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EXPLORING BEAM DIAGNOSTIC PERFORMANCES OF cSTART USING THE KARA BOOSTER SYNCHROTRON

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Abstract

cSTART is a future storage ring currently under development at KIT with the purpose of investigating various non-equilibrium beam conditions and the injection and storage of laser plasma accelerator (LPA) beams. To understand and control the non-equilibrium beam dynamics at cSTART, various beam diagnostics with demanding specifications are required.

First and foremost, suitable diagnostics are necessary in order to be able to operate the cSTART storage ring even under non-equilibrium conditions with ultra-short electron bunches. The KARA booster has been used as an important tool to explore diagnostics for cSTART due to similarities in parameters, in particular the low electron beam energy (53 MeV) and the relatively high revolution frequency. Several beam diagnostics installed in the booster will be also installed in cSTART, i.e. the BPM readout electronics, the beam loss detection system, etc. In this context, dedicated beam time was used to test the performances of the different beam diagnostics systems, and to prepare for workaround solutions in case of limitations if any. In this paper, we will describe the different experiments, emphasizing the procedures, and highlighting the applied analysis. Moreover, we will discuss the results obtained and elaborate on their indications for the cSTART performance.

INTRODUCTION

The main beam diagnostic systems for the operation of the cSTART storage ring [1] were ordered, and a few were already delivered. Meanwhile, some instrumentation such as the Libera ERXR [2] modified for TBT (turn-by-turn) beam position measurements has been characterized [3]. Moreover, the Libera Digit 500 digitizer [4] for TBT charge measurements in the the VLA-cSR (Very Large Acceptance compact Storage Ring) was also characterized with signal generators such as an AWG (Arbitrary Wave Generator) and with electron beams at FLUTE. In addition to beam position and charge measurements, tune measurements are crucial for understanding and optimizing the beam behavior. These measurements help to determine the stability of the beam and ensure optimal operating conditions. For tune measurements at cSTART, we will use a stripline kicker to be placed at one of the straight sections of the VLA-cSR. To define the specifications of such a stripline, we tried to perform some tests with the stripline electrodes in the KARA booster using different setups.

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KARA BOOSTER

The KARA booster synchrotron shares a few parameters with the VLA-cSR, such as beam energy and fast revolution frequencies (see Table 1). In the booster (see Fig. 1), the electron beam is injected from the microtron once a second and ramped up from 53 MeV to 500 MeV in 0.6 seconds corresponding to the booster cycle. To study the cSTART case, we tried to get the beam conditions in the booster as close as possible to that of cSTART. We store the beam at 53 MeV and clean all but one bunch to store only a single bunch.

Table 1: Parameters of the KARA Booster and the VLA-cSR

	Booster	**VLA-cSR**
Energy (MeV)	53 to 500 w/ ramp	50 to 90 MeV w/o ramp
Harmonic number	44	single bunch
Revolution frequency (MHz)	11.36	6.94
Bunch charge (pC)	10	1 to 200
Bunch length	30 ps	10 fs to 10 ps
Partial tunes (ν_h,ν_v)	(0.18, 0.74)	(0.16, 0.65)

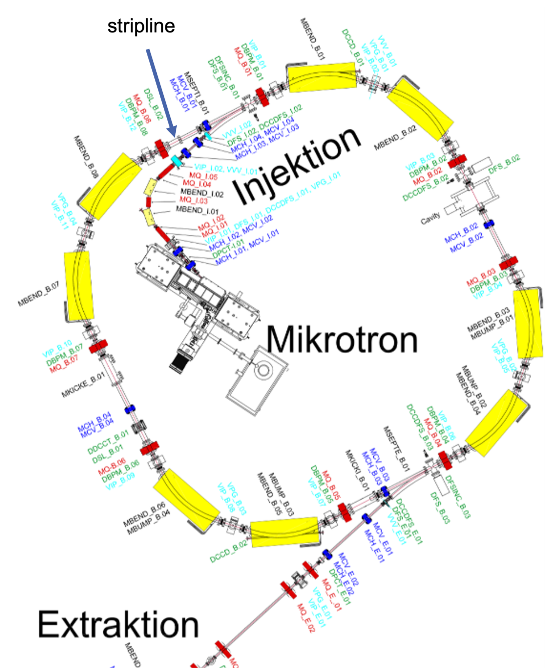

Figure 1: The schematic of the booster synchrotron including all diagnostics and the stripline kicker.

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TUNE MEASUREMENTS IN THE BOOSTER

The stripline chamber in the booster contains four electrodes, each with a length of 15 cm ($\lambda/4$=c*f_{rev}, c=light speed and f_{rev}=11.36 MHz). These electrodes are arranged at a rotation angle of 45° to the horizontal and vertical axes. A few years ago, a Dimtel BBB (Bunch-by-Bunch) feedback system [5, 6] was installed in the booster, and the stripline electrodes are used to provide transverse kicks on the beam. Due to the 45° diagonal arrangement, the transverse BBB system used one stripline to excite the beam in both transverse planes at the same time. This setup was used meanwhile to measure the transverse tunes, mainly the horizontal tune. This was performed over the energy-ramp by looking at the Fast Fourier Transform (FFT) of the beam oscillation provided by the BBB system. Another way to confirm the correct tune measurements was to perform the RF knockout (RF-KO) method, which used the perturbation frequency that corresponded to the betatron tune value to excite transverse coherent motion until the beam is kicked out. A third method of measuring the horizontal tune is to record the turn-by-turn oscillations after the beam had been given a large horizontal deflection by the extraction kicker magnet. It is worth here to mention that the B-BPMs in the booster are readout by the standard Libera SPARK ERXR electronics. The vertical tune was difficult to measure given that the position of the stripline is at the minimum of the β_y (see Fig. 2) which means weak vertical kicks received by the beam.

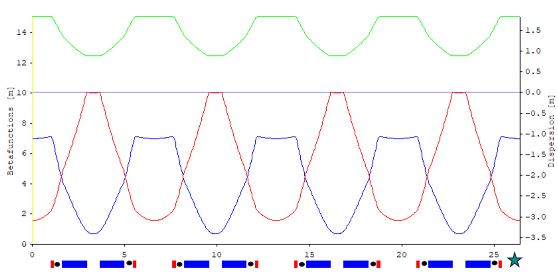

Figure 2: Top: Horizontal dispersion in the booster; bottom: β_x (blue) and β_y (red) along the booster, black circles represent the B-BPMs and the star represents the stripline.

Emulating Tune Measurements at cSTART

In the following, the beam is injected from the Microtron to the booster which was operated with a flat-bottom energy of 53 MeV, with no energy ramping of the magnets or the RF cavities.

Multi-bunch scheme at 53 MeV In these tests, no bunch filling pattern control was applied. In case of ramping, the beam arrives from the microtron (RF frequency= 3 GHz) to the booster (RF frequency =500 MHz) where it undergoes a re-bunching process leading to initial losses, which quickly stabilizes (see Fig. 3). In the case of injecting into the booster without ramping up the energy, the current decays faster and losses occur due to weak radiation damping at 53 MeV (see Fig. 4) and short Touschek lifetime.

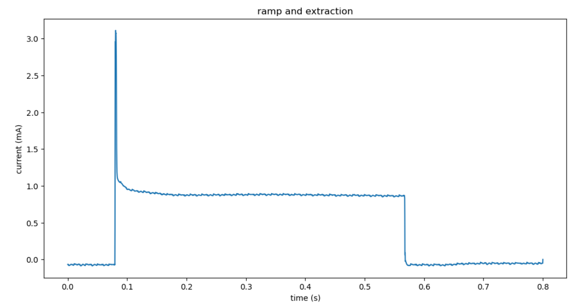

Figure 3: Beam current readout from the booster with a normal ramping cycle.

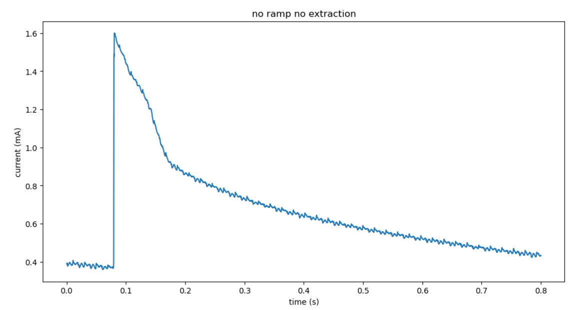

Figure 4: Beam current readout from the booster without ramping and extraction.

We were unable to reconstruct the tune without any external excitation and relying only on injection oscillations. After that, we activated the BBB excitation, thus providing an excitation on the beam with different frequencies and sweeping widths, but this was also not successful. Some expected reasons behind that might be the low currents injected, and thus the noisy TBT signals from the B-BPM readouts. In addition, the stripline has BNC correctors which limit the power allowed to send through. Moreover, we installed a Keysight 33500B waveform generator connected to a Rhode & Schwarz BBA150 broadband amplifier (9 kHz-250 MHz) on another stripline to mainly apply a noise signal to the beam and measure the tune. With a noise signal, we could not reconstruct the tune at any of the available BPMs. ν_x is expected at 2.2 MHz corresponding to 0.18. In contrast, the horizontal tune was beautifully seen on almost all BPMs when a square signal at different frequencies (1, 3, 5 kHz, ..) and a pulse signal (at 1 kHz) (Fig. 5), were applied to the beam. However, we were unable to reconstruct the vertical tune with any of the different waveform signals. For this reason, we prepared a scheme in order to provide only a vertical kick to the beam by connecting the two upper strips in series and one of them being connected to the amplifier and the second to a load. Unfortunately we couldn't measure this setup as the summer shutdown and maintenance period was due.

Single bunch scheme at 53 MeV Here, we wanted to test the single bunch regime in the booster and try to explore the limitations of measuring the tunes with only one bunch.

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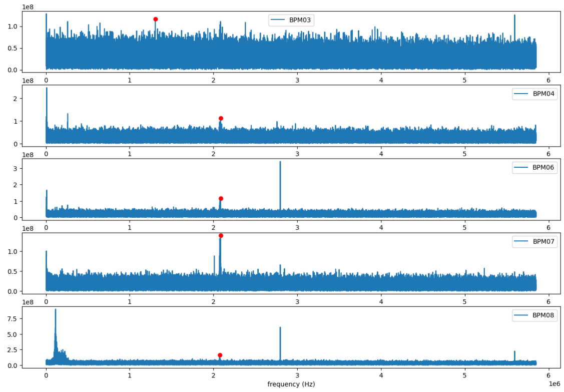

Figure 5: The FFT of TBT data of all available B-BPMs in the booster showing the correct ν_x values at 2.2 MHz when the beam is kicked with a pulse (1 kHz (50 % duty cycle), 100 mVpp).

With the BBB system, we used the cleaning method in which we select a cleaning pattern by choosing which bunches to kick out. With that we were successful in kicking all but one bunch out. We could confirm this by looking at the filling patterns from the BBB system and the current profile in the booster (see Fig. 6).

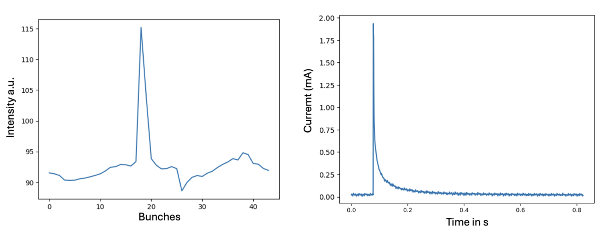

Figure 6: The filling pattern in the booster showing a remaining single bunch (left), and the fast decaying beam current over the booster cycle during single bunch cleaning (right).

SIMULATIONS OF TUNE MEASUREMENTS IN THE VLA-CSR

Preliminary simulations for tune measurements in the VLA-cSR have been carried out using a single kick from the stripline. The stripline will be placed in one of the four straight sections in the VLA-cSR. The simulation considered a perfect lattice, the only simulated noise was the BPM resolution (100 µm RMS). A kick (kick angle= 50 µrad) was performed after 100 turns from injection into the VLA-cSR and turn-by-turn data from all B-BPMs are then observed and analysed for the following 500 turns (Fig. 7). The kick was only performed over one turn. The betatron functions in the arc section of the VLA-cSR are presented in Fig. 8, where positions of B-BPMs and the orbit correctors are shown. The FFT from all B-BPM data showed clearly the horizontal tune expected at ν_x=0.16 (see Fig. 9)

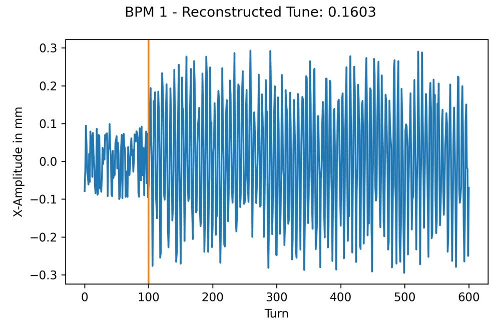

Figure 7: The TBT data from one B-BPM in the VLA-cSR where the kick from the stripline is represented with a vertical orange line.

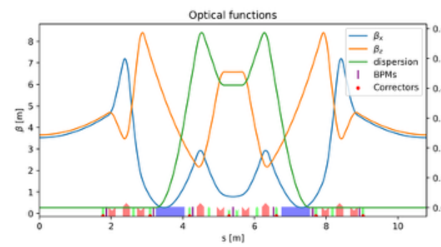

Figure 8: The β_x (blue), β_y (orange), and dispersion functions along the VLA-cSR arc section, showing positions of the button BPMs.

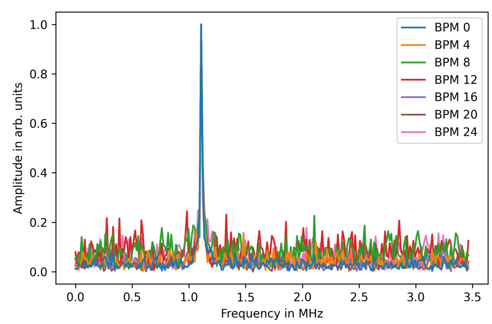

Figure 9: The FFT of the TBT from different B-BPMs in the VLA-cSR showing a nice peak at the tune frequency corresponding to ν_x= 0.16.

Implications on Stripline Design

To be able to reconstruct both transverse tunes, the stripline kicker will have four strips mounted horizontally and vertically instead of diagonally. The kick angle is specified at 100 µrad, further simulations including misalignments and correction schemes will follow to confirm this.

CONCLUSION

The KARA booster is a great tool to test different beam diagnostic performances of cSTART given the synergies between the two rings. Tune measurements were performed in the booster by emulating the cSTART conditions, as well preliminary simulation results were obtained. Further measurements are planned in the upcoming weeks and detailed simulation including misalignment errors and corrections along with diverse noise contributions.

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