 6. Though the vacuum pressure increases only by a factor 4, it shows a strong correlation with the abort kicker current in the waveform minimum, see Figure 7. This vacuum pressure increase indicates thermal outgassing of the ferrites due to increased temperatures. These increased temperatures alter the kicker impedance and therefore affect the current waveform through the kickers. At the same time, it also reduces the saturation magnetic field of the kickers, resulting in a decreased magnetic field for a given magnet current.

A few days after Run-13 had ended, all PFN tuning modifications were reverted to the initial state. When the kickers were fired, all current waveforms had returned to their nominal, initial state, similar to their appearance in the very beginning of the run, as illustrated in Figure 8. This reversal of effects can therefore be attributed to the ferrites having cooled over the course of several days without beam, which is further proof that all the observed phenomena were indeed caused by beam induced heating of the kicker ferrites.

CONCLUSION

During Run-13 a gradual degradation of the RHIC abort kicker performance was observed. This degradation has been attributed to beam induced heating of the kicker ferrites, thus altering both their impedance and their saturation magnetic field. While the modified impedance changes the

PFN 2 traces

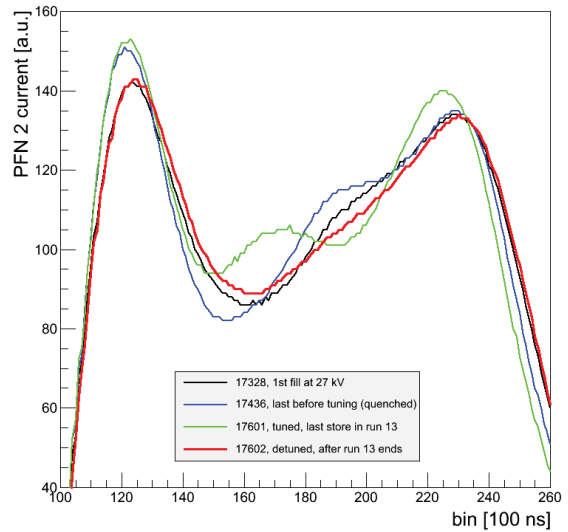


Figure 8: Evolution of the current waveform of PFN module 2 during the course of Run-13 as an example. The black line shows the current waveform for the first full energy store. After a few weeks, this waveform had been modified due to kicker heating, resulting in a lower current in the waveform minimum and subsequent quenches (blue). Retuning of the PFN raised the minimum current (green). A few days after the run ended and the kicker ferrites had cooled off, the tuning modifications were reverted, resulting in the red curve.

magnet current waveform through the kickers, the saturation reduces the resulting magnetic field for a given current. The combination of these two effects led to insufficient kick strength and therefore quenches of the downstream superconducting RHIC magnets. During the 2014 summer shutdown these abort kickers have been re-designed [1]. The CMD5005 ferrites have been replaced with CMD10 material, which has a less temperature dependent saturation curve. The geometry of the eddy current strip has been modified to reduce the kicker impedance and therefore the beam induced heating of the device. Additionally, a liquid cooling system has been added to minimize heating of the ferrites.

REFERENCES

[1] H. Hahn et al., "Design and Test of RHIC CMD-10 Abort Kicker", Proceedings IPAC 2015, Richmond, VA