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# TRANSVERSE AND LONGITUDINAL PROFILE MEASUREMENTS AT THE KARA BOOSTER SYNCHROTRON

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*Abstract*

In the booster synchrotron of the Karlsruhe Research Accelerator (KARA), the beam is injected from the microtron at 53 MeV and ramped up to 500 MeV. Though the injected beam current from the microtron to the booster seems good, the injection efficiency into the booster is currently low due to various effects. Consequently, an upgrade of the whole beam diagnostics system is taking place in the booster, in order to improve the injection efficiency through understanding the loss mechanisms and the behavior of bunches. Among these diagnostics tools are beam loss monitors, a transverse profile monitor and a longitudinal profile monitor. In this paper, we will describe the setups used for bunch profile measurements in both transverse and longitudinal planes and report on first data analysis results.

## INTRODUCTION

The injection complex of KARA [1](see Fig. 1) consists of a thermal DC electron gun (CW and pulsed mode), which generates a 90 keV electron beam, a racetrack microtron, which increases the beam energy to 53 MeV, and an injection line, which transports the beam to the booster where it is injected off-axis on a multi-turn scheme. The booster then ramps up the beam energy from 53 MeV up to 500 MeV in a cycle of 1 s. The booster parameters are summarized in Table 1. Recently, an upgrade of the booster's diagnostics system took place. This includes the installation of a new beam position monitor (BPM) readout electronics based on Libera Spark [2], a Dimtel Bunch-By-Bunch feedback system [3] in both horizontal and vertical planes, four Libera beam loss scintillators [2] near the injection and extraction septa, a CCD camera for transverse profile measurements and the preparation of infrastructure and equipment for longitudinal profile measurements. Moreover, various measurements and beam diagnostics tests are planned in the booster to predict the expected behaviour of some diagnostic tools in cSTART [4], a KIT project. In the following, we will describe the experimental setups for transverse and longitudinal profile measurements and report on recent results.

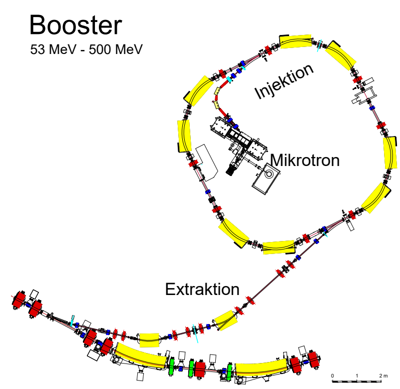


Figure 1: The schematic of the injection complex of KARA storage ring. Courtesy of U. Herberger, KIT.

Table 1: Important Parameters of the KARA Booster Synchrotron

| Parameter | KARA booster |
|---|---|
| Filling pattern | CW or single bunch |
| Energy | 53 MeV to 500 MeV |
| Circumference | 26.4 m |
| Revolution frequency | 11.36 MHz |
| RF frequency | 499.74 MHz |
| Harmonic number | 44 |
| Beam current | 5 mA |

## TRANSVERSE PROFILE MEASUREMENTS

Two synchrotron light ports (vacuumed) exist in the booster on two bending magnets, one after the injection point and one after the extraction point. For our transverse profile measurements we used the optical window near to the injection point, on which we mounted directly a prism and a CCD camera at 90° (see Fig. 2). The CCD camera is powered with a power-over-ethernet (PoE) scheme and synchronized to the injection trigger. We used two types of filters, a neutral-density (ND) filter and a broadband filter (model: FB500-40 [5]) for the transmission of green light in the range of 480 nm to 530 nm. It is worth mentioning that these filters needed to be removed when taking data at the fixed energy of 53 MeV, as due to the lower critical frequency of the SR radiation at injection energy the intensity of the radiation in the spectral range of the camera was too low with the filters. Furthermore, to avoid saturation

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in the camera, we set appropriate exposure times for different measurement conditions (dominantly beam energy and beam current). We assume that the source of the synchrotron light is the center of the bending magnet (740 mm from the aperture of the port/prism) and the distance from the prism to the camera is 83 mm. The calibration of the camera took place with a 5 mm square paper, where we placed the paper at 1.2 m (740 mm + 83 mm) from the camera and converted the pixels to mm. The calibration curve is presented in Fig. 3 and the calibration value is given by the slope of the fit which is 21 pixel/mm in this case.

Figure 2: The experimental setup of the CCD camera in the booster.

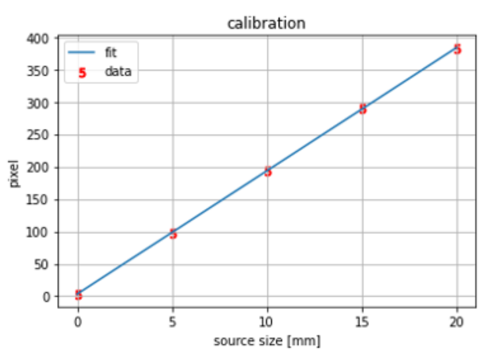


Figure 3: The calibration plot of the CCD camera´s lens.

To have an idea of the expected beam size values in the booster, we estimated the beam sizes at 500 MeV ($\sigma_x$ = 0.63 mm and $\sigma_y$ = 0.12 mm) from the design values of the emittances ($\epsilon_x$=150 nm · rad and $\epsilon_y$=2.3 nm · rad [1]) and the $\beta$-functions at the center of the bending magnet ($\beta_x$=2.7 m and $\beta_y$= 7.2 m). Measurements were taken before the latest accelerator shutdown in May. The results are shown in Fig. 4. The double core image seen just after injection at 53 MeV is mainly due to the fact of injecting on a multi-turn scheme with a kicker on the opposite side of the injection point. During ramping the two cores merge to a single core and we can clearly notice the beam size shrinking in both planes. Results of the beam size measurements and fits are summarized in Table 2. Measurements at different time stamps and thus different beam energies were achieved by delaying the trigger on the CCD camera by a few ms to a few hundred ms. The beam energies are derived from the ramping profile of the booster magnets. The data is thus integrated over all bunches and over several revolution periods (the number of revolution periods depends directly on the exposure time of the camera).

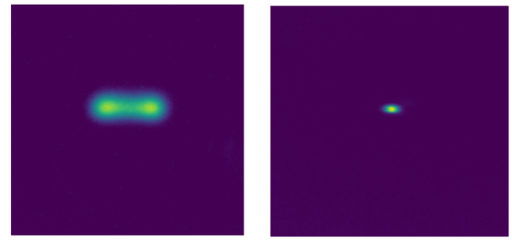

Figure 4: The synchrotron light image from the CCD camera in the booster before the shutdown, directly after injection at 53 MeV (left) and at the end of the ramping at 500 MeV (right).

Table 2: Measured Beam Sizes in the Booster Before the Shutdown in May

| **Beam energy (MeV)** | $\sigma_x$ **(mm)** | $\sigma_y$ **(mm)** |
|---|---|---|
| 53 | 2.2 | 0.85 |
| 100 | 2.1 | 0.93 |
| 150 | 1.75 | 0.95 |
| 200 | 1.43 | 0.93 |
| 250 | 1.18 | 0.8 |
| 300 | 0.93 | 0.7 |
| 350 | 0.8 | 0.63 |
| 400 | 0.7 | 0.55 |
| 450 | 0.68 | 0.48 |
| 500 | 0.75 | 0.4 |

After the shutdown, we observed a vertical blowup at higher energies in the booster (from around 350 MeV) (see Fig. 5), which is not yet understood. A few tests are planned to investigate the origin of such a blow-up.

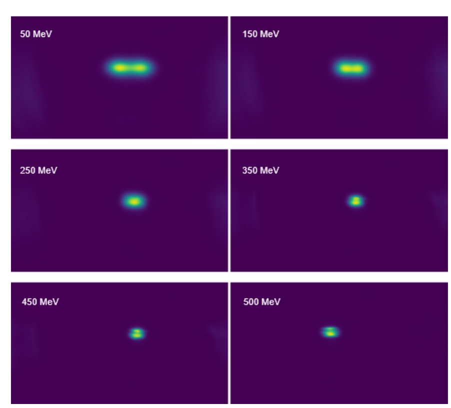


Figure 5: The synchrotron light image from the CCD camera at different beam energies after the shutdown, where a vertical blowup appears starting at about 350 MeV.

This observation already highlights the importance of performing transverse profile measurements to understand

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the beam dynamics in the booster as a step to improve the injection efficiency.

## LONGITUDINAL PROFILE MEASUREMENTS

To provide an insight on the longitudinal profile measurements in the booster, we combined the signal from the four pickups of a button BPM using a power combiner and we transported the signal to an experimental hutch outside of the booster radiation shielding wall via a 35 m coaxial cable. On the way, the sum signal is amplified with three pre-amplifiers of around 14 dB amplification each and readout with an oscilloscope. We triggered the oscilloscope to acquire one data-set every 231 turns of the booster for one injection resulting in about 30 000 measurement points per cycle. In each data set we acquired 200 ns of data corresponding to one and a half booster turns. The injected beam from the microtron to the booster is expected to have the temporal length in the order of 1.6 µs [1]. Given the mismatch in the RF frequencies between the microtron (3 GHz) and the booster (500 MHz), a re-bunching of the long beam arriving from the microtron takes place along with significant beam losses. After re-bunching is finished and by the start of ramping in the booster, the bunch length is expected to get shorter with energy. A plot of the measured bunch shape at 0.15 s, 0.5 s and 0.7 s after injection is presented in Fig. 6, where the bunch is very broad (with a non-defined shape) in the beginning of the booster cycle and gets more defined and shorter until the end of the ramping cycle. To get the bunch length over the energy ramp, we fitted all the bunches of each data set with a Gaussian fit individually. We then calculated the mean and standard deviation (std) of the $2 \cdot \sigma$ of the Gaussian fit, i.e. the rms bunch length, over all the bunches in the data set. Figure 7 shows a moving average over the mean values of the bunch lengths and their std as a measure for the statistical error (± one std) over a window of 1 ms (corresponding to 50 data sets).

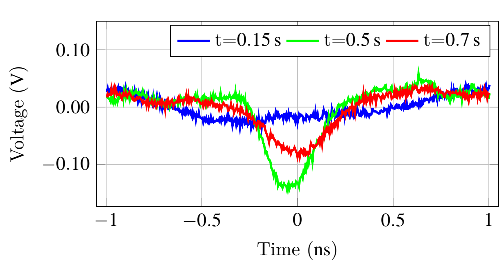


Figure 6: The bunch shape at three different time delays after the injection in the booster. Note: the signals have a negative polarity.

At the KARA storage ring (500 MeV to 2.5 GeV), we perform longitudinal profile measurements with a streak camera [6] placed at the optical light port. We plan to use the same streak camera for longitudinal profile measurements

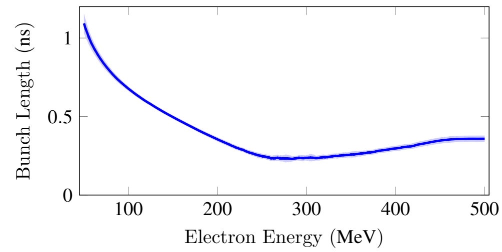


Figure 7: The fitted bunch length in the booster as a function of energy (blue line) along with errors (light blue band).

in the booster by transporting the synchrotron light from the booster to the optical light port via fiber optics, while a fiber optics adapter for the streak camera will be used. A photo-diode with a digitizer allows to measure the longitudinal profile, which will be used too. This will enable us to compare different methods of profile measurements and check the reliability of each at different bunch and booster conditions.

## SUMMARY

A substantial effort has been put to upgrade the diagnostics system of KARA´s booster synchrotron aiming to improve the bunch conditions and the injection efficiency. Few preliminary tests and measurements of the transverse profile using a setup with a CCD camera, and of the longitudinal profile through reading the sum signal from a button BPM with a real-time oscilloscope, have been achieved. Expected behaviours of the transverse and longitudinal profiles as a function of the beam energy have been observed. However, a vertical blowup at higher energies in the booster after the shutdown in May was seen, which is still not clear and under investigation. Such measurements are very useful to clearly understand the beam dynamics in the booster as a step to improve it. For this reason, the combined view from the BPMs, the profile and the tune measurements along with the BBB feedback system can bring improvements of the booster synchrotron operation.

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