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CHARACTERISATION OF THE FORESEEN TURN-BY-TURN BEAM POSITION INSTRUMENTATION FOR THE CSTART STORAGE RING

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Abstract

The KIT cSTART project (compact STorage ring for Accelerator Research and Technology) aims to demonstrate injection and storage of a high-intensity ultra-short bunch using the FLUTE linac as well as a laser-plasma accelerator (LPA). cSTART is planned to operate with a wide range of demanding parameters, such as bunch charge, bunch length, and energy spread (from the LPA), causing challenges for the choice of beam diagnostics with large dynamic ranges that are capable of operating within specifications. Moreover, turn-by-turn measurements are necessary in the cSTART storage ring, as bunch characteristics are expected to dramatically change within a single turn. In this paper, we will describe the planned beam diagnostics system of the cSTART storage ring focusing on the turn-by-turn signal processing and reporting on first characterization tests that were performed.

INTRODUCTION

The ultrashort (down to few femtoseconds) electron bunch injected into the VLA-cSR (Very Large Acceptance compact Storage Ring) of cSTART [1, 2] (see Table 1) will be stored up to approximately 100 ms. The long damping time compared to the storage time will provide us with the opportunity to study non-equilibrium beam dynamics in order to understand and control it. In this context, where beam parameters are expected to substantially change on a turn-by-turn basis, fast beam diagnostics are required. Another challenge for the beam diagnostics is being able to perform within specifications on a wide dynamic range of bunch charge like at cSTART. Standard beam diagnostics are not always able to satisfy the cSTART specifications, and thus customized versions might be required. In the following, we will emphasize the beam position monitoring system and specifically on its customized readout electronics.

Beam Position Diagnostics in the VLA-cSR

For measuring beam position in the VLA-cSR, 29 button beam position monitors (B-BPMs) will be installed (see Fig. 1), i.e. seven B-BPMs per arc and one button BPM in the injection straight. The cSTART B-BPMs, inspired by the B-BPM design of the ESRF (European Synchrotron Radiation Facility) (see Fig. 2) [3], have a diameter of 10.8 mm, a thickness of 2.5 mm and a gap of 250 μm.

Table 1: Main Parameters of VLA-cSR

circumference	43.2 mm
Energy range (no ramping)	40 to 90 MeV
Momentum acceptance	±4 %
Operation mode	single bunch
Revolution frequency (time)	6.94 MHz (144 ns)
Bunch charge	1 pC to 1 nC
Bunch length within one turn	10 fs to 10 ps
Injection rate	1 to 10 Hz
Damping time (h / v / l) at (50 MeV)	(29.5, 26.5, 12.6) s
Nominal momentum compaction	14.8×10^{-3}
Reduced momentum compaction	3.9×10^{-3}

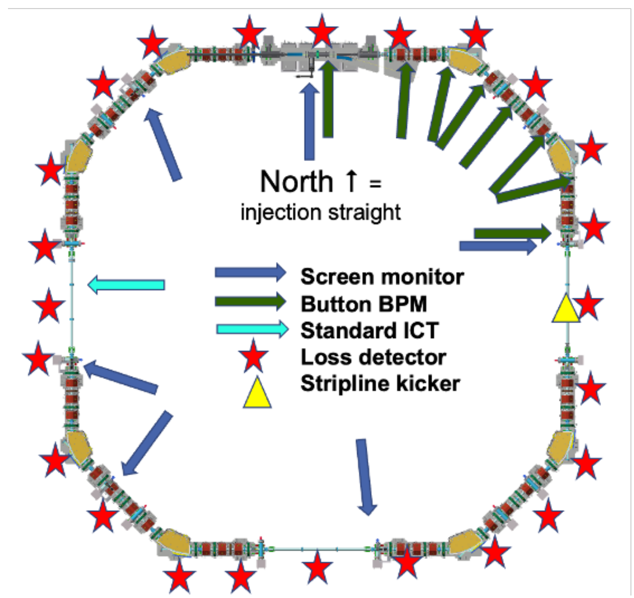

Figure 1: Beam diagnostics for operation in the VLA-cSR: B-BPMs are symmetrically installed in all arc-sections.

For the beam position, we require turn-by-turn measurements (at 6.94 MHz) with a resolution of 100 μm at a bunch charge of 100 pC. At KIT, we gained experience with Libera SPARK ERXR BPM readout electronics for synchrotrons [4] in the KARA booster. However, to comply with the specifications for cSTART, a modified prototype of the SPARK ERXR unit was produced, where a part of the front-end electronics (namely the surface acoustic wave (SAW) filter) has been replaced with a broader bandwidth SAW filter of 33 MHz (standard 15 MHz) keeping the central frequency at 499 MHz and the ADC sampling frequency set

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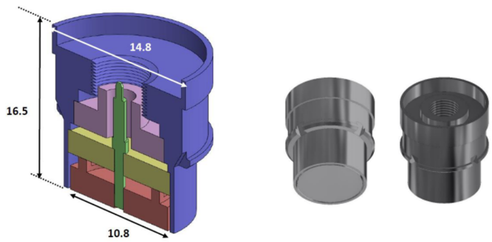

Figure 2: The cSTART B-BPMs inspired by the ESRF design.

to 117.954 50 MHz (which corresponds to 17 ADC samples per turn). The readout prototype receives two triggers, an injection trigger of 1 to 20 Hz and a revolution frequency at 6.9385 MHz.

TESTS OF THE MODIFIED LIBERA SPARK ERXR

Using a Signal Generator

First tests of the Libera SPARK ERXR prototype were performed using a signal generator (see Fig. 3) providing signals with different frequencies, signal amplitudes and signal width. The output of the signal generator was then split using a DC-40 GHz 8-way splitter with 4 channels going to the Libera SPARK inputs and one output to an oscilloscope. The EVG (Event Generator) provided timing triggers to the signal generator, the SPARK unit and the oscilloscope. The generated 6.94 MHz signals were observed with an oscilloscope and with the SPARK (see Fig. 4).

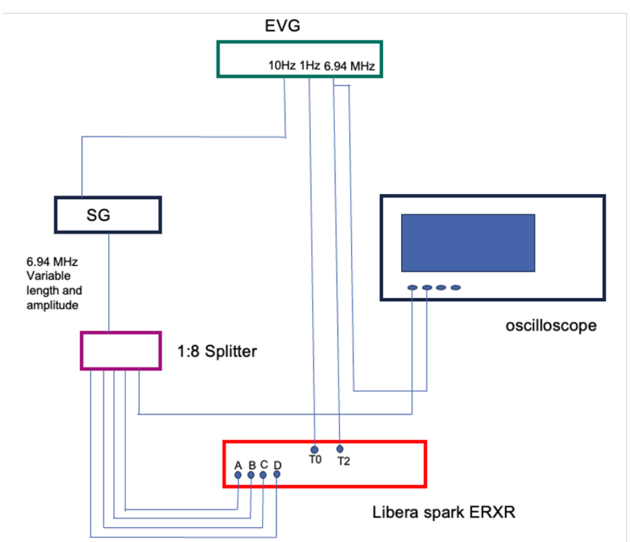

Figure 3: The test setup of the Libera SPARK ERXR prototype using an event generator (EVG) and a signal generator (SG).

Overlapping between successive turns To confirm the absence of overlapping signals between successive turns, a dedicated test was carried out that involves the variation of the Libera SPARK internal trigger delays. The signal generator delivered signals at 5 Hz so as not to fill successive turns (internal buffer memory) in the SPARK. The trigger delay in the SPARK was set in such a way as to place the signal in turn number 5; to the first order. The trigger delay was then varied over two turns (34 ADC samples) and the processed ADC counts "X" (see Eq. (1)) was then calculated for turns 5, 6 and 7. The results are shown in Fig. 5 where the dashed oval highlights the maximum reached ADC count in turn 6 where a minimum leakage of the signal is still present in turn 7 and estimated to be approximately in the order of 6 %. We consider this overlap small and acceptable for cSTART.

$$X = \sqrt{\sum_{i=1}^{17} x_i^2} \tag{1}$$

Dependency of position measurements over pulse length To confirm that the position measurements with the Libera SPARK in cSTART are acting in the same way at different bunch lengths, we performed a test using a Tektronix arbitrary waveform generator (AWG) (50 GSps) [5]. We used the AWG to generate square signals down to 50 ps (minimum reachable) and up to 1 ns, while keeping a relatively constant peak amplitude at 240 mV. For each pulse length, we measured the power of the 499 MHz component of the AWG signal with a spectrum analyzer and calculated the integrated ADC samples (following Eq. (1)) in channel A of the SPARK unit. The results are then plotted in Fig. 6, which confirms that the SPARK is picking up the 499 MHz component non-deformed regardless of the pulse length. Furthermore, in order to understand the case with Gaussian beams, we calculated the power of the 499 MHz component of a Gaussian signal over the same range of pulse lengths (blue curve in Fig. 6).

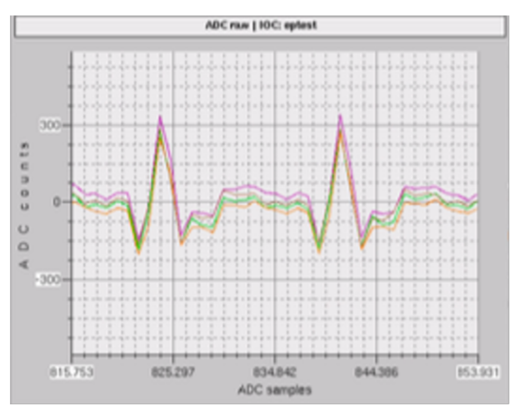

Figure 4: The raw ADC counts of the generated 6.94 MHz on the four Libera SPARK channels.

Using the Electron Bunch at FLUTE

Resolution against bunch charge A prototype of the cSTART button BPM block was installed at the end of the

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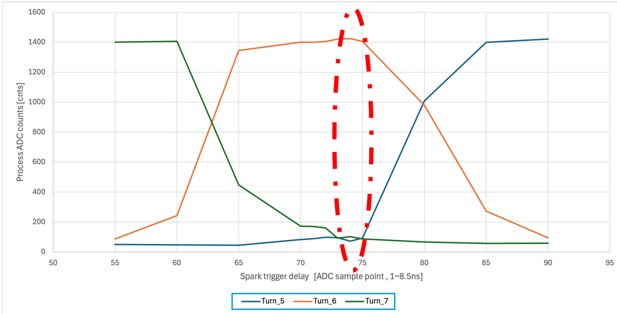

Figure 5: The processed ADC counts calculated for turns 5, 6 and 7 as a function of ADC samples while varying the delay trigger in the SPARK.

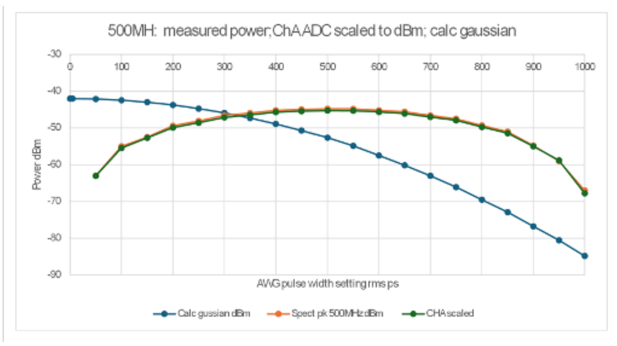

Figure 6: The power of the 499 MHz frequency component of the square signal from the AWG against the pulse length as measured with a spectrum analyser (orange), with the SPARK (green) and as calculated for a Gaussian signal (blue).

FLUTE linac. FLUTE (Far-infrared Linac and Test Experiment) [6, 7] will be used as one of the injectors to inject ultrashort bunches into the VLA-cSR, and thus we can use it to characterize the resolution of the beam position measurements with the modified Libera SPARK unit. Unfortunately, one of the four button BPMs was short-circuited, and thus we could not conduct absolute position measurements. To measure the resolution of the SPARK unit against the bunch charge, we chose to split one button signal using a 1:4 splitter and connect it to the four channels of the SPARK unit (see Fig. 7). The FLUTE bunch charge was then varied by varying the settings of the gun laser, and was read out using a Turbo-ICT upstream of the B-BPM block. The bunch charge seen at the SPARK inputs is then called the effective bunch charge and is a fourth of the actual ICT measured bunch charge. Moreover, the FLUTE linac was tuned to get a centered beam in the vicinity of the B-BPM block by observation on the last screen upstream of the B-BPM. FLUTE injection frequency was set to 5 Hz.

For each bunch charge, the average of the processed ADC counts of the signal on one channel of the SPARK over 100 shots was calculated. These values were then used to repeat similar tests with the signal generator by varying the amplitude of the generated signal to correspond to the SPARK measurements with bunch charge. The standard deviation of the SPARK calculated TDP (Time domain processing) position represents the resolution of the turn-by-turn measurements. The horizontal beam position resolutions at different effective bunch charges are plotted in Fig. 8 for measurements with the signal generator and the FLUTE bunch. The results show good agreement between both measurements. An estimated resolution of 100 μm at 50 pC is deduced, which is satisfactory.

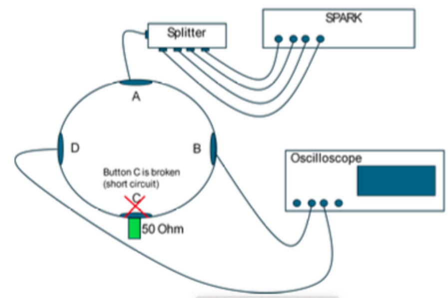

Figure 7: The setup of the characterisation tests of the SPARK connected to the B-BPM block at the end of FLUTE Linac.

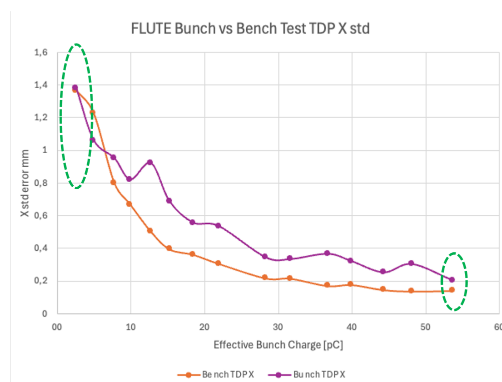

Figure 8: The resolution of the horizontal position measurements as a function of the bunch charge as calculated from tests with a signal generator (orange) and at FLUTE (purple).

CONCLUSION

Characterization tests of cSTART's modified Libera SPARK ERXR showed that the measured beam position resolution is aligned with the cSTART specifications. Furthermore, to improve the resolution at lower bunch charges, we plan to test low-noise RF amplifiers.

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