BROOKHAVEN
NATIONAL LABORATORY

BNL-72020-2004-CP

Bunch Patterns and Pressure Rise in RHIC

W. Fischer, U. Iriso-Ariz

Presented at the 9th European Particle Accelerator Conference
Lucerne, Switzerland
July 5-9, 2004

July 2004

Collider-Accelerator Department

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

Managed by
Brookhaven Science Associates, LLC
for the United States Department of Energy under
Contract No. DE-AC02-98CH10886

FOR UNCLASSIFIED, UNLIMITED STI PRODUCTS

Available electronically at-

OSTI:

http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper from-

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(865) 576-8401
Facsimile: (865) 576-5728
E-mail: reports@adonis.osti.gov

National Technical Information Service (NTIS):

Available for sale to the public from-

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22131
(800) 553-6847
Facsimile: (703) 605-6900
Online ordering: http://www.ntis.gov/ordering.htm

Printed on recycled paper

Submitted to EPAC '04, Luzerne, Switzerland, July 5-9, 2004

BUNCH PATTERNS AND PRESSURE RISE IN RHIC*

W. Fischer† and U. Iriso,
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

The RHIC luminosity is limited by pressure rises with high intensity beams. At injection and store, the dominating cause for the pressure rise was shown to be electron clouds. We discuss bunch distributions along the circumference that minimize the electron cloud effect in RHIC. Simulation results are compared with operational observations.

INTRODUCTION

In 2001 first tests were made to increase the bunch number in RHIC from 56 to 112. However, injection of many high-intensity bunches lead to unacceptable pressure rises in a number of warm locations [1, 2]. Since then continuous improvements were made to the vacuum system, but pressure rises are still observable with intense beams [3, 4]. In addition, 11 electron detectors were installed in 2 interaction regions. With these electron clouds could be observed concurrently with pressure rises [5].

During the 2002/2003 deuteron-gold run, RHIC was routinely operated with 110 bunches (108 ns spacing) in both beams from mid January to the end of February 2003. However with increasing bunch currents, backgrounds in all experiments became an issue. The background in PHOBOS improved when the bunch number was reduced again to 55 (216 ns spacing). During the 2003/2004 gold-gold run a pressure rise in PHOBOS could often be observed after the bunches were shortened in store [6]. The observations are consistent with electron clouds as the driver for the observed pressure rise.

In the following we investigate how a given number of bunches bunches should be distributed along the circumference to minimize the electron cloud density [7]. To describe bunch patterns we will use triplets of integer numbers (k_s, k_b, k_g). k_s gives the bunch spacing in buckets, k_b the number of bunches filled with that spacing, and k_g the number of "phantom" bunches added, i.e. bunches that are not filled in and therefore create a gap. Changing patterns can then be described by adding a new triplet. For example the configuration (2,2,1)(3,4,0) would correspond to the pattern

1-0-1-0-0-0-1-0-0-1-0-0-1-0-0-1-0-0

where 1 denotes a filled and 0 denotes an empty bucket. If not otherwise noted, it is assumed that a pattern repeats until the abort gap is reached.

* Work performed under the auspices of the US Department of Energy.
† Wolfram.Fischer@bnl.gov
contract # DE-AC02-98CH10886

ELECTRON CLOUD SIMULATIONS

Up to the 2002/2003 run only bunch patterns with constant bunch spacings could be implemented. 56 bunches had 6 buckets spacing, 112 bunches had 3 buckets spacing. However, to maximize the luminosity below the beam-beam limit, it is best to maximize the bunch intensity first, and the bunch number second. Thus bunch numbers between 56 and 112 may be desirable. We chose 68 bunches for the following investigation, which would yield a luminosity increase of 20% over 56 bunches. In our simulations, 68 bunches is also at the border of stability with respect to electron clouds. Small reductions in, for example, the secondary emission yield or electron reflectivity at small energies result in complete suppression of electron clouds.

The computer code CSEC was used to simulate the effect of different bunch patterns on the evolution of electron clouds. CSEC was written by M. Blaskiewicz, a description of the code can be found in Ref. [8]. To compare the effect of different bunch patterns on the vacuum, we assume the pressure is a monotonic function of the maximum elec-

Table 1: List of input parameters for electron cloud simulations. A detailed description of these parameter can be found in Ref. [7].

parameter	unit	value
bunch spacing	ns	108/216
beam offset	mm	0
bunches	...	68
rms beam radius	mm	2.4
pipe radius	mm	60
electrons generated/bunch	...	35000
electron generation radius	mm	60
full bunch length	ns	15
bunch shape parameter n	...	3
bunch charge	nC	12.6
longitudinal slices	per turn	108000
macro-particles, initially	...	25
smoothing length d	mm	1.0
ρ_{ce}, initial	pC·m^{-1}	0.2
P_0[10, 11]	...	0.6
P_∞	...	0.2
$E_{\rm reflect}$	eV	60
$P_{\rm rediffuse}$	...	0.5
δ_{max}	...	2.1
E_{max}	eV	310
$E_{\rm secondary}$	eV	8.9
α_δ	...	1.0
α_θ	...	1.0

Table 2: Comparison of bunch patterns tested in simulations.

parameter	unit	case no 1	case no 2	case no 3	case no 4	case no 5
bunch pattern	...	(3,68,52)	(3,23,17)	(3,12,8)	(3,4,0)(6,8,0)	(3,2,0)(6,4,0)
no of bunches	...	68	68	68	68	68
bunch intensity N_b	10^9Au	1.0	1.0	1.0	1.0	1.0
total intensity	10^9Au	68.0	68.0	68.0	68.0	68.0
maximum line density ρ_{max}	nC/m	0.92	0.67	0.28	0.22	0.20
average line density ρ_{ave}	nC/m	0.30	0.14	0.10	0.10	0.09

tron line density ρ_{max} or the average electron cloud line density ρ_{ave}, i.e. we search for the bunch pattern that minimizes ρ_{max} and ρ_{ave}. This disregards variations in the electron current into the wall, and variations in the energy spectra of the electrons with the different bunch patterns. However, one can reasonably assume that the current into the wall and the electron energies increase with the electron line density [9].

Five cases were simulated, each with 68 bunches, but in different bunch patterns. The basic parameters used in the simulations are shown in Tab. 1 (see Ref. [7] for a detailed description of these parameters). Assuming Au^{79+} as particle species, all cases showed electron cloud suppression for $N_b = 0.8 \cdot 10^9$; and sustained electron clouds for $N_b = 1.0 \cdot 10^9$. The cases are summarized in Tab. 2.

In the first case (Fig. 1) all 68 bunches are concentrated at the beginning of a turn, the pattern is (3,68,52). The electron cloud line density saturates within less than half a turn and reaches a maximum of 0.92 nC/m. The average line density is 0.30 nC/m. In the second case bunches are places in 3 trains with the pattern (3,23,17). The maximum electron cloud line density is reduced to 0.67 nC/m, and the average to 0.14 nC/m. In the third case the bunches are distributed in 6 trains with the pattern (3,12,8). The maximum electron cloud line density reaches only 0.28 nC/m, and the average only 0.10 nC/m after reaching a stationary state. In the fourth case, 6 mini-trains with 3 buckets spacing are inserted in a pattern with 6 buckets difference between bunches, for a pattern of (3,4,0)(6,8,0). The maximum line density is again reduced, to 0.22 nC/m, while the average changed only little. In the fifth case (Fig. 2), the bunches are distributed in the most uniform way around the circumference, with the pattern (3,2,0)(6,4,0). For this case the maximum and average line densities are reduced again, although only by a small amount compared to case three.

Both the peak line density and the average electron cloud line density are maximized if the bunches are concentrated in a single train of minimum bunch spacing, and minimized if the bunches are uniformly distributed around the circumference (see Tab. 2). With RHIC's six-fold symmetry, the bunch pattern must also have a three-fold symmetry to have approximately the same number of collision in all experiments. (Due to the abort gap some experiments have about 10% less bunch-bunch collisions than other experiments.)

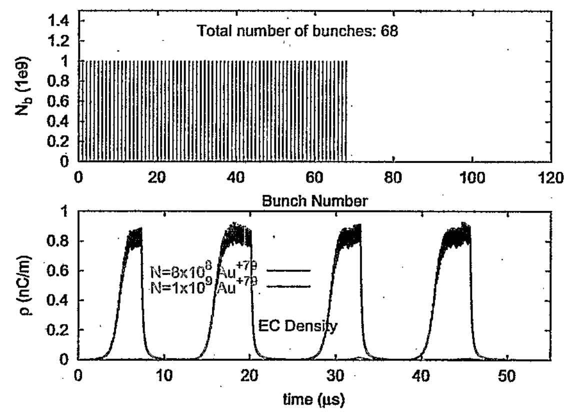

Figure 1: Simulated electron cloud evolution for 68 bunches over 4 turns (lower part). In the upper part the pattern (3,68,52) is shown over one turn. Note that the upper and lower part have different time scales.

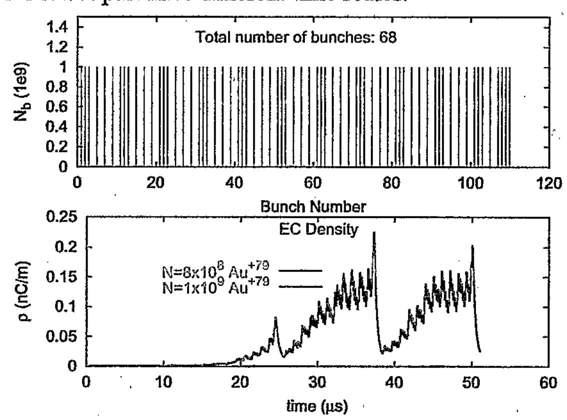

Figure 2: Simulated electron cloud evolution for 68 bunches over 4 turns (lower part). In the upper part the pattern (3,2,0)(6,4,0) is shown over one turn. Note that the upper and lower part have different time scales.

OPERATIONAL EXPERIENCE

In deuteron-gold operation during Run-3 (2002/03), the background at the PHOBOS experiment could be reduced by reducing the bunch number from 112 to 55. However, other parameters were changed at the same time [7]. The PHOBOS beam pipe is 12 m long, of 3.6 cm radius, and made of beryllium.

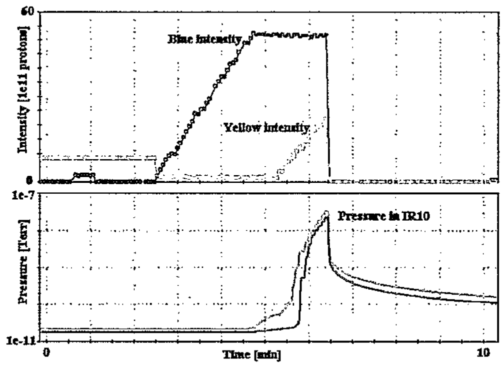

Figure 3: Injection of 30 proton bunches in the Blue ring and 24 bunches in the Yellow ring, with 3 buckets spacing. The pressure in IR10 reaches $3 \cdot 10^{-3}$ Torr.

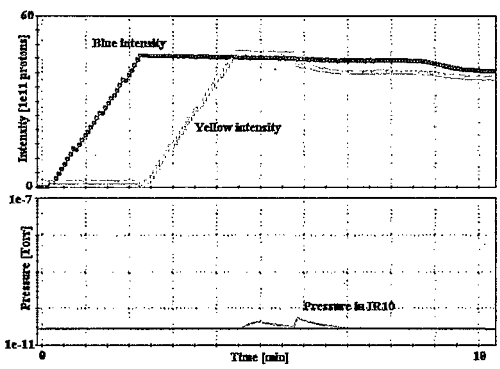

Figure 4: Injection of 28 proton bunches in the Blue and Yellow ring with 12 buckets spacing. The total intensity of both beams in IR10 exceeds the one shown in Fig. 3 yet the pressure stays below 10^{-10} Torr.

For Run-4 (2003/2004) flexible bunch patterns were implemented [15]. During gold-gold operation in Run-4 a reduction in the bunch number from 61 to 56, and an increase in the bunch intensity, allowed to reduce the PHOBOS background while maintaining the luminosity [6]. While the background problem was suppressed for some time, a further reduction in the bunch number to 45 became necessary later. Even under these the conditions, pressure rises could only be suppressed in about half the stores.

The clearest experimental observation supporting our conclusion from the simulations is shown in Figs. 3 and 4. Fig. 3 shows the injection of 30 proton bunches in the Blue ring and 24 bunches in the Yellow ring, with 3 buckets spacing. The pressure at the PHOBOS experiment in IR10 reaches $3 \cdot 10^{-8}$ Torr. Fig. 4 shows the injection of 28 proton bunches in the Blue and Yellow ring with 12 buckets spacing. The total intensity of both beams in IR10 exceeds the one shown in Fig. 3 yet the pressure stays below 10^{-10} Torr. Thus, uniform bunch distributions are clearly favorable to suppress electron cloud effects. This is consistent with observations at the B-factories [12, 13, 14].

SUMMARY

We analyzed the effect of different bunch patterns on the electron cloud density and vacuum in simulations and experimentally. Our simulations show that bunch patterns with the most uniform distributions of bunches along the circumference minimize the pressure rise. This conclusion is supported by the available experimental data. Due to RHIC's 6-fold symmetry, the bunch pattern must also have a 3-fold symmetry to provide approximately the same number of collisions to all experiments.

ACKNOWLEDGEMENTS

The authors are thankful for discussions with M. Blaskiewicz, F.-J. Decker, M. Furman, H.C. Hseuh, K. Ohmi, S. Peggs, G. Rumolo, T. Satogata, P. Thieberger and S.Y. Zhang.

REFERENCES

[1] S.Y. Zhang, "RHIC Vacuum Pressure Bump", BNL C-A/AP/67 (2002).

[2] W. Fischer et al., "Vacuum Pressure Rise with Intense Ion Beams in RHIC", EPAC 2002, Paris, BNL-68937 (2002).

[3] H. Hseuh, et al., "Improvement of RHIC Warm Beam Vacuum for High Intensity Operation", PAC 2003, Portland, Oregon (2003).

[4] S.Y. Zhang et al., "RHIC Pressure Rise and Electron-Cloud", PAC 2003, Portland, Oregon (2003).

[5] U. Iriso-Ariz et al., "Electron Cloud and Pressure Rise Simulations for RHIC", PAC 2003, Portland, Oregon (2003).

[6] G. Rumolo and W. Fischer, "Observations on background in PHOBOS and related electron cloud simulations", BNL C-A/AP/146 (2004).

[7] W. Fischer and U. Iriso-Ariz, "Bunch patterns and pressure rise in RHIC", BNL C-A/AP/118 (2003).

[8] W. Fischer, J.M. Brennan, M. Blaskiewicz, and T. Satogata, "Electron Cloud Measurements and Simulations for the Brookhaven Relativistic Heavy Ion Collider", Phys. Rev. ST Accel. Beams 5, 124401 (2002).

[9] M. Blaskiewicz, private communication (2000).

[10] M.A. Furman and M. Pivi, "Microscopic probabilistic model for the simulation of secondary electron emission", LBNL-49711, CBP Note-415 (2002).

[11] B. Henrist et al., "Secondary Electron Data for the Simulation of Electron Cloud", proceedings of the ECLOUD'02 Workshop at CERN, CERN Yellow Report CERN-2002-001 (2002).

[12] K. Ohmi, M. Tawada, and Y. Funakoshi, "Collision with finite crossing angle at KEKB", proceedings of the workshop Beam-Beam'03, Montauk, New York, AIP conference proceedings, to be published (2003).

[13] W. Kozanecki et al., "Beam-Beam Performance of the SLAC B-Factory", proceedings of the workshop Beam-Beam'03, Montauk, New York, AIP conference proceedings, to be published (2003).

[14] F.-J. Decker, A. Kulikov, M. Sullivan, "Bunch Pattern By-3 in PEP-II", PAC 2003, Portland, Oregon (2003).

[15] J.M. Brennen, J. Delong, T. Hayes, T. Le, L. Hoff, and F. Severino private communication (2003).