PROTON EMITTANCE MEASUREMENTS IN THE BROOKHAVEN AGS*

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Abstract

High luminosity and high polarization in RHIC require good control and measurement of emittance in its injector, the Brookhaven AGS. In the past, the AGS emittance has been measured by using an ion collecting IPM during the whole cycle. The beam profiles from this IPM are distorted by space charge forces at higher energy, which makes the emittance determination very hard. In addition, helical snake magnets and near integer vertical tune for polarized proton operation distort the lattice in the AGS and introduce large beta beating. For more precise measurements of the emittance, we need turn-by-turn (TBT) measurements near injection and beta function measurements at the IPM. A polarimeter target has been used as wire scanner for proton beam. A new type of electron collecting IPM has been installed and tested in the AGS with proton beam. The vertical beta functions at the IPM locations have been measured with a local corrector near the IPM. This paper summarizes our current understanding of AGS emittances and plans for the further improvements.

INTRODUCTION

Emittance is an important parameter for high luminosity in colliders. For RHIC operation, as the only polarized proton collider in the world, polarization preservation is dependent on emittance preservation. In general, larger emittance results in larger depolarizing resonance strength and consequently, larger polarization loss. Many techniques have been employed in the AGS to preserve polarization, such as partial snakes [1], horizontal tune jump quadrupoles [2] and harmonic orbit corrections. To further reduce polarization loss in the accelerator chain, it is necessary to control the emittance growth. As the first step, we need to measure emittance reliably.

The two partial snake magnets are helical dipole magnets with constant fields during the whole AGS cycle. Several compensation quadrupoles have been installed on both sides of each helical dipole to mitigate the optical effect but their effect is limited. Particularly at injection energy, these magnetic fields cause significant optical distortion which abates at higher beam energy. To convert measured beam profiles to emittance, the beta functions have therefore to be measured along the ramp.

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DEVICES TO MEASURE EMITTANCE

The major emittance measurement device in the AGS is an ion collecting IPM [3] installed back in 1980s. They are installed at β_{max} locations and measure both horizontal and vertical emittances. The device showed that the vertical emittance increased four times in the AGS. There are several problems with this measurement. First, the optics is greatly distorted by the helical dipole magnets. Since the beta function is not a constant along the ramp. Second, the space charge of the bunched beam is stronger at higher energy due to smaller beam size which results larger reported emittance [4]. To resolve these issues, several steps were taken. First, a corrector dipole was installed next to the vertical IPM and was used to measure beta function at the IPM. Second, emittance was measured by the IPM with debunched beam at various intensities to quantify the space charge effect. Third, an electron collecting IPM (eIPM) was installed and commissioned in the last run. There are two advantages of the eIPM. It does not have the space charge effect and it can provide the TBT emittance which is critical to check optical match at injection.

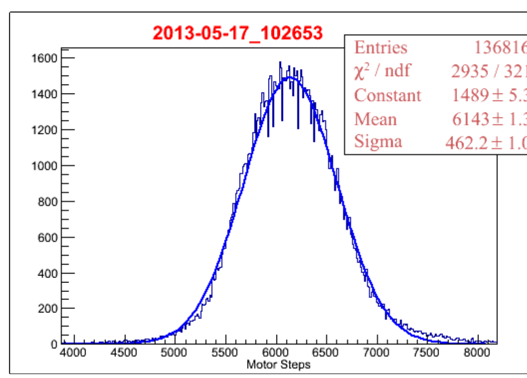

Figure 1: A horizontal beam profile measured by polarimeter. The smooth curve is the Gaussian fit. The horizontal axis is the step count. This particular profile gives beam sigma as 1.02mm. With dispersion contribution subtracted, the normalized emittance is 12.6πmm-mrad. Standard beta function 10m is used.

The AGS polarimeter measures proton beam polarization with a thin ribbon carbon target ($50\mu m$X$30nm$X$25mm$) and Si detectors sitting inside vacuum. The carbon target flying through beam provides beam profile and consequently measurement of emittance. One example of the measured profile is given in Fig. 1. The drawback of the device is that the ultra thin target could be stretched due to beam heating and deform

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during motion. The obtained profile is then distorted. This method can only give an upper limit of beam size.

β FUNCTION MEASUREMENT

One possible mechanism for emittance growth is noise on the ramp, such as noise from the main magnet or RF systems. Since the beta function changes on the ramp due to optics distortion of helical snakes and other effects, the emittance calculation has to be based on the real beta functions. A vertical dipole was installed at the vertical IPM in the AGS. This is used to generate a cusp in the closed orbit at the vertical IPM. The local beta function is measured by measuring the change in the profile center at the IPM as the current in this corrector is changed.

The shift in measured position of the beam centroid (ΔY_{IPM}) and the known dipole kick ($\Delta\theta_{dipole}$) can be used to calculate the beta function.

$$\beta = 2\frac{\Delta Y_{IPM}}{\Delta\theta_{dipole}}\tan(\pi Q) \tag{1}$$

where Q is betatron tune and β is the beta function in the corresponding plane. The measured beta functions are shown in Fig. 2. The beta functions at the IPM location should be around 22m (β_{max}) from model without helical snake magnets. Due to these magnets, the injection beta function is only about half of model value. The rise of β_y starts at 250ms, and the dip at 300ms could be a bad measurement due to transition crossing.

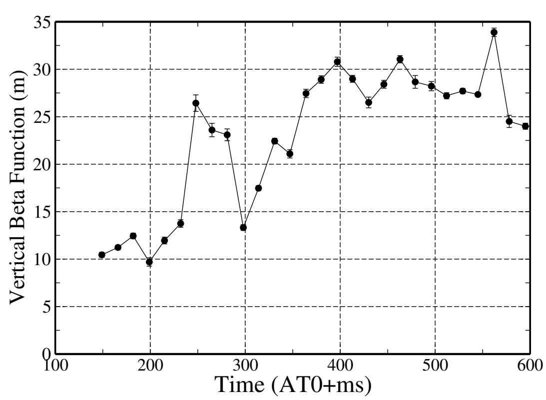

Figure 2: The measured vertical beta function along the AGS ramp. The flattop is reached at 581ms from the AGS T0. Transition is crossed around 300ms.

VERTICAL EMITTANCE

The reported vertical emittance by IPM showed a four times increase on the ramp. Several factors distort the reported emittance. First, the beta function is actually smaller at injection as shown by the beta function measurement. Second, the space charge due to bunched beam gives also larger emittance. To illustrate this effect, the beam was accelerated to flattop then decelerated back to injection without much beam loss. As Fig. 3 shows, the horizontal emittance does not show much change before and after the whole up and down ramps. Since the main purpose of the plot is to compare the emittance at injection energy, a constant beta function was assumed. It shows that the vertical emittance is larger by a factor 2 after up and down ramps, while the horizontal emittance does not show much change. The vertical emittance reduction on the down ramp shows that the large emittance reported at flattop is not real. It probably is due to space charge. To derive true emittance

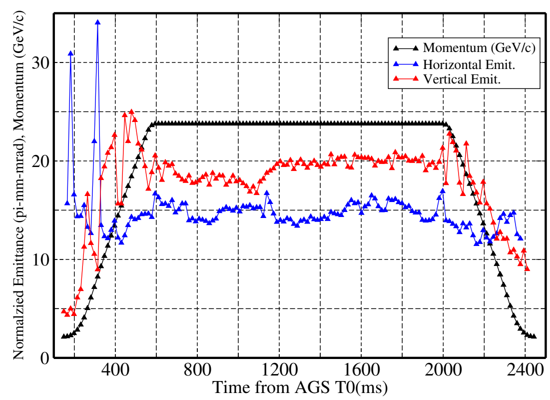

Figure 3: AGS emittance on the up and down ramp with 2×10^{11} intensity. Constant beta function of 22m was used for both vertical and horizontal planes.

in the vertical plane, the measured β_y is used. Fig. 4 shows the vertical emittance in the AGS on the ramp with various intensities. The spikes around 300ms are due to transition crossing. The emittance "growth" on the ramp is partially due to space charge: the reported emittance drops down at flattop with RF system turned off. The growth seems stronger with higher intensity. Similar to the down ramp plot, the emittance almost doubled from injection to flattop at 2×10^{11} intensity.

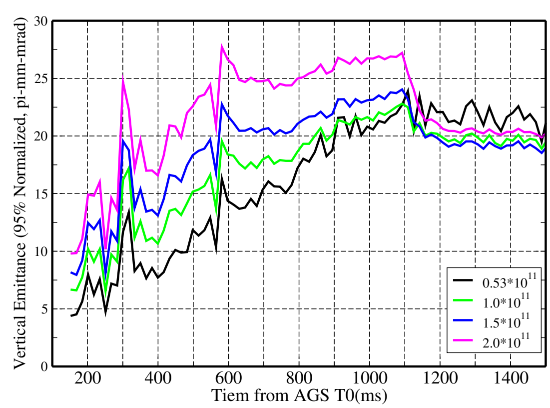

Figure 4: Vertical emittance in the AGS on the ramp with various intensities. At 1100ms, RF is turned off. The reported emittance is reduced as the space charge force is diminished.

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ELECTRON COLLECTING IPM

One possible source of emittance growth is the optics mismatch at injection. Due to the large distortion fields from the helical magnets, the optics is hard to model near injection. To measure the effect, a multi wire profile monitor was used to get TBT profiles. The noise from nearby injection kicker was overwhelming and we could not obtain the TBT profile. The other two devices can not provide TBT emittance either: the ion collecting IPM uses slow electronics and needs long integration time (in the order of 1-2ms or 350-700 turns) and polarimeter takes even longer time (about 500ms) to cross the beam. To get TBT emittance near injection, an electron collecting IPM similar to RHIC design [5] was installed in the horizontal plane and has been commissioned.

To save cost, permanent magnets are used as electron guide magnet. The advantage of eIPM is that it does not have space charge effect. Moreover, the fast electronics can give us TBT profiles with a pressure bump of 10^{-8} Torr for protons. Due to the time limit, the gas leak and the fast pre-amplifiers were not available for this commissioning period. The profile was taken with slow pre-amplifiers instead. In addition, without gas leak, the profiles for each turn have to be accumulated from about 100 AGS cycles. Clearly, it demonstrated the TBT capability for the device.

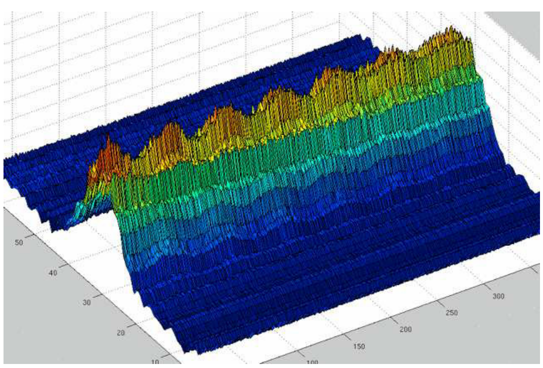

Figure 5: The average TBT profiles for the 300 to 600 turns at AGS injection.

HORIZONTAL EMITTANCE

To derive true emittance in the horizontal plane, in addition to subtracting the space charge effect, the dispersion contribution has to be removed. The longitudinal emittance at AGS extraction has been measured as 0.78eVs. The dispersion function at horizontal IPM location is about 2m. Since we have not done horizontal beta function measurement in the AGS yet, the β_{max} of 22m is assumed for the following analysis. Due to the distortion introduced by the helical snake magnets, The β_x will be larger than 22m. Thus the reported emittance near injection will be larger than the true values. Fig. 6 shows the horizontal emittance in the AGS on the ramp with various intensities. The early part of "reduction" indicates β_x actually is larger due to helical magnets. The spikes around 300ms is due to transition crossing. The emittance "growth" after 350ms is not real: as the reported emittance drop back to the level around 350ms at flattop when the RF system was turned off. The instrumentational effect is due to space charge effect. The eIPM data is also plotted for comparison. These data were taken with various intensities in different AGS cycles. In general, eIPM reports smaller emittance values. This could indicate different beta functions at the locations of the two devices (beta beating).

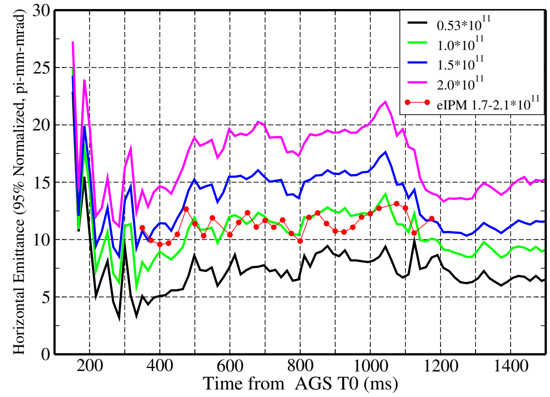

Figure 6: Horizontal emittance in the AGS on the ramp with various intensities. At 1100ms, RF is turned off. The reported emittance is reduced as the space charge force is diminished. The eIPM data was included for comparison. It is seen that the values reported by the eIPM is smaller than IPM (with RF off) by about 1-2pi.

SUMMARY

To determine AGS emittance, the vertical beta functions have been measured along the AGS ramp. Emittances have also been measured with beam debunched at flattop to eliminate the space charge effect. The preliminary results suggest some vertical emittance growth in the AGS, but the source is not fully understood. A new electron collecting IPM has been installed in the horizontal plane and commissioned. It has potential to collect TBT emittance information near injection, which is critical for optical match. The plan is to have a similar device for vertical in the coming run. Beta function measurements will continue and extend to vertical plane. With reliable emittance measurements, the emittance preservation through the injector chain will be possible. This will lead to higher luminosity and higher polarization for RHIC polarized proton operation.

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