MI8 line beam emittance measurement

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Abstract

The primary function of MI8 transfer line is to transport beam from Booster Ring to Main Injector (MI), and to Recycler Ring (RR) after NOVA upgrade. Its second, and very necessary, function is to match beamline lattice function, which begins with Booster lattice function at extraction point, to the machine lattice function of MI, or RR, at injection point. Because of its beamline lattice function and available profile monitors MI8 line also functions as lattice analyzer, and as emittance monitor. Beam profile data from MI8 line were taken with varying Booster injection parameters, and analyzed for beam emittance information. The results are reported here.

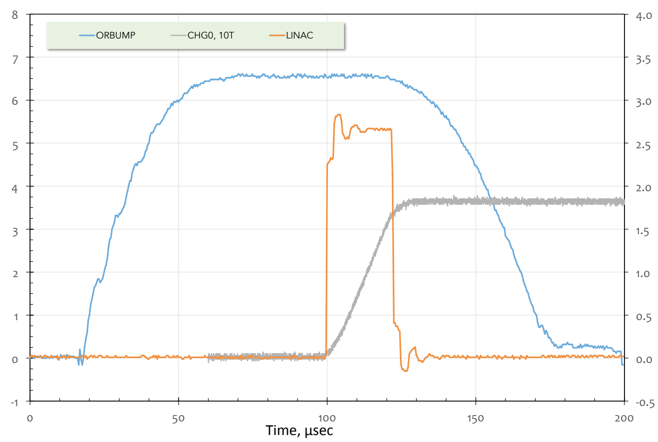

Figure 1. Booster injection OR-bump timing for 10-turns injection. Linac beam current is shown in orange trace and Booster beam intensity in grey. Operationally Linac beam always ends at a fixed time with respect to OR-bump, with its starting time changed depending on the number of turns to be injected. Note that the scale of primary and secondary vertical axises in this plot are both arbitrary.

The study

The profile data were taken on Feb. 18, 2016, shortly after MI8 line lattice analysis had concluded and the beamline lattice function became available. Among the objectives for the study were beam emittances from the Booster as a function of intensity, the effect of longitudinal bunch rotation, and emittance growth due to the stripping foil.

Beam intensity of Booster is adjusted by changing the injection duration of beam from Linac, which provides a constant flow of H- charge current. Figure 1 shows signals of injection OR-bump, Linac beam current, and Booster intensity, during regular operation cycles. Typically, injection intensities are programmed in integer number of turns to allow for more balanced beam distribution around Booster ring. For the study data were taken with Booster intensity set to 6, 8, 10, 12, 14, and 16 turns.

Transverse emittances

The results of emittances as a function of Booster turns is shown in Figure 2. Among plotted data are horizontal and vertical normalized 95% emittance, and horizontal emittances with and without longitudinal bunch rotation. The intensity reading ranging from 1.8 to 4.8 E12 are also plotted in grey plus signs, which references to the secondary y-axis on the right. Polynomial fits to emittance data showed that emittances are parabolic functions of injection turns.

Effect of bunch rotation

Bunch rotation in longitudinal phase space in Booster, before extraction, is a requirement for slip-stacking operation. Figure 3 shows analysis results of Δp/p distribution sigma. With bunch rotation turned off the sigma, shown in red dots, grew with increasing number of Booster turns. However, with rotation turned on the sigma, shown in green dots, appeared to stay fairly constant at around 0.5E-3, and an improvement of close to 40% at 14 Booster turns. The effect of longitudinal bunch rotation on transverse emittances are shown in Figure 2. Within statistical error the longitudinal bunch rotation have no visible effect on transverse emittances.

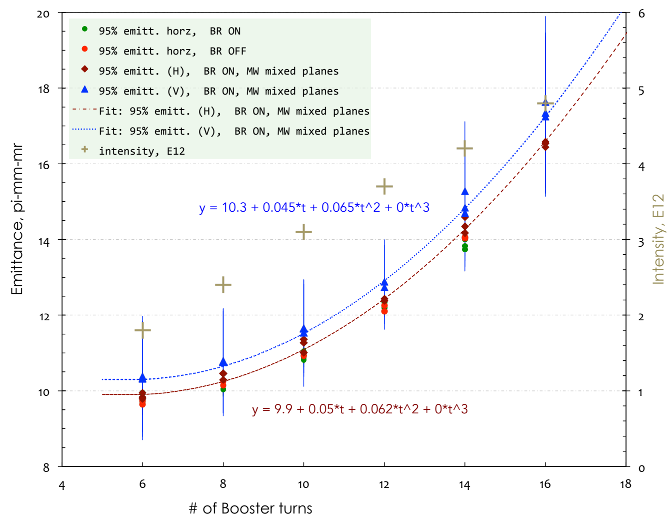

Figure 2. Measured beam transverse 95% emittances, horizontal plane in brown diamond and vertical plane in blue triangles, as a function of Booster injection turns. Emittances measured in horizontal plane only were plotted in solid dots. Green dots are with bunch rotation turned on and red dots with rotation turned off. The corresponding intensity readings, from 1.8 to 4.8 E12 proton per Booster batch are plotted in grey plus signs.

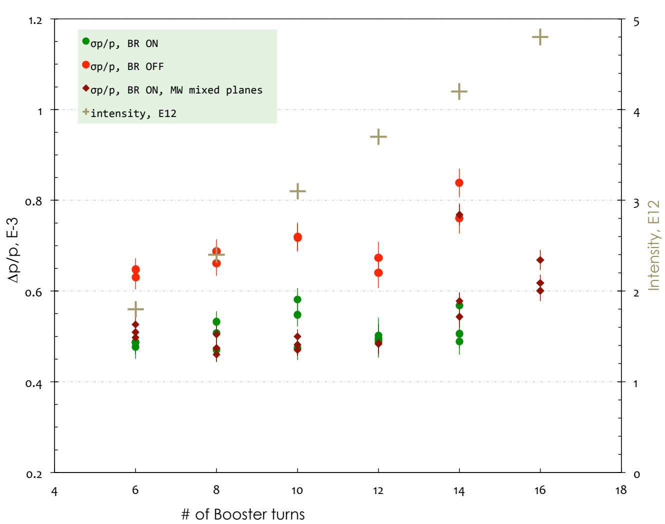

Figure 3. Measured momentum sigma, with and without longitudinal bunch rotation.

Effect of stripping foil

With multi-turn injection in the Booster it is expected that circulating beam will be passing through stripping foil multiple times. For this study Booster intensity was kept constant, and thereby the duration of Linac beam. By moving injection time relative to the OR-bump the number of turns beam has to pass through the stripping foil were changed, and the scattering effect documented.

The result of this study is shown in

Figure 4, for Booster intensity at 6 turns. Polynomial fits indicated that the observed emittance growths in both planes were practically linear at 0.03 π-mm-mr/μsec. With revolution time of 2.2 μsec this translates to a 0.07 π-mm-mr per turn in emittance growth.

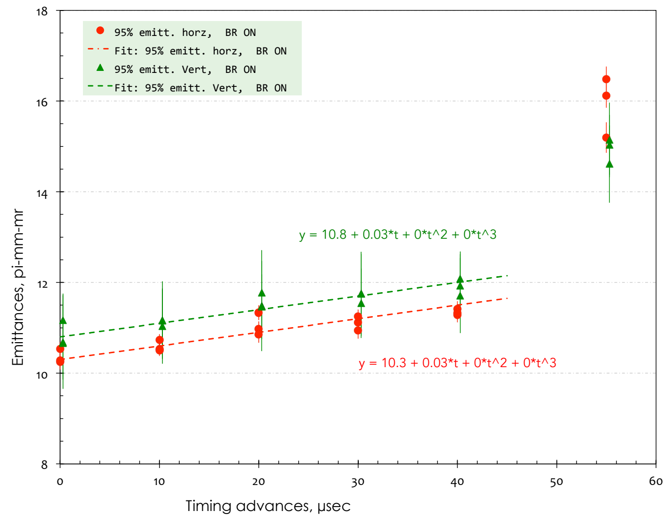

Figure 4. Measured transverse emittances as a function of Booster injection timing advances. Larger timing advance means injecting earlier. The intensity of Booster was kept at 6 turns.

It should be noted that other factor might also be contributing to the emittance growth, and that these growth rates are only setting an upper limit to the contribution from stripping foil. The large emittances seen at 55 μsec was believed to be caused by injecting beam before OR-bump flat-top was reached. For our next opportunity the same data should be taken, and with various Booster intensities to see if the growth rate is intensity dependent.

Summary

Beam emittances from Booster, as of February 2016, has been documented and presented. Larger emittances at higher number of Booster turn has been a well known fact. From this study result it is clear that scattering effect from stripping foil is not the cause.

In the absence of reliable beam emittance measurement tools in the Booster, it is difficult to diagnose where the source of emittance growth is. The measurements from profile monitors of the 400 MeV beam transport line indicates that emittances for a single turn beam is ~7 π-mm-mr in both planes (IPAC2015, p3979). The fact that extracted beam emittances, measured at MI8 transfer line, is 10 π-mm-mr at 6 Booster turn suggests a non-negligible emittance growth in the Booster. Further more, with beam transmission efficiency in the Booster falling from 99% at 10 turns to about 94% at 16 turns it is important to know if the space charge, or other magnetic error in the ring, is the cause for emittance growth.

More data with different injection parameters may provide more clues. Improving Booster operation is an on-going effort and emittance measurements need to be done with every improvement.