BNL-79903-2008-CP

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Presented at the 11th Biennial European Particle Accelerator Conference (EPAC 2008)
Genoa, Italy
June 23-27, 2008

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DISCLAIMER

ANALYSIS OF INTENSITY INSTABILITY THRESHOLD AT TRANSITION IN RHIC*

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Abstract

The beam intensity of ion beams in RHIC is limited by a fast transverse instability at transition, driven by the machine impedance and electron clouds. For gold and deuteron beams we analyze the dependence of the instability threshold on beam and machine parameters from recent operational data and dedicated experiments. We fit the machine impedance to the experimental data.

INTRODUCTION

In RHIC all ions with the exception of protons cross the transition energy when they are accelerated to full energy. The beam intensity that can be accelerated through transition is limited by transverse instabilities. Fast (compared to the synchrotron period of 100 ms) transverse instabilities were observed already in the first year of RHIC operation [1]. The instability could be characterized as a single bunch phenomenon with growth times of 15 ms and 120 ms [2]. Data from button BPMs reveal frequencies up to 3 GHz [4] (also see below). The instability is driven by the machine impedance, and enhanced by electron clouds which form at transition because the bunch length is shortened. Since electron clouds lower the intensity instability threshold, beam losses occur first at the end of bunch trains (see Fig. 1), and parts of the longitudinal distribution are removed (see Fig. 2). To stabilize the beam a γ_t-jump ($\Delta\gamma_t = 1$ in 30 ms) is implemented, sextupole settings are carefully controlled, and octupoles are turned on during the jump [1].

Table 1: Comparison of Yellow Au beam transition crossing in Run-7 (2007, Au in Blue ring) and Run-8 (2008, *d* in Blue ring). Parameters are for Au beam in the Yellow ring.

parameter	Unit	Run-7	Run-8
no of ramps for comparison	...	60	60
ramps with instability losses	%	45	5
ramps with detected coherence	%	13	58
number of bunches	...	103	95
average bunch intensity, before	10^9	1.07	0.98
transition γ_t	...	22.8	26.6
gap voltage	kV	150	150
synchrotron frequency, after	Hz	8.9	6.7
bunch length, before (FWHM)	ns	6.4	6.5
bunch length, after (FWHM)	ns	10.3	7.1
octupole strength	m^{-3}	-5	$-6...-12$

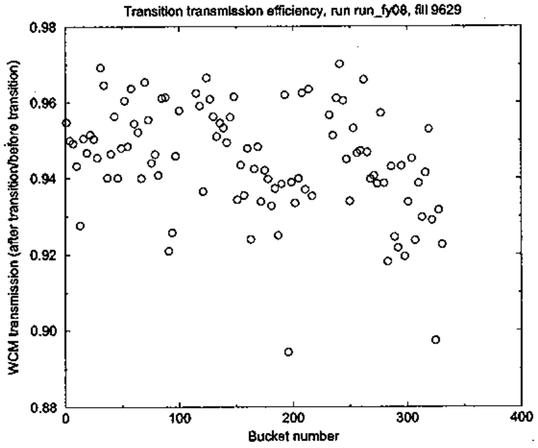

Figure 1: Transition transmission of Au bunches as a function of the location in the bunch train. The ring was filled with 3 trains separated by 3 long gaps (Run-8 non-operational test ramp).

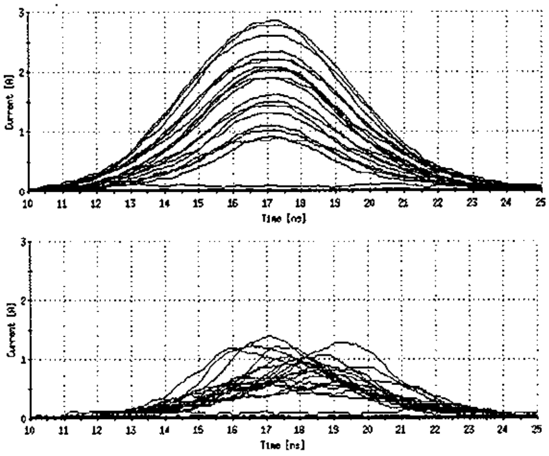

Figure 2: Longitudinal profiles of deuteron (*d*) bunches of different intensities in Run-8 before (top) and after (bottom) crossing transition (no octupoles).

In Tab. 1 the main gold (Au) transition crossing parameters are shown for the last 60 ramps in Run-7 (2007) [5] and Run-8 (2008) [6]. In both runs there was Au beam in the Yellow ring. The Blue ring had Au beam in Run-7 and deuteron (*d*) beam in Run-8. In Run-8 a different lattice was used for the Au beam, which has higher phase advances and reduced IBS growth rates [7], also resulting in a higher γ_t. With this the two beams crossed γ_t at different times in Run-8 allowing for a better radius control in the Yellow ring. To avoid modulated long-range beam-

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* Work supported by US DOE under contract DE-AC02-98CH10886.
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beam effects during the ramp the Yellow rf frequency is locked to the Blue rf frequency, and both the Blue and Yellow rf frequency control also have input from the radial loop. If transition in Blue and Yellow is crossed at the same time, it is difficult for the Yellow frequency control to satisfy both conditions, lock to the Blue frequency (which also responds to the Blue radial error) and respond to the Yellow radial error.

In Run-7 45% of the last 60 ramps showed transition losses like those shown in Fig. 1, in Run-8 only 5%. A coherence monitor (fast orbit rms, see Ref. [2]) detected coherent beam motion in 13% of these ramps in Run-7, and 58% in Run-8. For most of the ramps analyzed in Run-8 the coherence monitor was monitoring the last bunch in the train, usually most vulnerable because the electron cloud density reaches its maximum at the end of the bunch train. In Run-7 the coherence monitor was monitoring the most intense bunch. In Run-8 an additional transition monitor was available, confirming that some bunches were unstable on almost every ramp [8].

In Run-8 more attention was paid to avoid emittance growth due to instabilities out of concerns over mismatched beam sized at store that could reduce the Au beam lifetime (the d beam has IBS growth rates an order of magnitude smaller than the Au beam). This led to fewer bunches with reduced bunch intensity (Tab. 1). A test ramp in Run-8 with the same number of bunches, the same bunch pattern, and the same bunch intensity also showed the transition losses that were observed in Run-7 (Fig. 1).

With the different operational parameter sets for Run-7 and Run-8, and only a single ramp for direct comparison, no discernible difference in the intensity instability threshold at transition can be established.

INSTABILITIES DRIVEN BY THE MACHINE IMPEDANCE

In Run-8 a test ramp was done with only 20 bunches of varying deuteron bunch intensity and zero octupole strength at transition to determine the instability threshold under these conditions. The bunch spacing of 630 ns, 6 times larger than in operation, suppressed the electron cloud formation at transition, so that the instability would be driven by the machine impedance only. Figure 3 shows the transition transmission as a function of the bunch intensity, with an instability threshold of $0.55 \times 10^{11} d$. The longitudinal profiles, shown before and after transition in Fig. 2, can be fitted to a Gaussian profile with an rms bunch length of $\sigma_t = 2.35$ ns.

We used the code MOSES [9] to fit an impedance to the observed instability threshold, assuming a transverse mode-coupling instability (TMCI). A TMCI was also observed in the SPS [11]. For the case without tune spread in the beam, a broadband impedance of 2 MΩ/m shows mode coupling for the observed intensity instability threshold (Fig. 5). This compares with a broadband impedance of 3-5 MΩ/m determined in an earlier measurement [10].

However, since the fastest observed rise time (15 ms) is short compared to the synchrotron period ($\approx$ 100 ms) the instability in our case may be better described by beam breakup rather than mode coupling. Figure 4 shows a difference signal from a button BPM showing an unstable bunch with a frequency of 2 GHz.

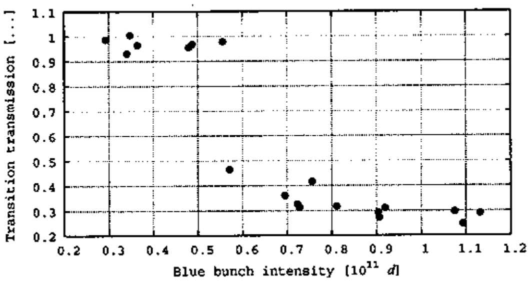

Figure 3: Blue transition transmission of deuteron bunches as a function of intensity and for zero octupole strength.

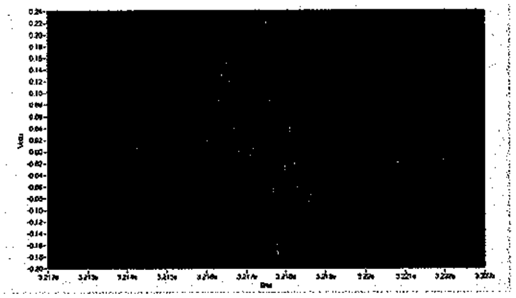

Figure 4: Difference signal from a button BPM showing an instability with a frequency of 2 GHz. The horizontal scale spans 11 ns. (Run-8 non-operational test ramp with d.)

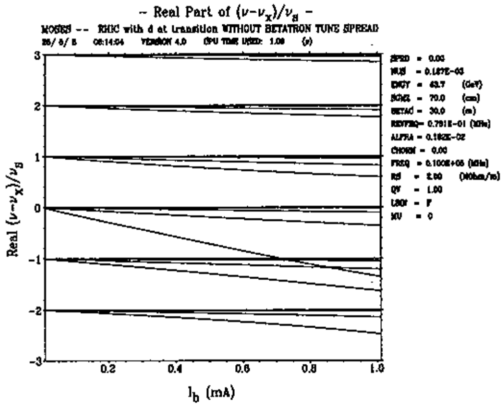

Figure 5: MOSES [9] output showing mode coupling for $I_b = 0.7$ mA, corresponding to 0.55×10^{11} d/bunch, the instability threshold found experimentally without octupoles and zero chromaticity. A broadband impedance with 2 MΩ/m and $Q = 1$ is used.

PARAMETER DEPENDENCE OF INSTABILITIES IN OPERATION

To increase the instability threshold in operation the sextupole and octupole settings at transition can be changed as well as the bunch pattern if fewer than the maximum number of bunches are used.

To avoid head-tail instabilities the sextupole families are set such that the chromaticity is negative before and positive after transition. The chromaticity measurement near transition is difficult and the exact time of the zero crossing is not known. In previous runs it was found that crossing zero chromaticity earlier, presumably before transition, is advantageous.

During a couple of ramps in Run-8, a transverse instability 250 ms after transition was observed by the coherence monitor. The chromaticity is anchored in two "stepstones" 2 s before and after transition, and interpolated linearly inbetween. The chromaticity set points increase by 10 units between these two stepstones, resulting in a chromaticity slope $d\xi/dt = 2.5\,s^{-1}$. To overcome the instability, the chromaticity set points before and after transition were increased by one unit, thus shifting the zero crossing time 400 ms earlier. On subsequent ramps, no instability was observed on the coherence monitor; however, the resulting beam emittance at store was larger than before the chromaticity change.

In Run-7 a pattern with 2 long gaps in the train was used, in Run-8 a pattern with closer to uniform distribution of the gaps. From simulation a smaller electron cloud density is expected for the latter case [12]. With the number of bunches close to the maximum in both cases the difference is not expected to be large.

During Run-8 the octupole strengths in the Yellow ring were increased at transition to suppress the instabilities. Figure 6 shows the octupole strength together with total Au beam intensity at transition and the average emittance of the beginning of the store. The average emittance is calculated from the luminosity and the beam currents and averages over both transverse planes of both beams. For Au beam with a normalized emittance of 12 mm·mrad, an octupole strength of $-10\ m^{-3}$ creates a tune shift of 0.0093 at the rms beam size.

In Fig. 6 one can see that the increase of the octupole strength around fill number 9550 led to a reduction of the initial store emittance and that the decrease of the octupole strength before fill number 9600 increased the emittance again. However, even with the large tune spread coherent beam motion was still detected in more than half of all ramps (see Tab. 1) indicating that at least a few bunches were still unstable. The octupole strength was not increased further over concerns of single particle losses due to the large tune spread. With a few exceptions for bunch intensities below 0.94×10^9 Au ions no coherent beam motion was detected, between 0.94 and 1.03×10^9 bunches were either stable or unstable, and above 1.03×10^9 bunches were generally unstable.

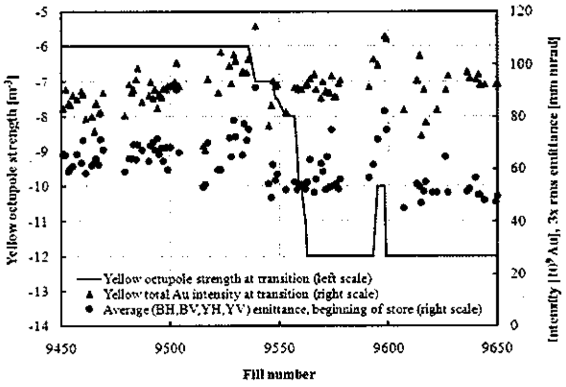

Figure 6: Average beam emittance at the beginning of d-Au stores for a number of fills during which the Yellow octupole strength and beam intensity was changed.

SUMMARY

With somewhat different operational parameters for Au beams in Run-7 and Run-8 no discernible intensity instability threshold can be established for the observed fast transverse instabilities at transition.

From a test ramp with deuteron beams and no octupoles a broad band impedance of 2 MΩ/m was found to reproduce the intensity instability threshold assuming transverse mode coupling. This compares with a transverse impedance of 3-5 MΩ/m found in an earlier measurement [10].

During operation in Run-8 the octupole strength was increased to create a tune shift of up to 0.01 at an rms beam size. With this instability losses could be suppressed and the average emittance growth reduced. However, the large tune spread is a concern for the single particle stability and even with the large tune spread some bunches are still unstable.

ACKNOWLEDGMENTS

The authors are thankful to T. Satogata for help with the data processing, and to E. Metral and G. Rumolo for help with MOSES and discussions on instability issues.

REFERENCES

[1] C. Montag et al., Phys. Rev. ST – Accel. Beams 5 084401 (2002).
[2] M. Blaskiewicz et al., PAC'03, pp. 3026-3028 (2003).
[3] F. Zimmermann, Phys. Rev. ST – Accel. Beams 7 124801 (2004).
[4] V. Ptitsyn, private communication (2007).
[5] A. Drees et al., PAC'07, pp. 722-724 (2007)
[6] C.J. Gardner et al., WEPP011, these proceedings.
[7] V. Litvinenko, private communication.
[8] P. Cameron, private communication.
[9] Y.H. Chin, CERN/LEP-TH/88-05 (2005).
[10] S.Y. Zhang et al., EPAC'02, pp. 1112-1114 (2002).
[11] G. Arduini et al., PAC'07, pp. 4162-4164 (2007).
[12] W. Fischer and V. Ptitsyn, BNL C-A/AP/295 (2007).
[13] M. Blaskiewicz et al., EPAC'02, pp. 1488-1490 (2002).