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ANALYSIS OF BEAM INDUCED PRESSURE INCREASES IN RHIC WARM VACUUM SECTIONS*

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Abstract

With increasing intensity of gold and proton beams during recent RHIC operations, pressure rises of several decades were observed at a few RHIC warm vacuum sections. The pressure increases were analyzed and compared with the beam parameters such as ion species, bunch intensity, total intensity, number of bunches, bunch spacing and beam loss. Most of these pressure increases were found to be consistent with those induced by either beam loss and/or electron multipacting.

1. INTRODUCTION

RHIC has a circumference of 3.8 km and comprises two interweaving rings (named yellow ring and blue ring) that intersect with each other at six locations. The total length of room temperature (warm) sections is approximately 1.4 km, consisting of 24 insertion regions, 12 final focusing regions and six interaction regions (called IP). The design vacuum of warm sections is < $5x10^{-10}$ Torr. The beam-gas lifetime, dominated by nuclear scattering with cross sections of ~10^{-24} cm^2 for Au, is several hundred hours at the design vacuum level, much longer than the ten-hour intra-beam scattering lifetime [1]. Background noise to detectors, due to beam-gas events in warm sections bracketing the experimental detectors puts more stringent requirement on RHIC beam vacuum systems [2].

The warm sections are pumped by ion pumps and titanium sublimation pumps, and monitored with cold cathode gauges (CCG) every 10 m. Most of the warm sections are in-situ bakeable to 250°C. The average pressures of the warm sections have reached below the design vacuum level, owing to gradual bakeouts of these sections over the last three years.

No notable changes in pressure were observed during the 1999 beam commissioning and the 2000 collider operation. However, pressure rises of several decades were measured during 2001 high-intensity Au and proton runs. These rapid pressure rises sometimes exceeded the CCG set points for gate valve interlocks and aborted the beams. The pressure rises were especially prominent during 110-bunch gold injection and became one of the major intensity-limiting factors for RHIC operation. Using logged CCG data and beam current monitor readings, the pressure rises in a few ramps were analyzed and discussed within the frame work of ion desorption, electron multipacting and direct beam loss.

2. PRESSURE RISES

2.1 Au Runs

Several types of pressure rises were observed during the 2001 Au run. Typical cases of pressure rises during stable ramps and stores for 55-bunch mode (with ~ 200 nsec bunch spacing) are shown in Fig. 1 where the initial bunch intensity was ~ $6x10^8$ Au^{+79}. The pressure of some unbaked sections would increase by a decade or less and then gradually decrease as the stored beam current fell. There were no notable pressure rises in most baked sections, e.g. IP10.

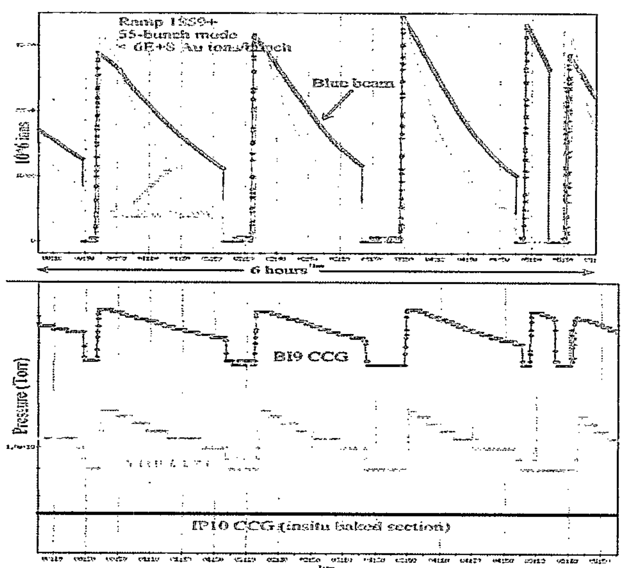

Fig. 1 Pressure rises during stable Au beam operation.

However, once the bunch intensity was raised beyond $8x10^8$ ions or when RHIC operated in 110-bunch mode (with ~ 100 nsec bunch spacing), rapid pressure rises of a few decades were observed during injection and ramp, particularly at several specific warm sections. Typical cases are shown in Fig. 2 for both 55- and 110-bunch modes. With 110-bunch mode (left side of figure), the pressure started to increase at $1x10^{10}$ ions for BO11 (blue ring outer 11 o'clock insertion region). The pressure

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exceeded the CCG set points after only 39 bunches were injected, which caused the beam to be aborted by a vacuum interlock. No changes in pressure were observed at IP12. The other important observation is that the pressure would peak at constant intensity, then reached another plateau with further injection.

The pressure rise in BO11 with the 110-bunch mode was much higher than that of 55-bunch mode (right side) even though the total intensity was much lower. The pressure at IP12 remained unchanged till the total current (sum of both B & Y) reached a threshold of ~ $7x10^{10}$ Au ions, then rose sharply and caused a vacuum interlock at a total intensity of $1x10^{11}$ ions.

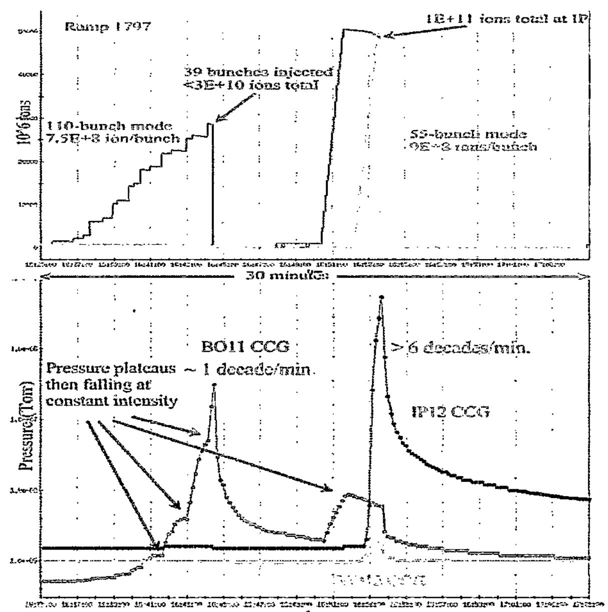

Fig 2. Pressure rises during 110-bunch and high intensity 55-bunch mode Au operations.

2.2 Proton Runs

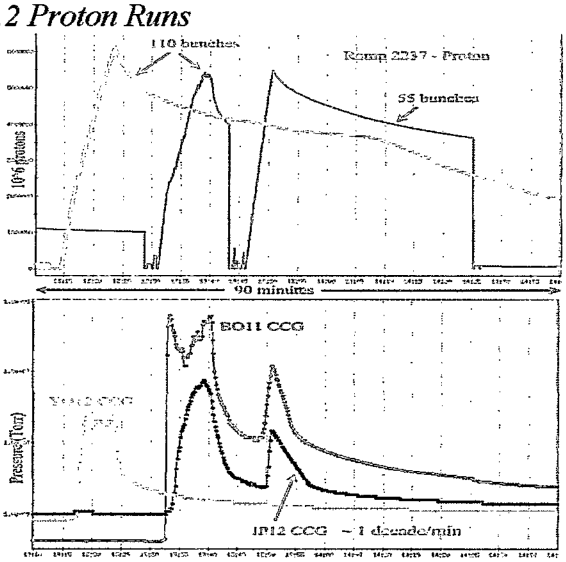

Fig. 3 Pressure rises during proton operation for both 110 – bunch and 55-bunch modes

Pressure rises during proton runs were in general much less than those during Au runs, even with similar total charges. Pressure instability was observed if the proton bunch intensity was raised beyond $8x10^{10}$ or when the machine was operated at 110-bunch mode, as shown in Fig. 3. In 110-bunch mode, the peak pressure of the YO12 was one decade lower than that of BO11 even with similar intensities. At BO11, the peak pressure for 55-bunch mode was much less than that of 110-bunch mode. Similar to the Au run, the intensity threshold for pressure rise at IP12 was ~ $.7x10^{12}$ protons (55 bunches), much higher than those of BO11 and YO12. The pressure fell rapidly with the acceleration. None of the pressure rises during proton runs exceeded the vacuum interlock limits.

3. ANALYSIS OF PRESSURE RISES

3.1 Saturation and Electron Multipacting

There are several potential mechanisms causing the pressure rises. The electrons from beam-residual gas ionization and other sources, heated up by the passing bunches, could bombard the vacuum wall and desorb more electrons and molecules (so-called electron multipacting). Electron multipacting could be very sensitive to bunch spacing and bunch intensity, but less to total intensity, and usually reaches saturation at constant intensity [3]. This is shown in figures 2 and 3 as well as in Fig. 4 below. In this 110-bunch ramp, the bunch intensity was relatively low. There was little increase in pressure in both B and Y, even though the total intensity was one of the highest reached,. This suggests the absence of ion desorption, which would be proportional to total intensity. The rate of pressure rises was usually only a few decades per minute another indication of electron multipacting instead of ion desorption and/or direct beam loss.

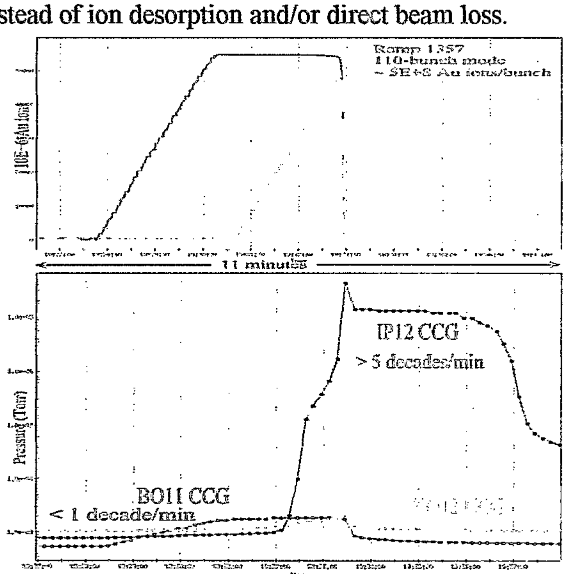

Fig. 4 Pressure rises during medium bunch intensity at 110-bunch mode Au operation suggesting the dependence on bunch intensity more than on total intensity.

3.2 Beam Loss Related Pressure Rise

Grazing-angle beam loss on the wall can desorb large amount of gas molecules [4]. Subsequent ionization by the circulating beam and the resulting electron and ion desorption can generate more gas molecules. A typical case is shown in Fig. 5. No significant pressure rises were observed at these sections until the start of acceleration, when beam loss occurred with a corresponding pressure increase at IP12. The beam loss increased rapidly over the next few seconds with a rapid pressure rise of over 10 decades per minute at IP12 before beam was aborted by the vacuum interlock. Assuming all of the beams were lost at IP12, with a known vacuum volume and no effective pumping at 10^{-5} Torr, ~ 10^{7} molecules were generated per lost ion. This desorption yield of direct beam loss was much higher than others reported [4]. Contribution from electron and ion desorptions could reduce this number somewhat.

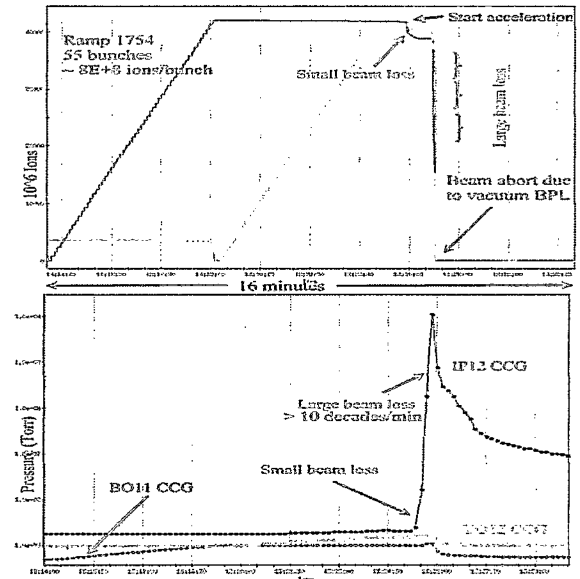

Fig. 5. Direct beam loss induced pressure rises during Au acceleration.

3.3 *Intensity Threshold for Pressure Rise*

The beam intensity threshold of initial pressure rises for Au and proton can be derived from a few high-intensity ramps. A typical case is shown in Fig. 6 for proton runs with 55 bunches. The thresholds for insertion regions BO11 and YO12 are ~ $4x10^{+12}$ protons, while that of IP12 is ~ $7x10^{+12}$, almost twice as high. A summary of thresholds for the start of pressure rises of various modes is shown below. The ratios of the total-charge thresholds between gold and proton beams depend on the bunch intensity therefore are approximate.

	IP	Insertion
P – 55 bunches	$7x10^{12}$	$4x10^{12}$
P – 110 b	$6x10^{12}$	$2x10^{12}$
Au^{+79} ions – 55 b	$7x10^{10}$	$2x10^{10}$
Au^{+79} ions – 110 b	~ $6x10^{10}$	$1x10^{10}$
Au / P charge ratio	~ 0.8	~ 0.4

All the slow (a few decades per minute) pressure rises tended to reach saturation at the end of injection, started to decrease slowly before capture, and then fell rapidly when acceleration began. This could possibly be due to the reduced beam size and beam loss after capture and acceleration, which would not produce enough residual gas ionization to sustain the electron multipacting.

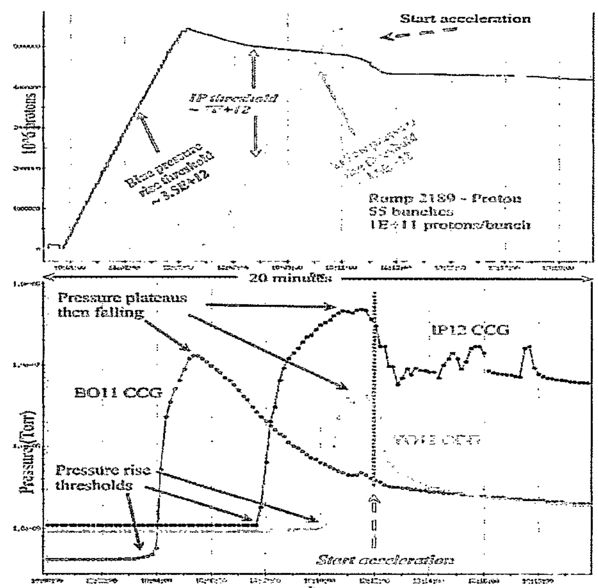

Fig. 6 Pressure rise thresholds for proton beams.

4 SUMMARY

A few recent RHIC ramps were selected to illustrate two different types of pressure rises; one with slow pressure rises of a few decades per minute and usually reaching saturation at constant intensity, and the other with rapid increases of over ten decades per minute resulting in pressure run-away. The first type is more sensitive to bunch intensity and bunch spacing, and is consistent with that of electron multipacting and electron desorption; while the second type is indicative of direct beam loss and subsequent desorption [5].

Electron detectors and solenoids are being installed in a few offending warm sections during the present shut down to measure the electron density and to confine the electrons for the next high intensity run. These measurements will be compared with those of ion desorption, electron multipacting/desorption and direct beam loss [6]. Additional warm sections are also being baked to reduce the desorption yields.

5. ACKNOWLEDGEMENTS

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