ABORT GAP STUDIES AND CLEANING DURING RHIC HEAVY ION OPERATION*

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Abstract

Since the RHIC Au-Au run in the year 2001 the 200 MHz cavity system was used at storage and a 28 MHz system during injection and acceleration. The rebucketing procedure causes significant debunching of heavy ion beams in addition to amplifying debunching due to other mechanisms. At the end of a four hour store, debunched beam can account for more than 30% of the total beam intensity. In order to minimize the risk of magnet quenching due to uncontrolled beam losses at the time of a beam dump, a combination of a fast transverse kicker and copper collimators were used to clean the abort gap. This report gives an overview of the upgraded gap cleaning procedure and the achieved performance. The upgraded procedure in conjunction with a new application allows to measure properties of the debunched beam routinely.

INTRODUCTION

While a 28 MHz cavity is used for injection and acceleration in RHIC,thus defining the total number of buckets in RHIC to be 360, a 200 MHz storage system for Au-particles is in use since the 2001 run. Beam debunching of heavy ions is due to a combination of RF failure, rebucketing and IBS [1] and can account for as much as 50% of the total beam. In addition, any species beam can debunch due to RF cavity failures. The two rings, blue and yellow respectively, and the six interaction regions (IR) of RHIC with the four experiments are sketched in figure 1. The abort gap is needed to make sure that the circulating beam is cleanly removed by the abort system [2]. Any significant beam in this abort gap will not be dumped properly and can therefore cause magnet quenches and background peaks for the experiments.

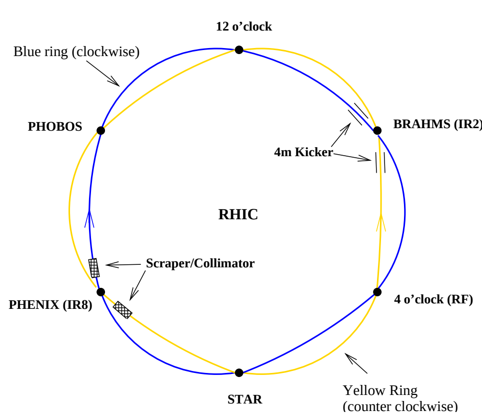

Figure 1: *Location of the kicker and collimators in the RHIC rings.*

HARDWARE

To attack these problems, the existing hardware of the transverse collimators [3] and the transverse kickers used for the tune measurement system [4] are combined. Any beam in the abort gap is excited transversely by the kickers while the collimators are positioned such that they are the limiting aperture in the rings. Figure 1 shows their location in the RHIC ring.

Each ring has one kicker module with four stainless steel striplines, each of which can be powered independently. The pulse voltage cannot be changed. For this application, the kickers are setup to excite beam within the abort gap, buckets 331-360. By selecting a kick frequency close to the horizontal and vertical betatron frequency the beam is kicked resonantly enhancing the effect on the beam significantly if compared with a single or non-resonant kicks. Finding the resonant frequency is crucial for the gap cleaning application and a set point equal to or very close to the betatron frequency was shown to kick bunched beam at storage out of the ring after a few dozens of turns. Typically 300 turns per trigger were used. The horizontal kicks are about 5 times more efficient than the vertical ones due to the different β-functions.

The RHIC collimators [3] consist of 45 cm long L-shaped copper scrapers placed downstream of the PHENIX detector in each ring allowing a positioning resolution of 0.5 μm horizontally and vertically. Four dedicated PIN diode loss monitors and four ion chamber beam loss monitors downstream of each scraper monitor beam losses caused by the collimator.

THE APPLICATION

The new cleaning application supports the two steps of the abort gap cleaning procedure:
(1) excite the debunched beam transversely and
(2) collimate the excited beam with the scrapers.

(1) In order to excite the debunched beam, the tune meter kickers are triggered such that in place of an occupied bucket beam in the abort gap is excited. The kicker is pulsed for 300 turns/trigger with a trigger repetition rate of 1 or 0.25 Hz. To enhance the cleaning efficiency, the frequency has to be as close as possible to the betatron tune of the debunched beam. The new Gap Cleaning application allows a tune scan in the range of suspect, 0.2 to 0.25,

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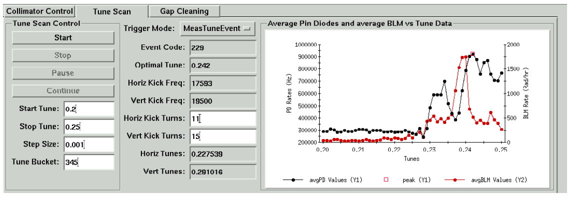

Figure 2: *The application panel to start a tune scan and to find the best resonant tunes for cleaning.*

where the losses at the collimator are recorded as a function of the kicking frequency in terms of betatron tune. Only the horizontal tune is scanned. An example is given in Fig. 2. To monitor the losses we use two independent loss monitor systems, PIN diodes and ion chambers. Once a resonant frequency is found, the application loads it into the gap cleaning procedure. The gap cleaning panel (Fig. 3)

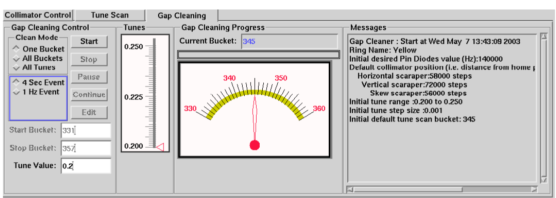

Figure 3: *The application panel to setup the gap cleaning process.*

allows three modes: (i) constant excitation tune and constant bucket, (ii) constant excitation tune but trigger timing is changed to step thru all gap buckets and (iii) constant bucket but excitation tune is varied in a variable range with a variable step size.

(2) At the beginning of the procedure, the scrapers are moved to a predefined position using the collimator control panel of the application (Fig. 4). For fine adjustments, a

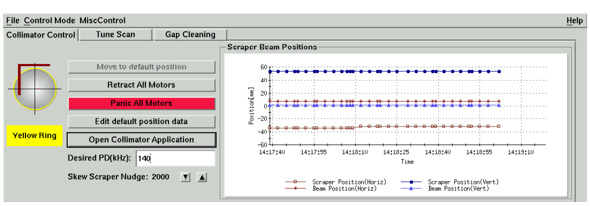

Figure 4: *Collimator control panel of the gap cleaning application.*

"wanted" rate from the PIN diodes, sensitive to scattered particles from the scraper jaw, are used to determine the 'good' location for gap cleaning. To keep high cleaning efficiency, the scraper position typically has to be adjusted a few times during the procedure which lasts approximately 30 minutes.

Regardless of the panel one is working with the application includes a set of convenience graphs as shown in Fig. 5. PIN diodes (top, left) and loss monitors (top, right) are both located downstream of the collimator. Also shown is the amount of debunched current in the blue or yellow

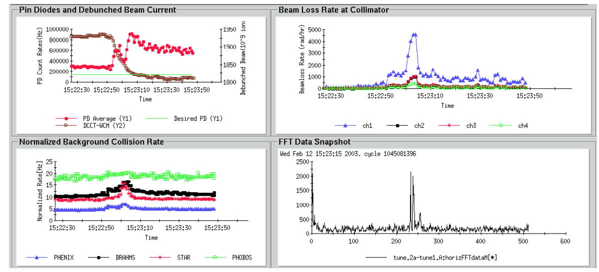

Figure 5: *The convenience graphs as shown in the gap cleaning application during a cleaning procedure on Feb. 12, 03.*

ring in units of 10^9 ions. Note that the tune spectrum (bottom, right) is obtained from debunched beam during the process. Experimental background rates allow monitoring of background increases due to the cleaning procedure while it is in progress. While PHOBOS is unaffected and PHENIX is mildly affected, STAR and BRAHMS see an increase of about 50% during parts of the cleaning.

THE DATA

Table 1 summarizes the magnet quench during the Au run in January and February of 2003. Note that, without RF failures, there is typically no debunching of the blue

Table 1: *RHIC magnet quenches between Jan 01 and Feb. 28 03, caused by either beam dump or aborts involving significant debunched beam I_{deb}.*

fill	**Ring**	$I_{deb.}$ **Blue**	**Yellow**	**cause**
		$[10^{11}$ d]	$[10^9$ ions]	
2640	Y	-	2	abort kicker
2736	Y	-	2	beam losses
2766	Y	-	2	beam losses
2769	B/Y	9	12	permit
2780	Y	2	6.7	permit
2803	Y	-	6.6	normal dump
2840	Y	-	42	permit
2852	Y	-	3	abort kicker
2859	B	14.5	1	permit
2884	Y	-	9.5	permit (cryo)
2911	B	0.5	3	abort kicker
2930	Y	-	3.6	abort kicker
2945	Y	-	3.5	abort kicker
2955	B/Y	0	8	abort kicker
2982	Y	-	5.5	permit
3006	B	3.5	4.3	permit
3011	Y	-	3.5	beam losses
3061	Y	-	20	permit

beam since it corresponds to deuterons. Accordingly there are much less blue quenches recorded. There are mainly three conditions under which debunched beam can lead to magnet quenches: (i) **abort kicker** prefires, (ii) **normal dump**s and (iii) **permit** pulls for any reason related or unrelated to the debunched beam. Note that abort kicker prefires will, if out of time, lead to quenches without any debunched beam present. In addition to this, high bunched **beam losses** will cause magnet quenches regardless of the amount of debunched beam in the machine.

With one exception (2955) all abort kicker prefires happened at times when the amount of debunched beam alone would not have caused a quench. However, the abort kicker not only prefired but also missed the gap, thus causing an enormous amount of beam losses in certain areas. In fills 2736, 2766 and 3011, the cause of the magnet quenches is most likely the bunched beam loss itself since $I_{deb} \leq 3.5\ 10^9$ Au ions in all three cases. There are 10 candidates left during a period of 2 months were the presence of debunched beam is most likely responsible for the quench. This corresponds to 30% of all recorded real magnet quenches in the two months and to about 10% of all stores during that period. One fill, 2803, ended with a quench because of a regularly initiated dump, ignoring the amount of debunched beam. In fill 3006 the blue magnet quench happened due to a gap cleaning procedure failure. The remaining 8 fills ended with a magnet quench because the permit tripped prematurely before the debunched beam could be removed. $I_{deb} \geq 5.5\ 10^9$ Au ions in all these fills. It should be discussed if loss monitor trip levels could be either disabled or increased significantly if $I_{deb} \geq 5.0\ 10^9$ Au ions. However, there were fills (for instance 2801) which ended without a magnet quench although they had a little more debunched Au beam than this limit. For deuteron beam the statistic is very small since deuteron beams mainly debunch due to RF failures. There is no quench case recorded with $I_{deb} < 9\ 10^{11}$ d but at least one case (fill 2801) where $I_{deb} = 8\ 10^{11}$ d without causing a quench. Therefore, the sustainable limit for debunched deuteron beam seems to be higher, around $I_{deb} = 8\ 10^{11}$ d.

Figure 6, bottom, shows the RHIC yellow beam currents at the end of store 2887. The difference between the total beam, measured by the DCCT [5] and the bunched beam current,measured by the WCM [6], corresponds to the debunched beam. It amounts to 17.5 10^9 Au ions or 63% when the cleaning procedure is started around 17:20. The procedure is stopped after about 35 minutes. Every tune measurement (top of fig. 6) indicates a trigger event for the beam excitation in the abort gap. Note that during the beginning of the procedure, tunes can actually be measured by coherent oscillations of the debunched beam. Tunes are in the order of 0.23 during this example. The cleaning rate here is a record of $0.44 10^9$ ions/minute. After pausing for about one hour gap cleaning is resumed and the beam is dumped without problems around 19:00. In general, cleaning rates in 2003 were around 0.22 10^9 for Au ions and around 0.15 10^{11} for d. The rates vary from fill to fill and depend strongly on the cleaning efficiency. However, the average for heavy ions could be increased by a factor of about 1.8 compared to the last Au-Au run [7].

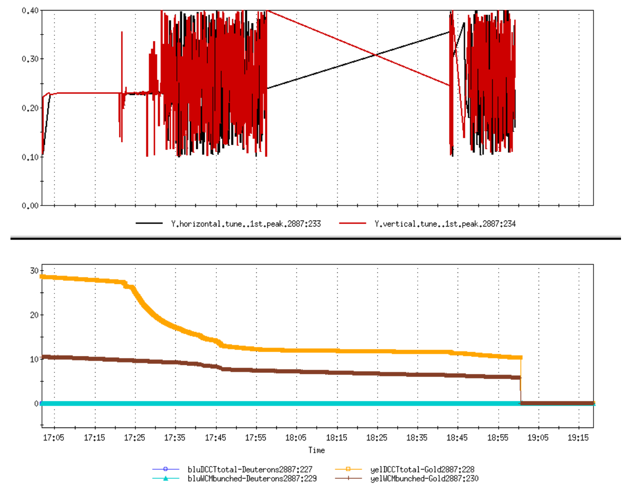

Figure 6: *Top: Tune measurements as a function of time during the end of store 2887, Feb. 03 03. Bottom: Bunched and total yellow beam current as a function of time during the same store.*

CONCLUSION

With the new gap cleaning application the efficiency of the procedure could be almost doubled compared to last year and is found to be 0.22 10^9 Au ions/minute and 0.15 10^{11} d/minute on average. Still, a total of 10 fills, i.e. about 10% of all stores in the examined period of dAu running, ended by a magnet quench due to debunched beam. This number corresponds to 30% of all recorded real magnet quenches. However, 7 of them were caused by premature loss monitor permit trips and disabling or increasing the loss monitor trip level could help avoiding these cases. The sustainable limit for debunched Au beam could be confirmed to be $5.0\ 10^9$ and a preliminary limit for deuterons was found to be $8\ 10^{11}$.

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