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DISCLAIMER

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Abstract

The large scale application of non-evaporable getter coating in RHIC has been effective in reducing the electron cloud. Since beams with higher intensity and smaller bunch spacing became possible in operation, the emittance growth is of concern. Study results are reported together with experiences of machine improvements: saturated NEG coatings, anti-grazing ridges in warm sections, and the pre-pumping in cryogenic regions.

INTRODUCTION

Over several years, significant improvements have been achieved in the reduction of electron clouds (EC) and dynamic pressure rises at RHIC. However, these remain factors that can limit the luminosity. After the electron cloud was identified as the main cause of the dynamic pressure rise in 2003, 50 m of non-evaporable getter (NEG) coated pipes were installed in 2003 for beam tests. With the confirmed electron cloud reduction, more NEG pipes were installed in 2004 and 2005.

By eliminating the worst pressure rise spots, 110 bunches with 0.9e11 protons per bunch could be filled in RHIC in 2005, up from 55 bunches with 0.7e11 protons per bunch in 2004. In 2005, a clear correlation between the number of bunches and the transverse emittance was observed. The intensity threshold of emittance growth was 140e11 protons in total. In 2006, the beam of 110 bunches with 1.5e11 protons per bunch could be filled in RHIC, and the intensity threshold of emittance growth is increased to at least 260e11 protons.

We report on the electron cloud and dynamic pressure rise reductions, as well as experience with the saturated NEG coatings, the anti-grazing ridges for EC reduction in warm sections, and pre-pumping in cryogenic regions.

Since the electron cloud is non-uniformly distributed in the RHIC rings, the dynamic pressure rise measured by vacuum gauges is also used as indicator of the electron cloud, based on the close correlation of EC and dynamic pressure rise [1,2].

APPLICATION OF NEG COATINGS

The expected properties of NEG coating include a reduced secondary electron yield (SEY), a low electron impact molecular desorption rate, possible lower ion desorption rates, and additional pumping after activation.

For RHIC application, most essential needs are the lower SEY, which can raise the electron multipacting threshold, and also lower electron desorptions, which can reduce pressure rise given electron doses on wall. These were qualitatively verified during machine operations and beam studies in 2004 with 50 m NEG pipes installed. The positive results lead to additional 200 m and 180 m NEG pipes installed in 2004 and 2005, respectively. Activation of the NEG is usually carried out at 250 C for 4 hours at the end of a 4 day in-situ bakeout of the sections.

In Fig.1, beam induced pressure rises in 2004, 2005, 2006 are shown for 12 Q3-Q4 straight sections in the Blue ring. The pressure was measured with the gauge pw3.2 that is located at the middle of the 34 m long warm section. The dynamic pressure rise there is usually higher than at the other two gauges, pw3.1 and pw3.3, located at the ends of the section. All beams are with a bunch spacing of 108 ns, an average bunch intensity of about 1.5e11 protons, and comparable bunch lengths. In 2004, injection of less than 50 bunches caused a pressure rise at 2 sections to 3e-6 Torr, approaching a beam permit limit. In 2005, these 'hot' spots with the highest pressure rise were eliminated. With similar improvement in the Yellow ring, higher intensity beam could be injected and accelerated in RHIC. In 2006, the situation is further improved.

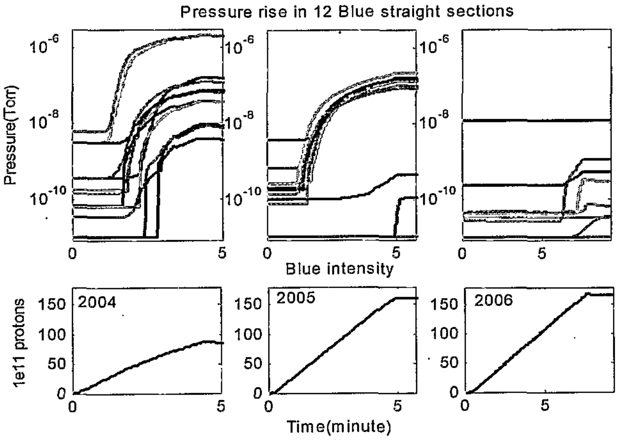

Fig.1. Dynamic pressure rise in 12 Blue Q3-Q4 warm straight sections in 2004 to 2006. The beams have 108 ns bunch spacing, with similar bunch intensity and bunch length. The beam conditions were chosen for comparison of dynamic pressure rise, not for typical operations. With complete NEG coated pipes, the pressure at 3 sections in 2005 and 5 sections in 2006 remained at 1e-11 Torr.

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In 2005, the pressure rise in all sections with newly installed NEG pipes was significantly reduced, and the pressure rise remained the same in unchanged sections for beams with same conditions including bunch spacing, bunch intensity and bunch length. In 2006, again, the pressure rise of sections with newly installed NEG pipes was reduced, but significant pressure rise reduction at unchanged sections was also observed. This is under investigation.

BEAM EMITTANCE GROWTH

Under typical operating conditions, the overall beam induced electron cloud in 2005, with 0.9e11 protons per bunch and 110 bunches, was in fact increased from that in 2004, with 0.7e11 protons per bunch and 55 bunches. The beam emittance calculated from ZDC (zero degree calorimeter) of experiments PHENIX and STAR was increased at high intensity. As a result, the highest intensity beam did not yield the highest luminosity. For example, the fill 7327 with 104 bunches and 0.90e11 protons per bunch, gave rise to average a ZDC rate of 3.97 kHz (luminosity of 10.2e30/cm^{2}s), but the fill 7264 with 82 bunches and 0.87e11 protons per bunch had 4.32 kHz (11.1e30/cm^{2}s).

In Fig.2, the average beam size of the two experiments at the collision points is depicted against the total beam intensity for the last 44 fills in 2005 100 GeV polarized proton run. The emittance increases with the total intensity above a threshold, similar to that observed at KEKB [3] and PEP II [4]. Also plotted in Fig.2 are the last 90 fills in the 2006 run. The intensity threshold of the emittance growth has been increased to at least 260e11 protons in total, but it cannot be clearly identified.

In a beam study, 110 bunches with 1.9e11 protons per bunch were injected, then the RF voltage was increased from 160 kV to 300 kV to shorten the bunch length and enhance the electron multipacting. The bunch intensity was higher, and the bunch length was shorter than those in current operations. The beam emittance observed by the ionization profile monitor (IPM) shows some correlation with the pressure rise observed at 4 Q3-Q4 straight sections for both rings, which have higher pressure rise than other warm sections. In Fig.3, the Blue vertical emittance is shown together with the beam intensity and pressure rise, as well as the Yellow horizontal emittance together with intensity and pressure rise.

In the 2006 100 GeV proton operations, the typical beam emittance in early collisions was below 20 πμm, whereas the usual emittance at the RHIC injection is below 15 πμm. The emittance of the injected beam shown in Fig.3 is a little larger than usual, because of the higher bunch intensity. The beam emittance was increased by some 15 πμm within half an hour, to about 35 πμm. The fastest increase of the emittance is coincided with the peak of the pressure rise in both Blue and Yellow.

The electron cloud induced emittance growth at RHIC is not accompanied by an apparent beam instability. This is similar to observations at KEKB [3], where vertical emittance growth was seen without evidence of head-tail beam instability. This is also in qualitative agreement with a simulation at CERN [5], where a slow emittance growth exists with the electron cloud, but below the instability threshold. With the modest electron density of 6e11/m^3, the emittance growth without beam instability in [5] is faster than the one shown in Fig.3 for RHIC.

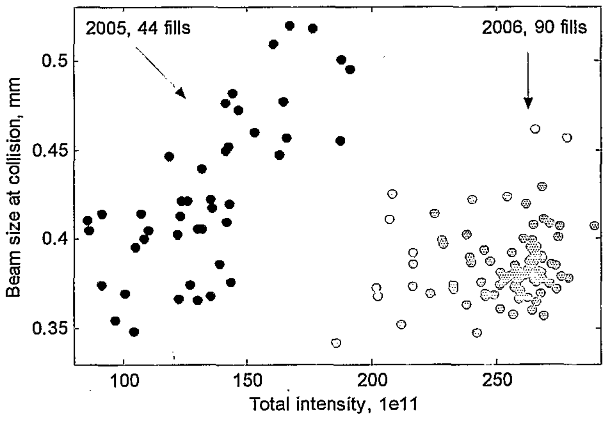

Fig.2. Average beam size at the collision points of the experiments PHENIX and STAR versus the total beam intensity in 2005 and 2006 100 GeV polarized proton runs. The beam size is calculated from the ZDC rate. A total of 44 fills in the late 2005 run, and the 90 last fills in 2006 run are shown. The data in 2005 were sampled at softev physics event, and the data in 2006 were sampled at 1.5 h after ramp start, both at early beam collisions. The intensity threshold of the beam emittance growth is clearly increased in 2006, but not identifiable.

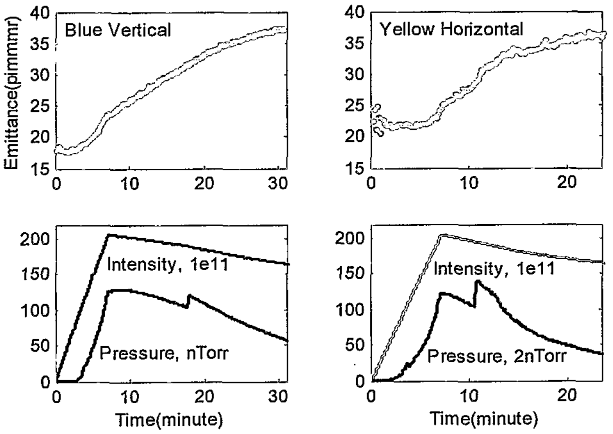

Fig.3. Correlation of beam emittance growth with dynamic pressure rise. The beams have 1.9e11 protons per bunch and about half of the normal bunch length. Blue vertical and Yellow horizontal emittances observed by the IPM are shown together with the pressure rise in Blue and Yellow, respectively. The first peak of pressure rise is at the end of injection, and the second peak is when the RF voltage was ramped up, which shortened bunch length, and enhanced the electron cloud.

STUDY RESULTS OF PRESSURE RISE REDUCTION

With the installed NEG pipes, the possible needs of re-activation are of concern. One section of NEG pipes was saturated by dry nitrogen as a test. In Fig.4, the pressure rises of a section without NEG pipes are compared with active and saturated NEG pipes. The pressure rise of the saturated NEG coating is similar to the un-saturated one. It was noticed that at the NEG coated sections, the pressure rise at the center of sections, pw3.2, is the lowest [2]. The saturated NEG coating kept this characteristics. More complete saturation with CO is planned for further study.

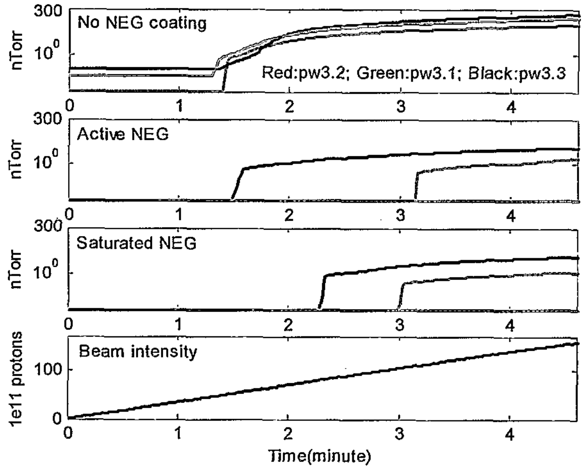

Fig.4. Pressure rise of the sections without NEG coated pipes, and with active and saturated NEG coated pipes. The pressure rise at the center of the sections, pw3.2, usually is the highest and becomes the lowest for both active and saturated NEG coatings. The pressure rise at pw3.1 and pw3.3, which are at the ends of the sections, are also reduced.

Since the activation of NEG in the interaction regions (IR) is very difficult or often impossible, the application of saturated NEG coating in the IR is of interest.

To better understand the electron cloud in the RHIC warm sections, anti-grazing ridges were installed for beam tests [6,7]. For similar beams, 5 Yellow sections with unchanged chamber conditions in 2004 and 2005 had shown similar pressure rise, but the pressure rise of Yo5 with anti-grazing ridges had the peak pressure reduced by a factor of 50. This is shown in Fig.5. Furthermore, at Yo5, the pressure rise reduction at the center of the section, pw3.2, is more pronounced, which is the same characteristics of the pressure rise reduction at the NEG coated sections. The anti-grazing ridges have a potential use in interaction regions, but concerns exist for additional background generation from beams coming into the IR.

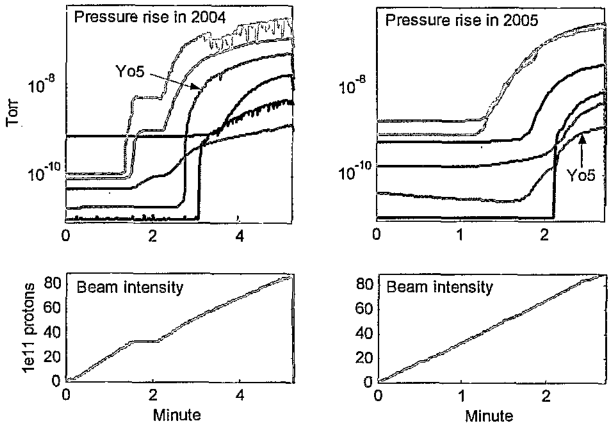

Fig.5. 6 Yellow Q3-Q4 straight sections are compared for similar beam injections in 2004 and 2005. The purple line in pressure rise is for the section of Yo5, which is reduced by more than a factor of 50 in 2005 with the anti-grazing ridges. Pressure rises of other 5 sections without change in chamber conditions are about the same.

A pressure rise of a few decades has been observed in some cold sections during machine studies for beams with higher intensity than in normal operations. The cold bore gas densities were monitored with cold cathode gauges connected to the cold bore through a small conduit. This cold bore increase in the gas density was thought to be caused by electron clouds. Before cool-down some sections had a pressure of 1e-1 Torr, leading to 10 monolayers of condensed hydrogen after cool-down. The cold bore sections with high gas density were analyzed and found to contain mostly of hydrogen. To reduce the electron-impact desorption for high luminosity operation, turbo and ion pumps were installed to reduce the average pressure before cool-down to 1e-7 Torr, leading to less than one monolayer levels after cool-down.

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