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COMPARISON OF FESCHENKO BSM AND FAST FARADAY CUP WITH LOW ENERGY ION BEAMS

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Abstract

A comparison between Fast Faraday Cup and Feschenko longitudinal bunch shape detectors was recently performed at HELIAC Advanced Demonstrator beamline at GSI. Feschenko bunch shape monitor (BSM) uses the time to space conversion by means of secondary electrons emitted from a wire correlated to a rf deflector [1], while the fast Faraday cup (FFC) measures the deposited charge in a cup geometry matched to 50 Ω. The FFC design aims to minimize the bunch shape dilution due to field polarization and secondary electrons produced on irradiation [2]. An He^{1+} with 100 µA average current and 1.4 MeV/u kinetic energy is utilized for this comparison. A buncher upstream of the detectors was operated to focus the beam longitudinally. The results are discussed in this contribution.

INTRODUCTION

Longitudinal charge distribution measurements are essential for the commissioning and optimization of linear accelerators. The emergence of new nonlinear beam dynamics concepts employing a variation of particle synchronous phases different from the traditional -30 deg resonance acceleration pattern, e.g. KONUS [3], EQUUS [4] has called for better understanding of longitudinal phase space and relevant instrumentation. Charge distribution measurements of non relativistic heavy ions beams are not feasible with electromagnetic-field sensing devices like capacitive pickups because the field distribution is elongated in comparison to charge distribution. A commonly used instrument for longitudinal beam profile measurements is the Feschenko bunch shape monitor (BSM), which relies on the time-to-space conversion of electrons emitted when the beam interacts with a wire [5]. Alternatively, there has been several designs for a Fast Faraday Cup (FFC), which intend to avoid the induction of image charges on the cup before the charges are deposited on the cup while maintaining a 50 Ω geometry [6–8]. Recently, longitudinal charge distribution measurement using coherent transition radiation in GHz regime has been investigated [9]. Although BSMs and FFCs are widely used, no benchmarking of these devices among each other is known to us. In this contribution, we compare both of these monitors under similar beam and machine conditions and the experimental results are discussed.

The tests were performed at the Helmholtz Linear Accelerator (HELIAC) *Advanced Demonstrator* beam line at GSI [10]. The HELIAC components marked in grey were not installed. Various charge states and ion species were delivered to the test setup by the GSI High Charge State (HLI) injector with an kinetic beam energy of 1.4 MeV/u and a duty cycle of up to 25 % in the regime of some 30-100 µA average current. The beam line is equipped with phase probe sensors, a slit-grid emittance measurement device, beam position monitors, beam profile grids as well as Feschenko BSMs. Recently a test Fast Faraday Cup was made available on loan from Fermilab for comparison with Feschenko BSMs, which was installed to the preliminary line setup with a beam pipe substituting the cavities. The test beamline (with the cavities to be installed) is shown in Fig. 1.

BUNCH SHAPE MONITOR

The bunch shape monitor of Feschenko type provides for precise measurements of heavy ion beams with an accuracy of up to ±0.5 deg at an rf frequency of 108 MHz [5]. It consists of three main parts: a thin filament in the beam line, an optical system and an electron multiplier. The thin filament is irradiated by the heavy ion beam, and thus emits secondary electrons in all directions. The optical system, which is entered by the secondary electrons through a pinhole at the border of the beam pipe, provides for the suppression of noise and translates the time dependent electron current $I(t)$ to a spatially resolved signal $I(z)$, primarily with use of an deflecting electric field. A narrow part of the spatial signal is steered to enter the secondary electron multiplier, where it is measured. Thus, $I(z)$ is scanned successively by steering and subsequently available for readout. The installed version of the Feschenko BSMs optical system features additional bending magnets for further noise reduction [1].

A measurement series with the Feschenko-BSMs has been successfully used to calculate the longitudinal phase portrait of the bunch with use of an advanced tomographic reconstruction technique at the HELIAC *Advanced Demonstrator* beam line [11]. Although a useful device, there are couple of shortcomings of the BSM, first of which is the averaged nature of the measurement, i.e. measurement at each phase is a different macropulse which does not allow resolving the bunch length variations between consecutive macropulses.

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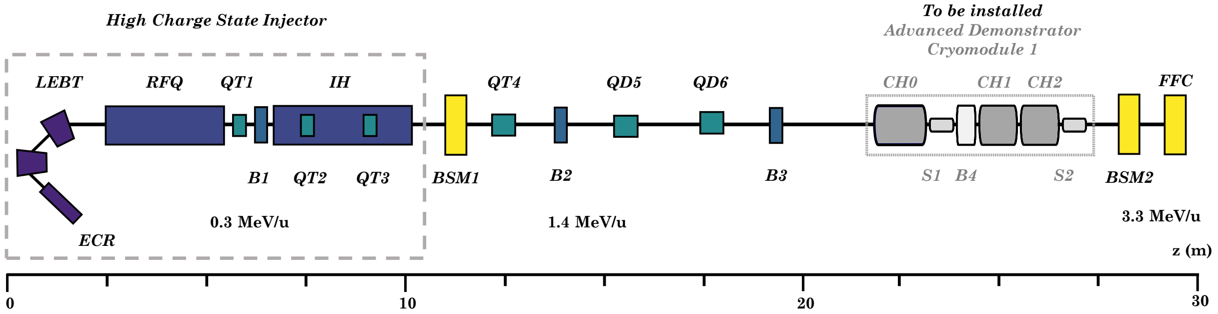
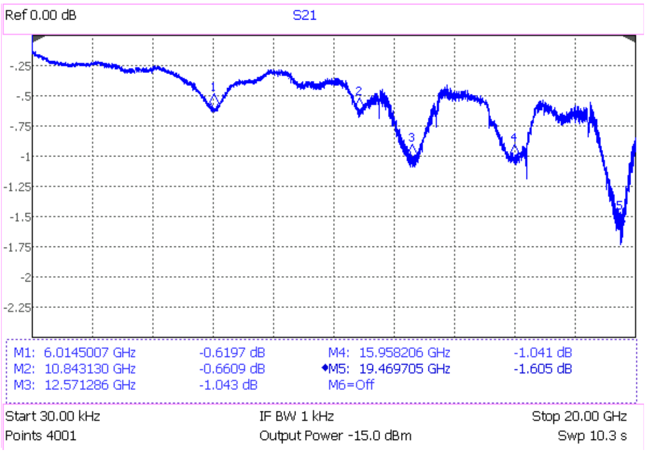


Figure 1: Relevant beamline and its components: Quadrupole Triplet (QT), Buncher (B), Interdigital H-Mode Cavity (IH), Feschenko Bunch Shape Monitor (BSM), Quadrupole Doublet (QD), superconducting Crossbar H-Mode Cavity (CH), superconducting Solenoid (S), Fast Faraday Cup (FFC). The greyed out components were not installed during these tests.

Thus, bunch-by-bunch longitudinal profile measurements which are required for countering intensity effects or any other fast changes using a low level rf feedback are outside the scope of BSM. Secondly, careful tuning is required for many parameters in order to align the beam with the wire and obtaining appropriate secondary electron statistics at the final detector. In context of phase space reconstruction, there is a limitation given by the measuring time of the BSM. A typical measurement time of 1-2 min per profile is experienced for high resolution measurements. At least 10 measurements at different buncher rf-amplitudes are necessary for the reconstruction, which makes this analysis time-consuming. The usage of Fast Faraday Cup is being investigated in these contexts.

FAST FARADAY CUP

The Fast Faraday Cup used in this work was obtained on loan from Fermilab with details discussed here [12]. Its design consists of a ground plate with an oriface diameter of 0.8 mm which allows a small part of the beam to reach the collector plate at a "gap distance" of 1.7 mm from the oriface. The collector is basically a hole in the central conductor of a coaxial cable terminated into two symmetric 50 Ω outputs to avoid reflections. The depth of collector hole is chosen to avoid secondary particles leaving the collector. The choice of gap distance and oriface aperture is dependent on the beam velocity and is chosen to avoid dilution or widening of the measured charged distribution with respect to actual charge distribution for the HLI beam parameters. Further details of these design considerations for certain simplified geometries can be found here [13]. The scattering parameters of the device were measured up to 20 GHz and the terminations were found to be well matched. The S21 parameter is shown in Fig. 2. The relevant region is upto 8 GHz until which the frequency response is rather constant. A wideband amplifier with 10 GHz bandwidth (0.01-10 GHz) was used [14] as the termination followed with semi-rigid cables. The signal was digitized with a Lecroy wavemaster WaveMaster 830Zi-B^{TM} with the maximum sampling rate of 80 GSa/s and an analog bandwidth 22 GHz. Challenges associated with FFC measurements are discussed later in this report.



```
M1:  6.0145007 GHz     -0.6197 dB     M4:  15.958206 GHz     -1.041 dB
M2:  10.843130 GHz     -0.6609 dB    ◆M5:  19.469705 GHz     -1.605 dB
M3:  12.571286 GHz     -1.043 dB      M6=Off
Start 30.00 kHz                 IF BW 1 kHz                 Stop 20.00 GHz
Points 4001                     Output Power -15.0 dBm      Swp 10.3 s
```

Figure 2: S21 measurement of the FFC from 30 kHz to 20 GHz.

MEASUREMENTS

Figure 1 shows the schematic of the test set-up. The bunchers B2 and B3 were manipulated to change the longitudinal orientation and phase profile of the He^{1+} ion beam. Figure 3 (top) shows the initial section of the overlaid measured signals from the FFC and an immediately preceding pick-up (PU) for a single 100 µs macro-pulse. Figure 3 (bottom) shows the enlarged view showing three rf periods at the peak around 20 µs from the start of signal recording. The beam was transversely focused onto the FFC opening in order to concentrate all the charges on the FFC collector plate and obtain this single-shot FFC measurement. The average beam current was 102 µA for this specific macropulse. Signal amplitude fluctuations within the macro-pulse are evident both on FFC and PU signals. The cause of these rather large beam current fluctuations is not clear, but was consistently observed on FFC, pick-up as well as BSM signal in the reported measurements. Figure 4 (top) shows the same FFC

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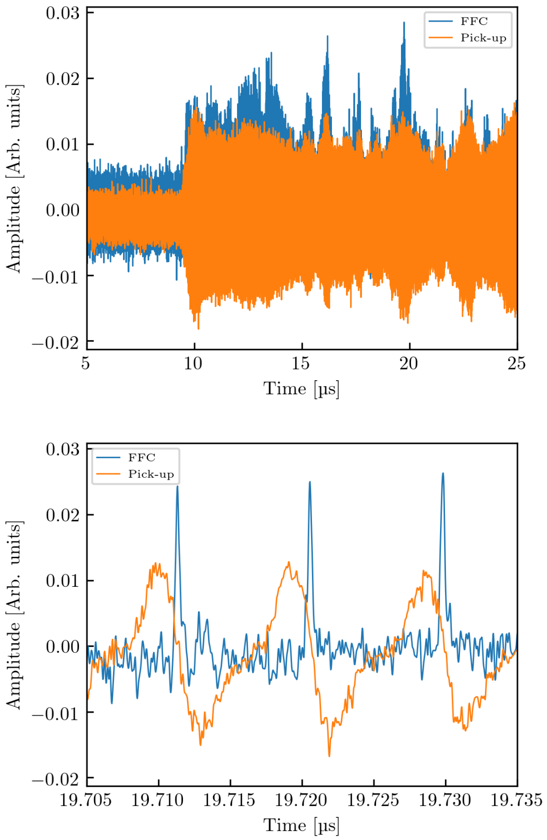

Figure 3: (Top) Direct digitized signals from a single macro-pulse from FFC and pick-up, the fluctuations are similar and visible in both pick up and the FFC. (Bottom) Enlarged view at 19.72 µs for three consecutive rf periods.

signal as in Fig. 3, but splitted and stacked per rf period in units of µs and degrees. The plot shows the evolution of bunch length and signal strength during the macro-pulse. There are <10% fluctuations in the bunch length over the macropulse. Figure 4 (bottom) shows an integrated bunch shape measurement over the macro-pulse. Such an integrated pulse is used for comparison with the bunch shape monitor (BSM) discussed next.

Figure 5 shows the FFC and BSM signals for three machine settings. The profiles are normalized to the area under the profiles. The Feschenko BSM is installed ≈ 1 m upstream of the FFC. The BSM scans with 1 deg per macro-pulse with a temporal resolution of 1 µs. Thus one BSM measurement covering 200 deg phase requires 200 macro-pulses. The FFC measurement is performed within a single macro-pulse with the same procedure as mentioned for Fig. 4 (bottom). One has to note that the transverse beam alignment was performed in order to irradiate the FFC oriface by the core of the beam. In hindsight, it appears that the BSM wire was not irradiated by the core of the beam, which is potentially the reason behind large "noise" observed on the bunch shape measured by the BSM. The bunch shape results are consistent with each other and agreement is rather good given

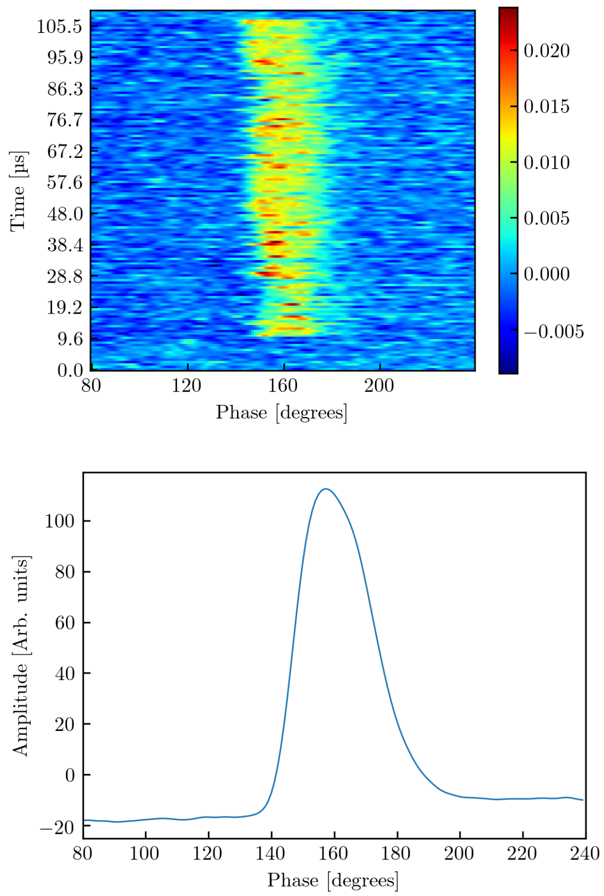

Figure 4: (Top) Time domain signal sorted per rf period over the macro-pulse for FFC. (Bottom) Integration along y-axis resulting in an averaged longitudinal profile over the full macro-pulse.

that both the measurement techniques are fundamentally different. An additional measurement was performed for FFC to observe the dependence of longitudinal profile on the transverse measurement location of the sampled beam, e.g. coupling on longitudinal and transverse planes. Figure 6 (top) shows the measured charge distribution when the FFC was displaced upto 5 mm vertically. The plots are not normalized to charge in this case in order to highlight the change in obtained signal as a function of FFC position. No significant change in the measured charge distribution is seen as a function of transverse position. Interestingly, for certain offsets ($\Delta x = -2$ mm in this case) of FFC, a fixed frequency close to third harmonic of rf in this case is picked up. The exact cause is not clear yet and will be investigated further.

CONCLUSION AND OUTLOOK

The first results comparing the devices look promising, and some further test measurements need to be performed to fully characterize the measured charge distribution from the FFC.

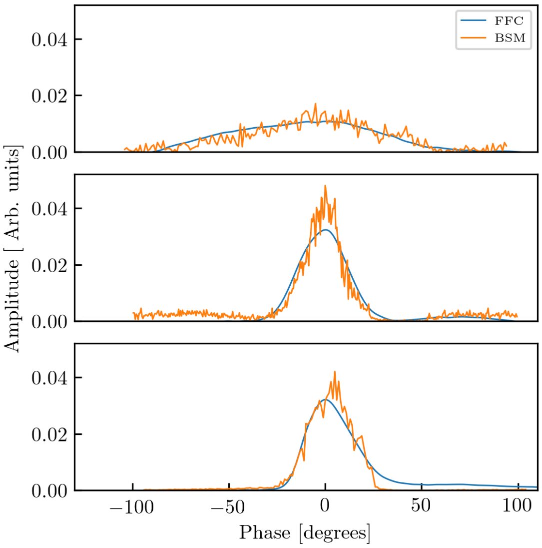

Figure 5: Comparison of the normalized longitudinal profiles of FFC and BSM for three machine settings, (Top) B2 = 0 V, (Middle) B2 = 2.35 V, (Bottom) B2 = 2.35 V with additional transversal beam focus onto FFC input.

1. Investigatation of interferences observed on the FFCs at some transverse location with respect to beam is required. Further, transition radiation generated when charges cross the oriface also needs to be simulated.
2. Measurement of the potential effect of secondary emissions on the measured profile. This effect can be investigated by applying a bias either on the collector or ground plate in line with [6].
3. Further thermal simulations in order to determine the intensity thresholds which the non-cooled FFC can withstand.

Finally, the potential increase in oriface radius need to be evaluated for improved signal to noise ratio as well as easier alignment with the beam. Therefore, widening the oriface diameter and all consequent changes in the FFC design are under consideration.

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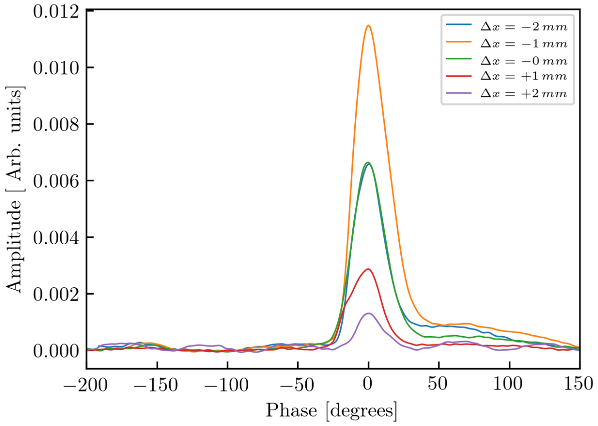

Figure 6: FFC is moved by ±2 mm and the profile is measured at each step.

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