UPGRADE OF BEAM INJECTION DIAGNOSTICS AT BNL NSLS

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Abstract

In this paper we report the upgrade of the diagnostics of the beam injection system at BNL NSLS. Installation of commercially available turn-by-turn beam position monitors (BPMs) in the VUV and X-Ray rings allowed us to build the detailed injection models for each of the rings. In addition we built the tools for real time monitoring of and troubleshooting the beam injection into the rings.

INTRODUCTION

The NSLS accelerator complex consists of the 120 MeV linac, the booster accelerating the beam to 740 MeV and the two storage rings: 800 MeV VUV ring and 2.8 GeV X-Ray ring. Injection into each of the rings is performed at 740 MeV energy. The injection hardware in each of the rings consists of an injection septum (DC-magnet in case of the VUV ring and pulsed one for the X-Ray ring) and three fast multi-turn kickers. A single turn-by-turn (TBT) BPM was added to each ring for the purpose of injection monitoring. As a result a set of tools was created which are successfully used for troubleshooting injection problems. In this paper we discuss the operation of this diagnostics using the VUV ring as an example.

VUV RING INJECTION SETUP

The beam is injected into the VUV ring through the septum (BUISH) when the amplitudes of the three injection kickers (bumps BUIFB1, BUIFB2 and BUIFB3) are close to their peak values. Fig. 1 schematically shows the locations of the injection hardware and the fast kicker waveforms.

Since the duration of the kicker pulse is 1.3 us and the electron orbital period in the VUV ring is 170 ns the injected beam is affected by the kickers on multiple turns after the injection. This substantially complicates the injection process. At pick-up 5 (see Fig. 1) we installed a dedicated turn-by-turn BPM (Libera Electron [1]) to study and monitor the injection. The Libera unit is synchronized with the VUV ring orbital period and is triggered by the Booster extraction kicker trigger.

Since we can communicate to the machine from MATLAB through the “middle layer” software [2] and since the Libera settings and readings are easily accessible from MATLAB, Accelerator Toolbox (AT [3]) is a natural environment to model the ring injection. Thus we built the injection model by integrating the fast kickers into the AT model of the VUV ring.

The AT provides tools for beam tracking and calculation of lattice functions. Our AT model includes the linear ring lattice as well as kicks from sextupoles. It was calibrated with MATLAB-based LOCO [4].

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BUILDING INJECTION MODEL

Since the kicker waveforms are nearly identical up to a scaling factor, we used the measured BUIFB2 waveform for each modelled bump. In simulations we only use half-wave of the sinusoid and ignore the residual kicker field. Each kicker’s amplitude in the model is scalable, but the width of the waveform is kept constant.

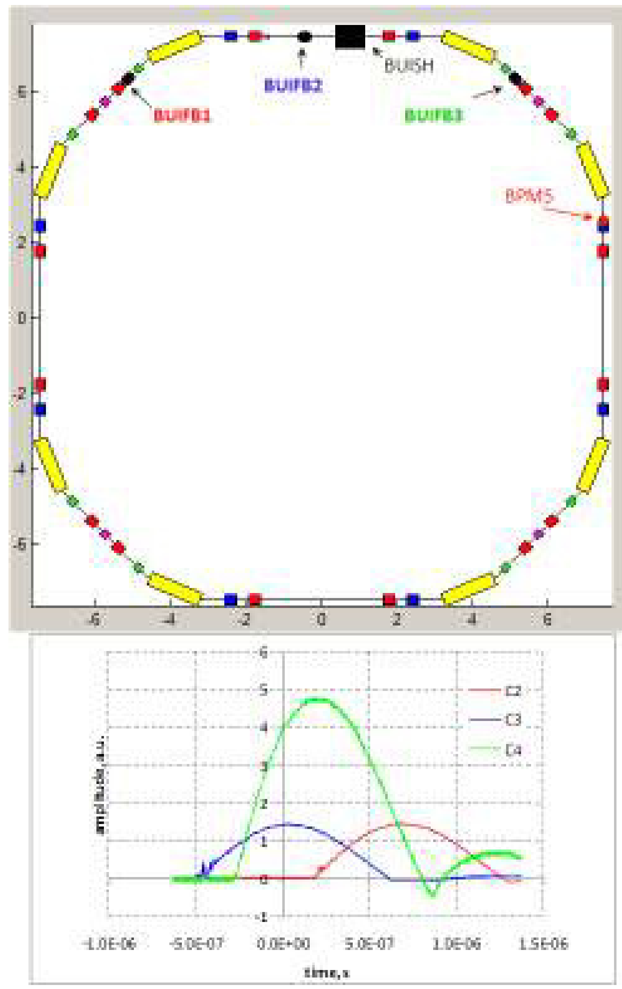

Figure 1: Locations of injection septum and fast injection kickers in the VUV ring (upper plot). The turn-by-turn diagnostics is connected to BPM5. Lower plot shows measured fast kicker waveforms in arbitrary units. Red line is BUIFB1, blue is BUIFB2 and green is BUIFB3.

Initial benchmarking of the model was performed with the stored single-bunch beam. Fig. 2 shows the readings of the TBT BPM over 20 turns versus the model predictions for the stored beam kicked with BUIFB1.

As one can see, there is a good agreement between the model predictions and the measured data. The same level of agreement was obtained for BUIFB2 and BUIFB3, as well as all three kickers turned on simultaneously. The benchmarking was performed both at the stored beam

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energy of 800 MeV and at injection energy of 740 MeV. Good agreement between the model and the measurements was also obtained at various beam currents, from a few milliamps typical for injected beam to more than hundred milliamps.

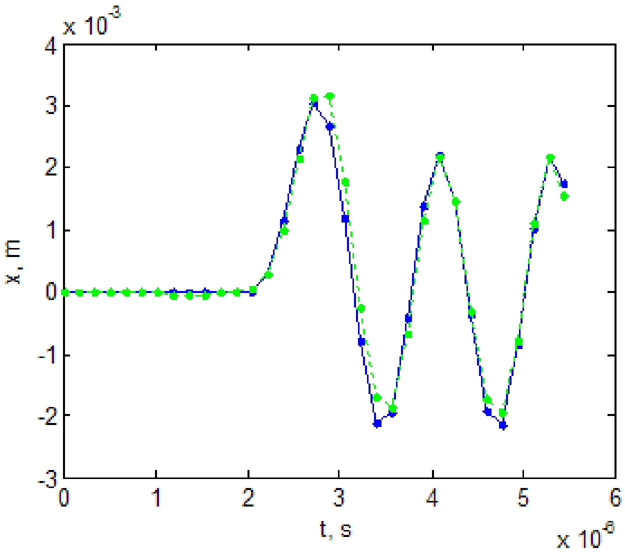

Figure 2: The oscillations of the stored beam kicked by BUIFB1 as read by TBT BPM #5 (green trace) and modelled (blue trace). Each dot represents BPM reading on a single turn.

Our next step was to measure the actual injection with the TBT BPM. We turned off the RF, to make sure that the beam is not accumulating in the ring. The obtained Libera readings are shown in Fig. 3.

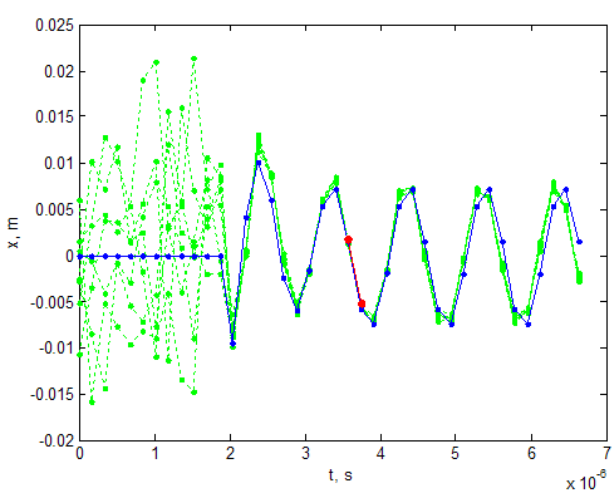

Figure 3: TBT BPM readings of the beam injected into the empty ring (green traces) taken over multiple injections. The noise up to the 12th turn (t≈2 µs) from beginning of the plot shows that there is no beam in the ring. Two red dots show the data we use to calculate the beam coordinates at injection point. The blue line shows the simulated trajectory of the beam injected with these initial coordinates.

As one can see, the injection readings are quite repeatable. The readings taken over multiple injections show that the beam is entering the ring on the 12th turn after the trigger comes to the Libera. This conclusion is confirmed by the sum signal from the TBT BPM buttons.

To find the initial horizontal coordinates (x, x') of the beam at the injection point we first determine x' at the BPM#5 location at the 21st turn (after Libera trigger) from the x-readings at the 21st and 22nd turn. Note, since the kickers are already off by this time we can use a simple single-turn matrix between the turns 21 and 22. Next, we find beam (x, x') at the exit of the injection septum on the 21st turn. Finally, we backtrack, taking into account the effects of the kickers, beam with found (x, -x') through the inversed ring lattice from turn #21 to turn #12 (from the Libera trigger). This gives us the initial beam coordinates at the moment of injection. We also use the found coordinates to simulate the trajectory of injected beam. As Fig. 3 demonstrates, the simulated readings of TBT BPM coincide with the experimental data quite well.

INJECTION MONITORING AND TROUBLESHOOTING

A dedicated software tool was created to monitor and to troubleshoot the injection. It is a MATLAB-based GUI that allows one to control the injection settings, take the readings of TBT BPM and analyze the obtained results by comparing them to the latest injection model. The user interface is shown in Fig. 4.

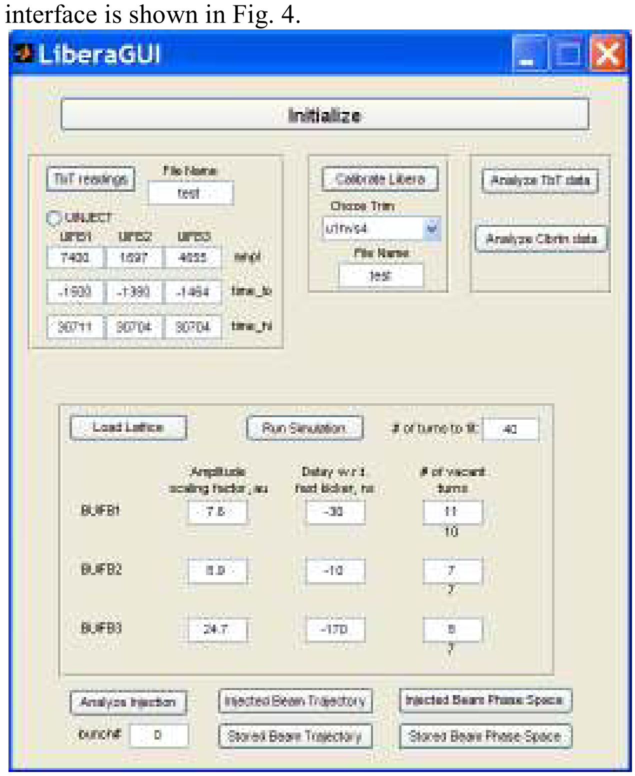

Figure 4: A GUI for the software tool to monitor, analyze and troubleshoot the injection process.

One of the most interesting examples demonstrating the power of the developed injection troubleshooting tools was during the failure of one of the kickers. As a result for some limited period of time we had to operate with two-bump injections, which is fairly unconventional.

The failure of BUIFB1 caused a sharp decline in the injection rate. The measurements of the TBT BPM sum signal showed that a substantial part of the injected beam was lost on the 6th turn after the injection. The analysis of the measured injection data showed that on this turn the beam horizontal trajectory was deflected too much in the injection septum region, causing the beam loss (see Fig. 5).

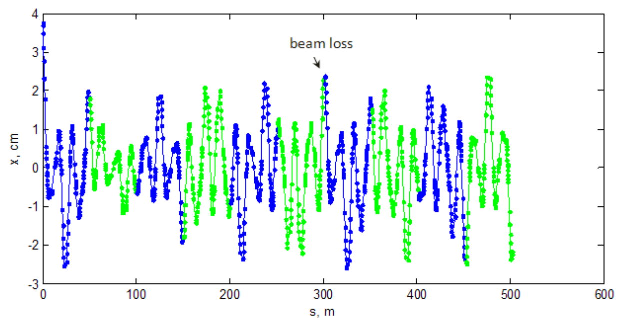

Figure 5: The betatron oscillations of injected beam obtained from the injection analysis. Only two kickers (BUIFB2 and BUIFB3) are operating at nominal settings. New turns start where the line colour changes. The initial s-coordinate corresponds to the injection septum exit on the first turn.

Scanning the kicker settings in our model with BUIFB1 off we found (Fig. 6) that increasing the nominal amplitude of BUIFB3 by a factor of ~1.7 significantly reduces the amplitude of the betatron oscillations of the injected beam.

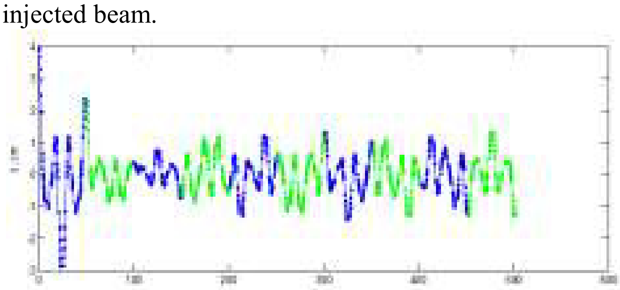

Figure 6: The projected betatron oscillations of the injected beam with only two kickers (BUIFB2 and BUIFB3) operating. BUIFB3 amplitude is set to its nominal value, while BUIFB2 amplitude is increased by factor of ~1.7. New turns start where the line colour changes. The initial s-coordinate corresponds to the injection septum exit on the first turn.

Indeed, when the kickers were set to the settings found in our simulations the beam loss disappeared and the injection rate increased significantly, as demonstrated in Fig. 7.

After BUIFB1 was repaired, as an additional test of our model, we simulated and performed a two-bump injection with BUIFB1 and BUIFB3. Our simulations showed that adjusting the BUIFB3 timing by -340 ns and increasing the amplitude of BUIFB3 by a factor of ~1.4 one can perform a two-bump injection with almost no loss. Measurements with found kickers' settings confirmed our analysis (see Fig. 7).

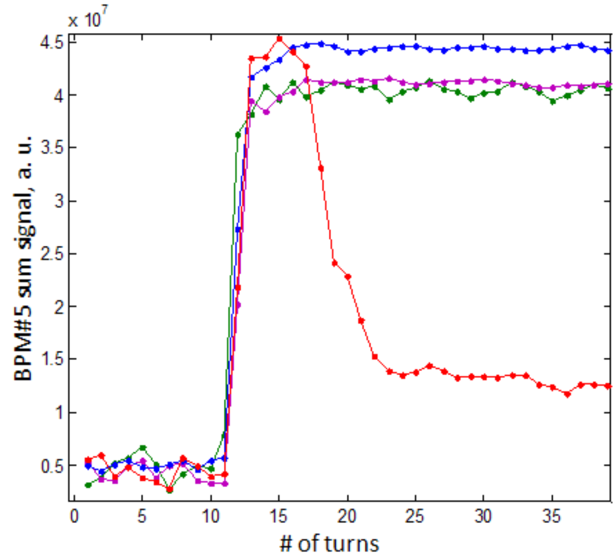

Figure 7: Sum signal of TBT BPM for the injected beam. Each point represents a BPM reading on a single turn. The injection is happening on the 12th turn. The green line represents the nominal 3-bump injection. Red line is two bump injection with BUIFB1 off. The magenta line is the modified two bump injection with increased BUIFB2 amplitude. The blue line is two bump injection with optimised settings of BUIFB1 and BUIFB3.

CONCLUSIONS

In this paper we presented the injection diagnostics tools based on the turn-by-turn beam position monitors installed at the NSLS storage rings. Using the example of the VUV ring we described the procedure of building the relevant injection model. We discussed the software that we developed for monitoring, analysis and troubleshooting of the injection process. As an ultimate demonstration of application of the developed tools we described our successful experience with optimizing a fairly unconventional two-bump injection, which was temporarily used during a kicker failure.

ACKNOWLEDGEMENTS

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