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IMPLEMENTING BUNCH-BY-BUNCH DIAGNOSTICS AT THE KARA BOOSTER SYNCHROTRON

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Abstract

In the upcoming compact STorage ring for Accelerator Research and Technology (cSTART), LPA-like electron bunches are only stored for about 100 ms, in which the equilibrium emittance will not be reached. Therefore, to measure parameters such as bunch profiles, arrival times and bunch current losses, bunch-resolved diagnostics are needed. The booster synchrotron of the KARA accelerator accepts pre-accelerated bunches from a racetrack microtron and accelerates them further over a 500 ms long energy ramp. As the KARA booster synchrotron has a similar circumference and injection energy as the cSTART storage ring, new bunch-by-bunch diagnostics developed there can be transferred to the cSTART project with minimal effort. Currently the diagnostic system of the booster is not designed for bunch-by-bunch diagnostics, thus after using the booster as a testbed for cSTART, such a system could be used permanently. At the booster synchrotron we use the picosecond sampling system KAPTURE-II to read-out a button beam position monitor and an avalanche photo diode at the synchrotron light port.

INTRODUCTION

At the KARA booster [1, 2] ($C = 26.4\,\text{m}$) we develop diagnostic methods, which have similar repetition rate and resolution requirements like the storage ring ($C = 43.2\,\text{m}$) in the project cSTART [3, 4], because the rings' circumferences are very similar. At cSTART the storage time of the beam (about 100 ms) will be shorter than the damping times ($> 12\,\text{s}$). To investigate the non-equilibrium dynamics in the storage ring, turn-by-turn (TBT) diagnostics are required. To also get information on every bunch, in addition to TBT, also bunch-by-buch (BBB) processing is needed.

At the KARA booster we use several commercial Libera Spark ERXR BPM TBT devices from Instrumentation Technologies [5]. These units can keep several 10k revolutions with about ten samples per revolution in a buffer after a trigger signal. For the booster this equals a capture time of several milliseconds. Decimated continuous streaming is also available with a sample rate of about 100 kHz or 1 sample per 110 turns.

For BBB acquisition, higher sampling rates and buffer sizes are needed. An oscilloscope is one default tool for digitizing non-stationary time signals. This is done by sampling the signal in equidistant intervals and chopping it into segments by means of a trigger. If the bunch length is high compared to the RF bucket distance, this equidistant sampling is sensible. For very short bunches, most samples would be zero and the local sampling rate of the bunch would be too small. Other issues are minimal trigger hold-off periods, which prevents capturing consecutive turns and limited buffer memory sizes. Often the trigger system is limited and cannot do segmented acquisitions (on a primary trigger source) with a separate segment trigger on a secondary external source.

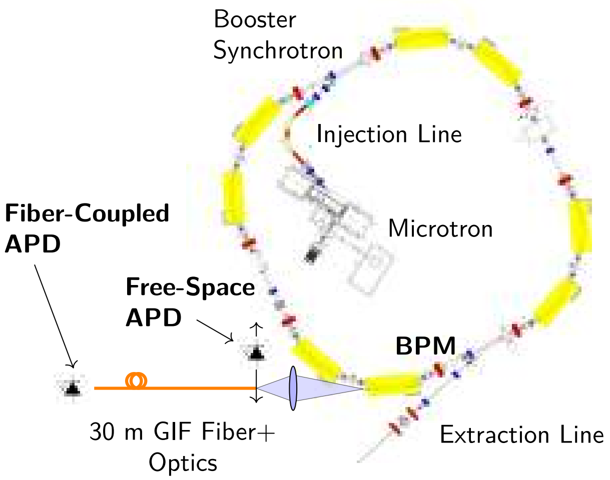

Figure 1: Booster synchrotron of KARA with added diagnostic elements; used detectors highlighted in bold.

The picosecond sampling system KAPTURE-II [6] has eight separate channels which can be used to either sample eight different detector signals or sample individual bunches at eight different times via an RF power splitter. An ultra-fast track-and-hold unit in combination with a picosecond delay chip allows setting the exact sampling points with 3 ps steps along the bunch. With a revolution trigger and a secondary external trigger, it is possible to start the capturing of full turns/segments in sync with the beginning of every injection. Through the PCIe/DMA streaming capabilities it is possible to digitize each bunch in every turn of a booster cycle of about 600 milliseconds.

With the setup shown in Fig. 1 we aim to use a fiber-coupled photo diode as the detector and verify the measurements with a button BPM.

BUTTON BPM SETUP

The four button plates of the BPM are combined with an RF power combiner. The resulting sum signal is largely independent of the beam position and is routed through a 30 m coaxial cable to the diagnostics lab. There, three

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14 dB/4 GHz RF amplifiers are used to match the BPM signal level to the input of the oscilloscope and KAPTURE-II.

FIBER-GUIDED SYNCHROTRON LIGHT SETUP

To prevent high-end readout electronics from being damaged by radiation, they should not be placed inside the booster enclosure. Also the booster is not equipped with an optical beamline to guide the synchrotron radiation from the dipole magnets to the outside of the enclosure. Therefore, here we study the feasibility of a cost-effective fiber optical solution to bring the synchrotron radiation to the diagnostics lab. This would also allow to use the same detector and readout electronics for different locations by changing fibers or using an optical switch, which would also be beneficial for use at cSTART.

The optical fiber should have a high product of acceptance angle and fiber diameter, called etendue, to capture as much light as possible [7]. However the modal dispersion of large diameter multi-mode fibers is in the order of several hundred picoseconds per meter, which would distort the signal too much. Therefore we use a 65 µm gradient index fiber, which only suffers from minimal modal dispersion. The 30 m long FC/PC terminated fiber connects a 20 mm diameter manually focusable collimator with focal length 40 mm to the diagnostics lab. The collimator optics are near-infrared anti-reflex-coated to reduce losses due to reflections.

Various detectors, from very fast to very sensitive, can be used in the diagnostics laboratory. The results presented here were measured with a fiber-coupled avalanche photodiode (APD). The Thorlabs APD450C features a bandwidth of 0.3 MHz to 1600 MHz and is optimized for 1260 nm to 1620 nm.

Alignment Procedure

The fiber collimator reacts very sensitively to misalignment, as shifts and small tilts move the focal spot, which is similar in size to the fiber, away from the fiber end plane. For alignment, synchrotron radiation is needed, so the accelerator needs to be in operation. However, the booster enclosure cannot be entered in this case, making manual adjustments impossible. Thus a six degree of freedom (DoF) hexapod platform is used (see Fig. 2). It allows the assembly to be moved in all three spatial axes as well as tilted by 10 degrees around these axes.

We carried out the alignment parasitically during normal operation. This means that the magnets ramp from 53 MeV to 500 MeV once per second over 600 ms. There is no orbit correction during the ramp and the corrector magnets are not ramped at all. Therefore the beam orbit is not constant and the focal point of the synchrotron radiation moves. This is especially visible near the end of the ramp, where the dipole flux is at a flat top but the bumper magnets ramp to prepare the beam for extraction, see Fig. 3. If the alignment of the collimator assembly is optimized for a spot on the bumper curve, it is not possible to get any signal at times right after the injection. After injection, the radiated synchrotron light power changes largely with rising beam energy. Thus for low energies using the marginal regions of the focal spot are especially unfeasible.

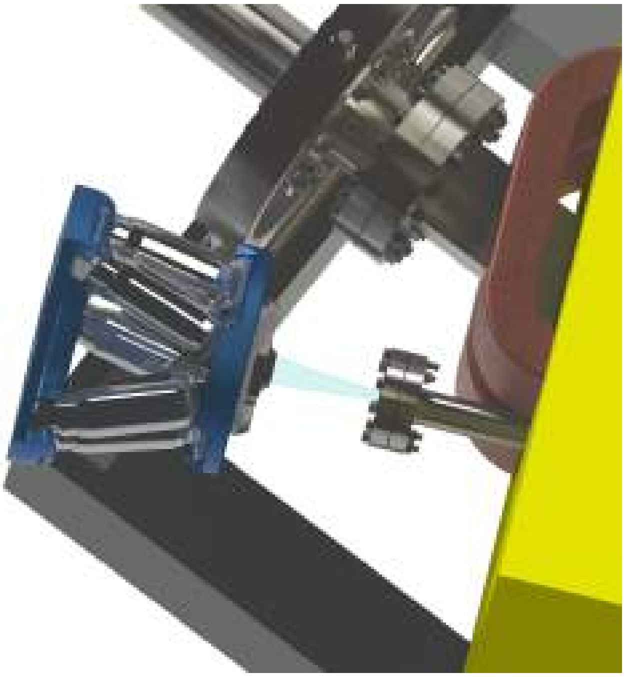

Figure 2: Six degree of freedom hexapod platform to align the fiber collimator to the synchrotron light beam coming out of one dipole magnet (Illustration shows hexapod as far away from the window as possible).

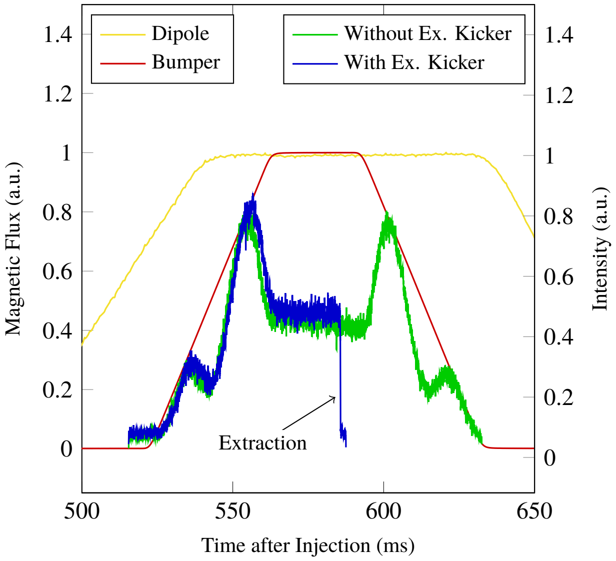

Figure 3: Relation between measured photo detector intensity and magnetic flux in the dipole and bumper magnets; zoomed in on bumper/dipole plateau. The observed intensity fluctuations are due to the movement of the focal point caused by the bumper magnet, which pushes the beam towards the outer wall in preparation for extraction.

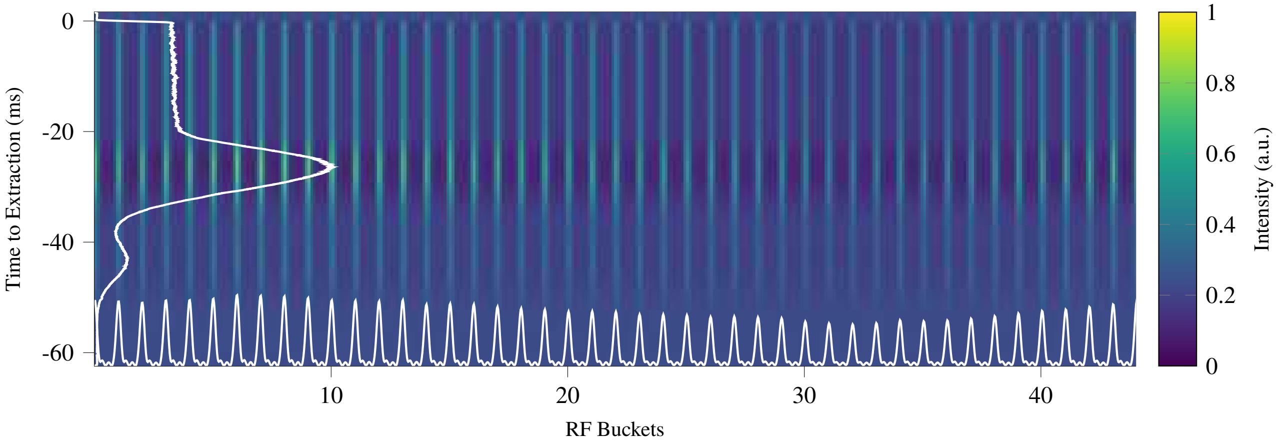

Figure 4: Measurement with a 4 GHz oscilloscope resolving all 44 bunches in the booster; only about 1 out of 100 turns is captured; projections of the 2D signal on the coordinate axes are shown in white. The profile on the left axis corresponds to the blue trace in Fig. 3.

With the collimator assembly adjusted for highest optical intensity just before extraction, the measurement in Fig. 4 was taken. It shows that up to approx. 50 ms before extraction, the fiber collimator is outside the focal point of the synchrotron radiation. Maximum capture efficiency is achieved while the bumper pushes the beam outwards. This is reproducible, as can be seen in Fig. 3 without the extraction kicker, in which the electron beam returns to the starting position without the influence of the bumper.

MEASUREMENTS WITH KAPTURE-II

To verify the measurement method with KAPTURE-II, two of the eight channels of KAPTURE-II are used: One is connected to the BPM and amplifier setup, while the other one is connected to an avalanche photo diode placed directly on the hexapod inside the booster, removing the influence of the fiber and collimator. Using only one KAPTURE-II channel per detector limits the system to only one sample per bunch on this detector.

The APD measurement in Fig. 6 compared to the BPM in Fig. 5 shows only noise right after injection but after about 100 microseconds, a clear filling pattern is observed, which indicates the focal point is properly adjusted. The shape of the 2D filling patterns of APD and BPM do not match. This is most likely due to the optical measurement with the APD depending on beam orbit, while the BPM measurement does not.

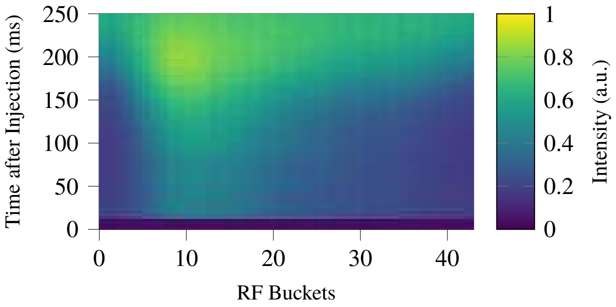

Figure 5: KAPTURE-II measurement with sum signal of one button BPM capturing one sample of every bunch in the booster.

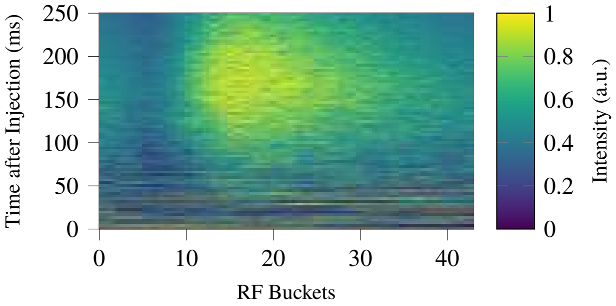

Figure 6: KAPTURE-II measurement with an avalanche photo diode mounted in the booster capturing one sample of every bunch in the booster.

OUTLOOK

With all eight channels of KAPTURE-II fully calibrated, it is possible to fit e.g. Gaussian profiles to measured samples and thus extract for each bunch parameters like bunch length and the bunch arrival time [8]. The adoption of faster photo detectors can open up the possibility of studying rebunching effects from 3 GHz to 500 MHz after the booster injection. Finally, the system should be integrated into the EPICS control system to show the operator a summary of every injection cycle to aid in optimizations.

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