BEAM EXPERIMENTS TOWARDS HIGH-INTENSITY BEAMS IN RHIC *

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Abstract

Proton bunch intensities in RHIC are planned to be increased from $2 \cdot 10^{11}$ to $3 \cdot 10^{11}$ protons per bunch to increase the luminosity, together with head-on beam-beam compensation using electron lenses. To study the feasibility of the intensity increase, beam experiments are being performed. Recent experimental results are presented.

INTRODUCTION

Head-on beam-beam compensation in RHIC is expected to allow polarized proton beam collisions with bunch intensities of up to $3 \cdot 10^{11}$ protons per bunch, thus roughly doubling the luminosity [1]. While RHIC was originally designed with $1 \cdot 10^{11}$ protons per bunch in 56 bunches in mind, gradual improvements allowed for close to $2 \cdot 10^{11}$ protons per bunch in 109 bunches, which is four times the design beam intensity [2].

The envisioned intensity increase by another 50 percent may require additional system upgrades [3]. To identify these requirements, beam experiments have been performed. However, the present Accelerator Safety Envelope (ASE) imposes strict intensity limitations. At present, the total beam intensity per ring is limited to $2.5 \cdot 10^{13}$ protons at 250 GeV, or $2.3 \cdot 10^{11}$ protons per bunch in 109 bunches. Since these limitations scale with beam energy as $E^{0.8}$, beam experiments at higher intensities can only be performed at lower energies. For future RHIC runs radiation safety is re-analyzed for the higher intensity, and additional shielding and fencing may be installed.

The cryogenic RHIC BPM cables are rated for a maximum temperature of 123°C. With short, high intensity bunches the signal level on these cables can reach levels that cause excessive heating of these cables. Since the signal level depends on the actual beam orbit position with respect to the BPM center, beam orbit excursions need to be limited. For that purpose an interlock system has been implemented that aborts the beams if the measured orbit position at any BPM exceeds a pre-defined safe limit. This system was used to prevent damage to the BPM cables during high intensity tests.

BEAM DUMP

The RHIC beam dump was originally designed for 56 proton bunches with a bunch intensity of $1 \cdot 10^{11}$ protons per bunch, with a safety factor of two [4]. When RHIC operated for the first time at 250 GeV proton beam energy, beam aborts at intensities above $1.2 \cdot 10^{11}$ protons per bunch in 109 bunches caused quenches of the downstream superconducting quadrupoles, because the safety factor of two had been exceeded. To improve the situation, simulations had been performed that proposed thickening the beam pipe wall of the circulating beam next to the beam dump, which was accomplished by twenty 5 inch long sleeves slid into the beam pipe. This allowed the beam intensity to be raised to $1.8 \cdot 10^{11}$ protons per bunch, with the new limit expected to be around $2.5 \cdot 10^{11}$ protons per bunch.

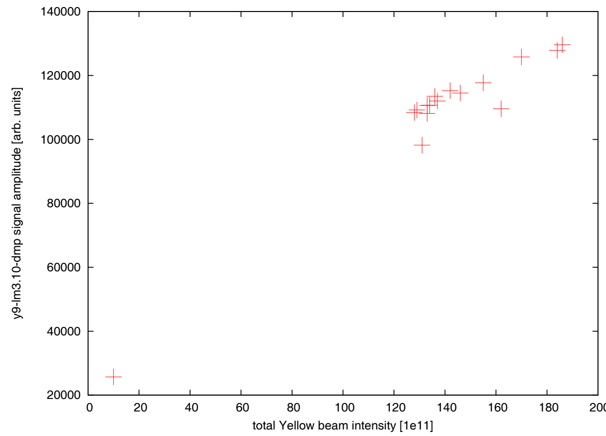

Figure 1: Loss rate measured at dump beam loss monitor y9-lm3.10-dmp vs. total Yellow beam intensity at time of dump.

In order to study potential increases of this limit by measures such as increasing the kicker strength or moving the closed orbit closer to the beam dump, dedicated beam loss monitors have been installed in a location where the radiation level during a beam abort is proportional to the beam loss rate at the downstream magnet that is in danger of quenching. Due to the high radiation dose during beam aborts these monitors had to be de-sensitized in order to not saturate. As Figure 1 shows, the measured loss rate is now proportional to the beam intensity as long as no other parameters are changed. Therefore, this loss monitor can be used in future studies to increase the limit of safe beam aborts.

Since the RHIC beam dump system was designed for a much lower beam intensity than envisioned for future operations, structural soundness of the stainless steel exit window is a potential concern. Detailed numerical studies of the heat deposition and associated thermal stress in the win-

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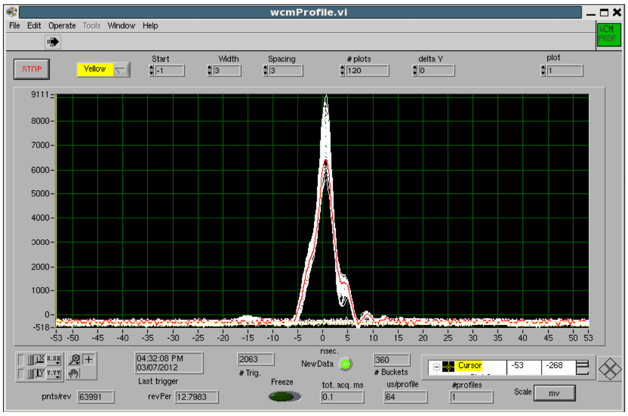

Figure 2: Wall current monitor profiles of 109 Yellow bunches at injection during high intensity tests. At an average intensity of $2 \cdot 10^{11}$ protons per bunch and an average RMS bunch length of $\sigma_s = 2$ nsec, the average of the bunch peak currents reaches 7.5 A.

dow have been performed, and it has been determined that bunch intensities as high as $3.9 \cdot 10^{11}$ protons per bunch in 109 bunches can be safely dumped with the present system, with a safety factor of two [5].

ELECTRON CLOUD AND RESISTIVE WALL LOSSES

Short, high intensity bunches are prone to electron cloud instabilities that need to be controlled for successful operation. In addition, they add to the cryogenic load due to resistive wall losses in the uncoated stainless steel beam pipe.

These effects were experimentally studied at injection energy. To generate short bunches, quad mode pumping was employed in the AGS. Upon injection into RHIC, these short bunches were then captured in the 28 MHz RF buckets. At an average bunch intensity of $2.6 \cdot 10^{11}$ protons per bunch, a peak current of $I_{\max} = 7.5$ A was thus achieved, corresponding to an RMS bunch length of $\sigma_s = 2.2$ nsec, Figure 2.

With a full load of 109 bunches in the Yellow ring, Figure 3, the helium temperature rose by $\Delta T = 40$ mK, which corresponds to an additional cooling power requirement of $\Delta P = 300$ W. This measured additional load agrees very well with calculations based on parameters such as the resistivity of the beam pipe, which resulted in an expected load of 270 W.

During injection of these high intensity bunches, an interesting vacuum phenomenon was observed in the vicinity of the Yellow RF cavities. The additional injection of a single bunch sometimes led to a sharp increase in the vacuum pressure, as one would expect from effects such as an electron cloud. After a sufficiently long waiting period of typically ten seconds the vacuum pressure recovered, and an additional bunch was injected. While one expected a similarly sharp pressure rise, the opposite actually happened - a sharp pressure drop. In other instances, injecting a bunch did not change the vacuum pressure at all. This is illustrated in Figure 4.

Figure 3: Yellow bunch-by-bunch fill pattern during high intensity tests at injection. The average intensity of the 109 bunches reaches $2.6 \cdot 10^{11}$ protons per bunch.

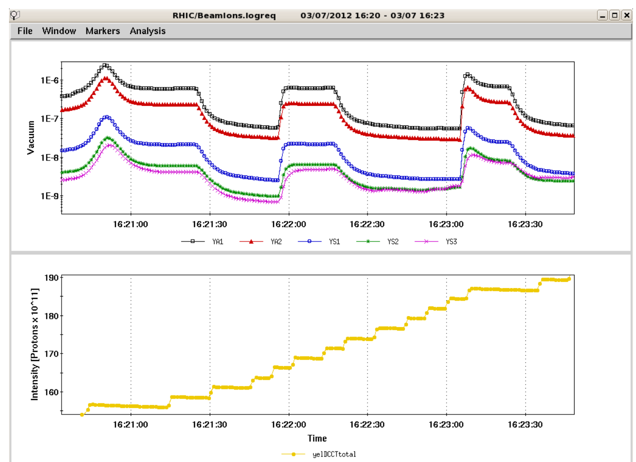

Figure 4: Vacuum pressure in the Yellow RF region (top) during the latter part of the Yellow injection process. Each intensity step in the lower plot corresponds to the injection of one additional bunch.

HIGH INTENSITY RAMP

After these injection studies, a high intensity ramp was attempted. Due to RF problems in the Blue ring, only six high intensity bunches were injected in each ring and ramped to 100 GeV store energy, using the 9 MHz RF system. This test ramp, with $3.0 \cdot 10^{11}$ protons per bunch in Blue and $2.6 \cdot 10^{11}$ in Yellow, showed nearly perfect transmission, as shown in Figure 5. At store energy, the bunches were rebucketed into the 28 MHz system, which is standard procedure for proton beams in RHIC.

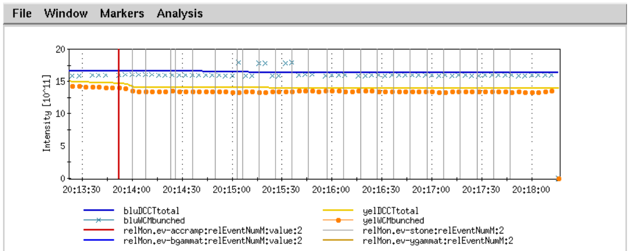

Figure 5: Total beam intensity of six bunches in each ring during a high intensity test ramp.

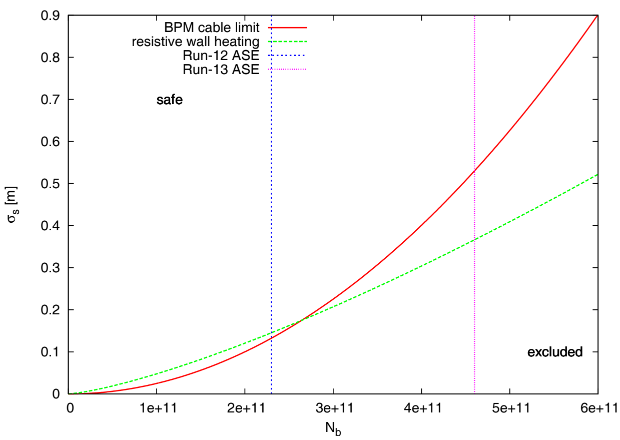

Figure 6: Minimum allowable bunch length vs. bunch intensity, assuming 109 bunches per ring, as given by the cryo load due to resistive wall losses (green) and by preliminary rough estimates of heating limits for the cryogenic BPM cables for a 20 mm beam offset (red). The blue and magenta vertical lines indicate the limits imposed by the accelerator safety envelope (ASE) for previous runs (blue) and future runs starting in FY13 (magenta).

SUMMARY

A variety of beam experiments have been performed in RHIC to study the readiness of the machine for high intensity proton operations. A full load of 109 high intensity bunches with $2.6 \cdot 10^{11}$ protons per bunch was successfully injected into the Yellow ring, and the resulting cryo load increase due to resistive wall losses was measured, which agreed very well with theoretical expectations. Figure 6 graphically summarizes the bunch length limitations as a function of bunch intensity imposed by BPM cable heating and cryogenic load, together with the ASE limits on intensity due to radiation safety considerations.

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