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HIGH CHARGE DEVELOPMENT OF THE APS INJECTOR FOR AN MBA UPGRADE*

C.-Y. Yao#, N. Sereno, Ju Wang, M. Borland, Doug Horan, H. Shang, X. Sun, K. Harkay, R. Lindberg, J. Calvey, Advanced Photon Source,
Argonne National Laboratory, Argonne, IL 60439, USA

Abstract

The APS MBA (multi-bend achromat) upgrade storage ring will employ a "swap out" injection scheme and requires a single-bunch beam with up to 20 nC from the injector. The APS injector, which consists of a 375-MeV linac, a particle accumulator ring (PAR), and a 7-GeV synchrotron (Booster), was originally designed to provide up to 6 nC of beam charge. High charge injector study is part of the APS upgrade R&D that explores the capabilities and limitations of the injector through machine studies and simulations, and identifies necessary upgrades in order to meet the requirements of the MBA upgrade. In the past year we performed PAR and booster high charge studies, implemented new ramp correction of the booster ramp supplies, explored non-linear chromatic correction of the booster, etc. This report presents the results and findings.

INJECTOR TIMING

At 2 Hz operations we have achieved ~10 nC in the PAR. In order to achieve up to 20 nC beam charge the injector cycle must be extended to at least 1 s to accumulate enough Linac bunches, and to allow sufficient damping time. A prototype timing module that supports both 2Hz and 1Hz operations has been designed and is currently under hardware test.

NON-LINEAR RAMP FOR THE BOOSTER MAIN SUPPLIES

The Booster accelerates beam from 375-MeV injection energy to 7-GeV extraction energy in 224 ms. Damping time, bunch length and beam stability varies during this process. We mainly rely on chromatic correction and radiation damping to maintain beam stability.

Chromatic correction for the booster is complicated by the eddy current in the vacuum chamber due to ramping of the dipole field. The original sextupole strengths are designed to maintain a +1 chromaticity in both planes at extraction energy. This is inadequate for high charge beam. In order to provide higher chromatic correction at low beam energy we developed a new ramp correction programs that support non-linear ramps for the quadrupole and sextupole supplies. Figure 1 shows a non-linear ramp for the SD sextupole supply. This allows us to apply high chromatic correction during the first half of the ramp where the beam instability is stronger.

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#cyao@aps.anl.gov

We are also considering upgrading the sextupole power supplies to higher current ratings to achieved a chromaticity of 6 to 7 in both planes in the full Booster cycle.

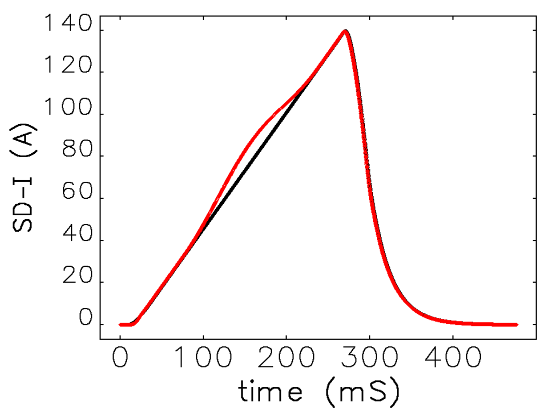

Figure 1: SD magnet new non-linear (Red) and original linear (Black) ramps.

NEW BPM AND CORRECTOR RAMP SYSTEM

A new Booster BPM system has been designed that utilizes a BSP-100 [1] module that was originally developed for APS storage ring. The new system will provide up to 10 average beam orbit readings along the 224 ms energy ramp.

A V344 arbitrary waveform generator (AWG) module and a V490 ADC module [2] are selected for the new corrector ramp control system.

The BPM system is under test and EPICS interface for a single V344 module has been tested. Full implementation is under way.

ANALYSIS OF BOOSTER CHAMBER IMPEDANCE

The Booster vacuum chamber is made of 316L stainless steel, and the associated longitudinal and transverse impedance was obtained using standard analytic formulas. In addition, Table 1 lists the vacuum components that represent the main contributions to the geometric impedance. The wakefields due to these elements were calculated using the 3D electromagnetic code GdfidL [3], with the exception of the rf cavities.

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Since the accelerating cavities are large and approximately cylindrically symmetric, we used the 2D ECHO code [4] to compute the associated wakefields in a reasonable time.

Table 1: Booster Chamber Impedance Components

Item	Total number	Item	Total number
Bellow	50	4-blade stripline	2
Vacuum port	84	5-cell rf cavity	4
Vert. stripline	1	Kicker chamber	2

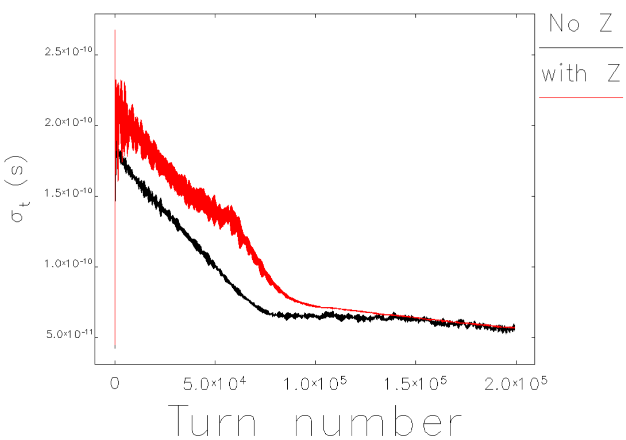

Figure 2: elegant simulated bunch length during a booster ramp with longitudinal impedance (red) and without longitudinal impedance (black).

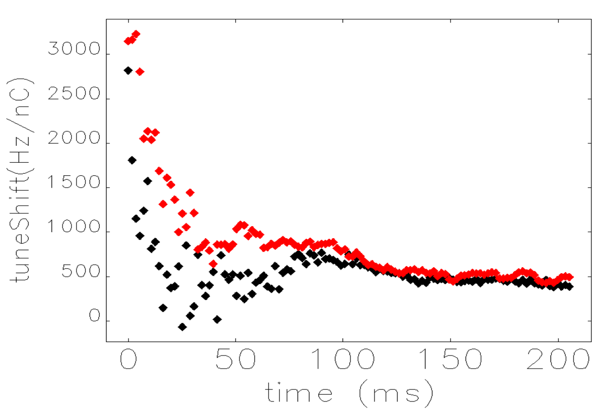

Figure 3: Vertical-tune shift data of the booster 132-nm lattice. The two traces are from two measurements.

Preliminary tracking results indicate that including the longitudinal impedance does not significantly change the beam dynamics if the bunch charge is within the original design envelope of 1-6 nC. We show this in Figure 2, where we plot the tracking predictions for the bunch length σ as a function of turn number for a 5 nC beam charge. The low-energy part of the plot indicates that the impedance may detrimentally affect the low energy behavior at injection for the high charges required by the MBA Upgrade. We plan to investigate this further in the near future.

In conjunction with these simulations, we have also measured the charge-dependent tune shift of the booster beam to characterize the effect of the transverse impedance. For comparison, for this lattice and the impedance model, the simple equation [5]:

$$\Delta\nu_\beta = \frac{-iQ_{bunch}}{2\gamma(mc^2/e)}\int d\omega\beta_y \frac{Z_y(\omega)}{(2\pi)^2} e^{-\omega^2\sigma_t^2} \quad ,$$

predicts a vertical tune shift of 800Hz/nC at extraction energy. This is reasonable good agreement with the measurement shown in Figure 3.

BOOSTER RF RAMP

The Booster rf system is driven by an arbitrary function generator (AFG). Its original waveform was calculated based on the required synchrotron radiation loss and energy gain per turn, which is dominated by the former and is roughly proportional to 4th power of beam energy.

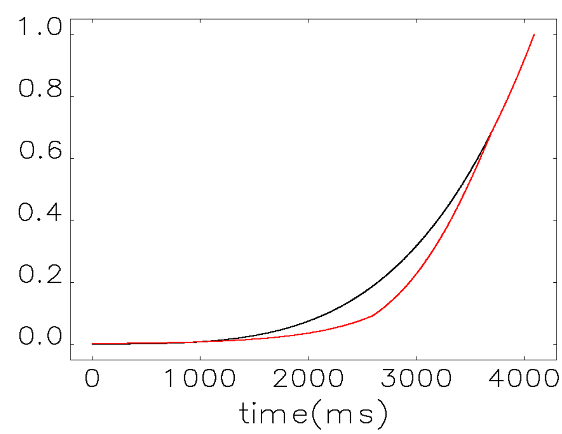

Figure 4: The original (black) and new (red) rf ramp waveforms.

It was observed that at around a beam energy of 3 GeV the beam can become vertically unstable probably due to the short bunch length. We reprogrammed the AFG waveform to a different waveform that keeps the gap voltage lower during the first 2/3 of the ramp and ramps up quickly in the last 1/3 or the ramp. This new rf waveform suppresses the vertical beam instability. Figure 4 shows the original and the new rf waveforms.

PAR VERTICAL BEAM SIZE GROWTH INVESTIGATION

During high charge injector study we observed that the vertical beam size of the PAR grows linearly with beam current. Measurement of charge dependent tune shift of the PAR beam showed a positive slope, which is opposite to expected shift from impedance effect and is consistent with ion trapping.

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To test the ion trapping assumption we measured vertical beam size under two conditions: (1) vacuum pumps are on; (2) vacuum pumps are turned off. Figure 5 shows the result. Clearly there is dependence of beam size growth on vacuum pressure.

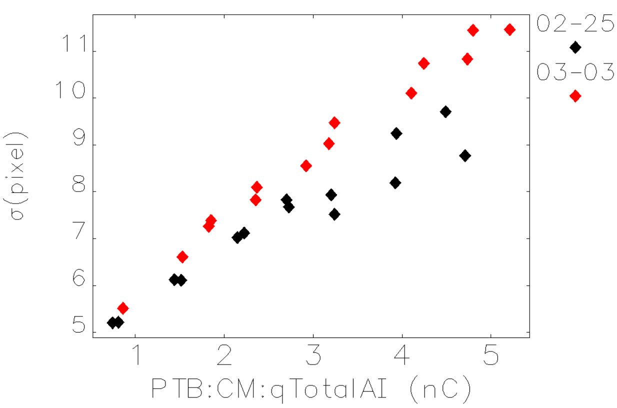

Figure 5: Vertical beam size vs beam charge: Red: vacuum pumps are off, Black: vacuum pumps are on. The pressure readings at two of the pumps are 5 nTorr and 11 nTorr for pumps off and on cases, respectively.

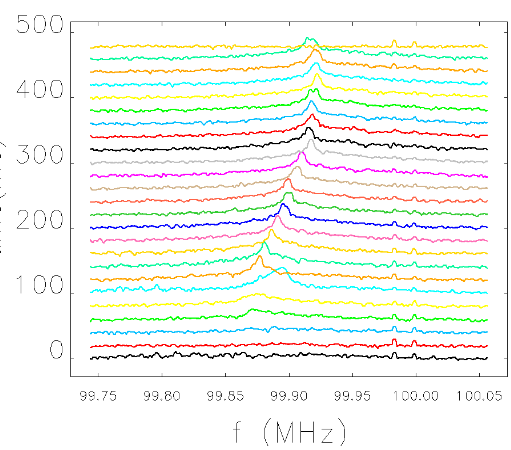

Figure 6: PAR vertical-tune timing scan with 3.3 nC beam charge in normal injection mode.

The PAR has a cycle time of 500 ms. Beam accumulation completes around 50 to 150 ms, depending on the number of linac bunches selected. To observe the ion build-up process we recorded vertical tune in 20 ms steps in a PAR cycle. Figure 6 shows the tune spectra and figure 7 shows the tune shift fit results. The tune shift increases linearly with time early in the cycle, the rate of increase slows as the ion density approaches neutralization. In the linear regime, the tune shift at 4.2 nC is about 3×10^{-5} ms^{-1}. A simulation performed with an ion instability code [6], assuming a vacuum pressure of 5 nTorr, predicts a tune shift of 1.4×10^{-4} ms^{-1} for 4.2 nC. The discrepancy with measured data could be explained by uncertainty in the vacuum pressure and gas composition, or by the contribution of other collective effects to the tune shift.

CONCLUSION

An active research and development program has been carried out in the APS injector machines order to meet the high charge injection requirement of the APS MBA upgrade. We have identify some deficiencies and are implementing improvement in Booster orbit correction, chromaticity correction, and injector beam diagnostics areas. We will continue to identify and correct limitations and deficiencies for high charge operations.

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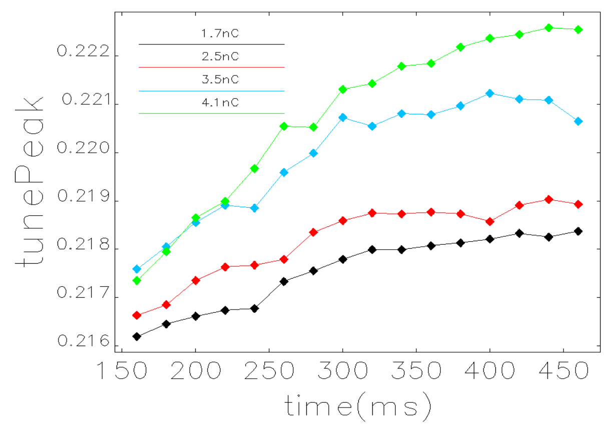

Figure 7: Vertical-tune vs time for different beam charge. Legend is beam charge. Beam accumulation completes around 150 ms.

REFERENCES

[1] A. Petryla, et. al., "Status of the RF BPM upgrade at the Advanced Photon Source," proc. of PAC07, FRPMN116, p4390-4392.[2] "V344 8-channel VME 32 MHz arbitrary waveform generator," http://www.highlangtechnology.com /DSS/V344DS.html

[3] W. Bruns, H. Henke, "A General Purpose Electromagnetic Code for Designing Microwave Component," NATO Science Series II: Mathematics and Chemistry Volumn 203, 2005, pp. 73-91.

[4] I Zagorodnov and T. Weiland, Phys. Rev ST-Accel. Beams, 8, 042001 (2005).

[5] W.C. Chao, Phyics of Collective Beam Instabilities in High Energy Accelerators (Wiley, New York, 1993).

[6] L. Wang, et. al., "Suppression of beam-ion instability in electron rings with multibunch train beam fillings," Phys. Rev. ST-Accel. Beams, 14, 084401(2011).