EXPERIMENTAL EVALUATION OF LONGITUDINAL MOMENTUM DEVIATION FOR LOW ENERGY HEAVY ION BEAM WITH QUASI-3D PROFILE MEASUREMENT ON THE BEAM LINE

Xingguang Liu#, Takashi Yoshimoto

Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama, Kanagawa 226-8503
High Energy Accelerator Research Organization(KEK),1-1 Oho, Tsukuba, Ibaraki 305-0801

Abstract

Longitudinal dependent transverse beam profile measurement is realized with a newly developed quasi-3D profile monitor which is modified from the multi-wire grid based profile monitor. With the beam profile measured at a region where a definite value of disperse function exists, the longitudinal energy difference can be evaluated. In this paper, the longitudinal momentum deviation for a low energy heavy ion beam due to the beam loading effects happened at two locations have been discussed with experimental measurements simulation results: (1) the extraction gap of an Electron Cyclotron Resonance Ion Source (ECRIS); (2) the post-acceleration column of the high voltage platform which the ECRIS is embedded in.

INTRODUCTION

Beam profile measurement is one of the most essential requirements for the accelerator system. Among different types of the beam profile monitors, the multi-wire grid profile monitors are commonly used to measure the transverse beam profile at the Low Energy Beam Transport (LEBT). Usually, these profile monitors are installed at various positions to measure the beam profile along the beam transport line.

From the viewpoint of the linear single particle motion, a particle's transverse excursion from the referential orbit is:

$$x = x_b + D\frac{\Delta p}{p} \quad (1)$$

It is separated into two parts: the first part, $x_b = \sqrt{\varepsilon\beta}\cos(\varphi)$, is the betatron oscillation, where ε is the beam emittance, β is the beta function and the φ is the phase of the particle motion; the second part, $D\frac{\Delta p}{p}$, is the excursion due to dispersion, where D is the dispersion function and $\frac{\Delta p}{p}$ is the momentum deviation from the referential particle.

For a beam containing many particles, the second part can be seen as the excursion of the beam center which can be measured with profile monitor. However, in order to experimentally obtain the longitudinal momentum deviation within the beam, longitudinally dependent beam profile is needed. For this purpose, the existing multi-wire grid profile monitors have been modified to be able to take the longitudinally dependent beam profile.

In the next section, the experimental setup will be described including the quasi-3D profile monitor. The longitudinal momentum deviation for a long beam (4 ms) will be evaluated with the results of the profile monitors. Our study shows that the beam loading effects happened at the extraction gap of the ion source and the post-acceleration column are the reasons for the longitudinal momentum modulation. Experimental measurements with simulation results will be given to confirm these sources and their contributions.

EXPERIMENTAL SETUP

Ion Source

The ion beam is generated by a 9.4 GHz Electron Cyclotron Resonance Ion Source (ECRIS) [1]. A schematic of the ECRIS is shown in Fig. 1. It takes some time for the plasma to be built up by microwave heating before the beam can be extracted. Therefore, the extracted beam is usually several milliseconds long (4 ms in this study). The extracted beam will be transversely focused by the Einzel Lens, which is installed right after the extraction region of the ECRIS. The whole ECIRS is embedded in a High Voltage Terminal (HVT). In this study, the ECIRS is set at 14kV and the HVT at 186 kV so the beam energy is 200 kV after it passes the post-acceleration column and leaves the HVT. An Einzel Lens has been used as a focusing device as long as a longitudinal beam chopper [2].

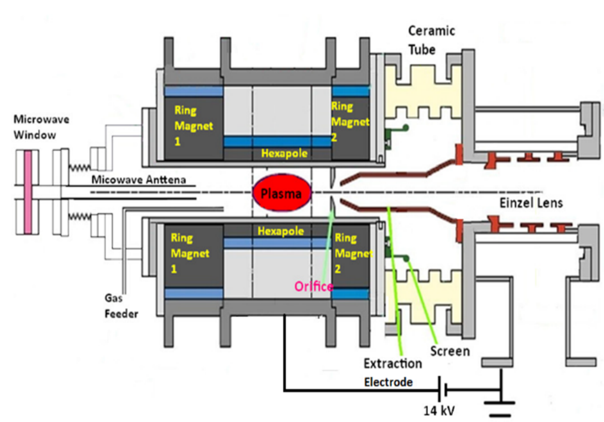


Figure 1: Schematic view of the ECRIS.

#liuxg@post.kek.jp

LEBT line

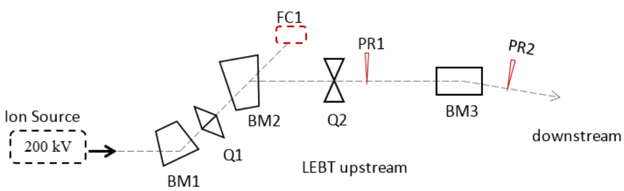


Figure 2: The upstream region of the LEBT line.

After the beam passes through the post-acceleration column, it enters into the LEBT line. A schematic view of the upstream region of the LEBT line are shown in Fig. 2. It consists of three bending magnets and two quadruple magnets. For the beam diagnostics of this region, one Faraday Cup (FC1) is installed on the test bench (on the extended line after BM2), and two profile monitors are installed after Q2 and BM3 respectively (PR1 and PR2 in Fig. 2).

In order to evaluate the momentum with Eq. 1, dispersion function along the beam line is required. Because the dispersion is resulted from the bending magnets, the dispersion function and its derivative are assumed to be zero at the entrance of the LEBT line. The dispersion function for this region is plotted as in Fig. 3, in which s is the distance along the referential orbit.

Quasi-3D profile monitor

Fig. 4 (a) shows a picture of the monitor unit of PR1. The core part of the monitor unit is a wire grid plate, which is attached to a stem head controlled by a motor driver. A picture of the multi-wire grid is shown in Fig. 4 (b) and its parameters are listed in Table 1.

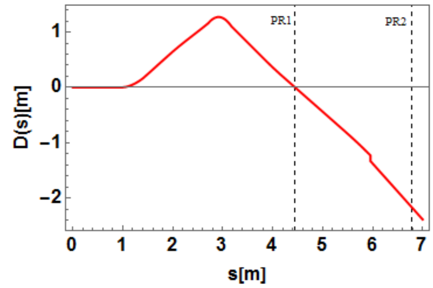
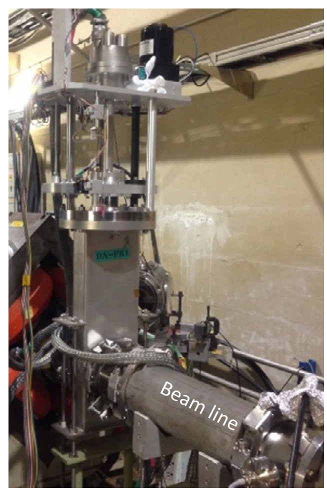


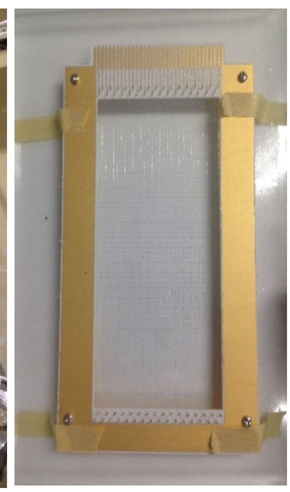
Figure 3: Dispersion function of the LEBT upstream.

Table 1: Parameters of the Wire Grid

Diameter of wires	30 µm
Wire spacing	2.5 mm
Number of wires	32 wires for X/Y
Measureable range	(-4 to 4 cm) for X/Y
Material	Au-plated W
Frame insulation	Ceramic



(a) Monitor Unit



(b) Wire grid

Figure 4: Monitor Unit and wire grid of PR1.

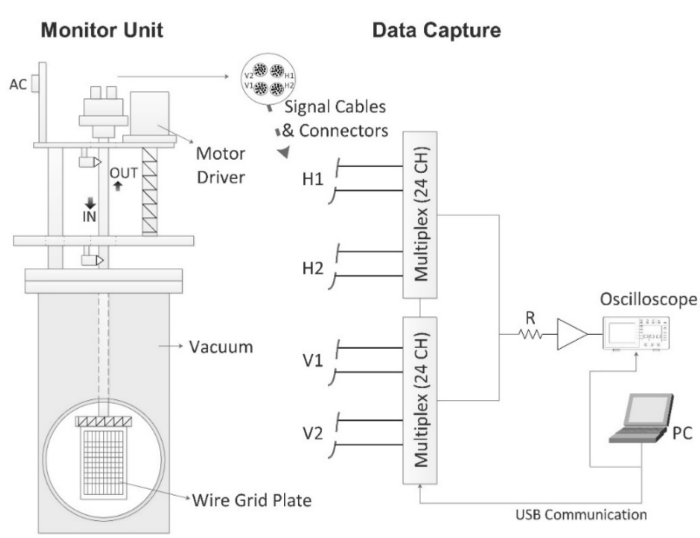


Figure 5: Schematic view of the monitor unit and the data-handling diagram.

The existing profile monitor can only take horizontal or vertical beam profile without longitudinal information. In order to make it capable of capturing longitudinally dependent horizontal or vertical beam profile, a new data capture unit has been made. Its configuration and connection to the monitor unit is illustrated in Fig. 5.

There are 32 channels (wires) in the horizontal or the vertical direction. These channels are well insulated from each other and are bundled into four groups (H1, H2, V1, and V2) to be connected easily with multi-pin connectors (Fig. 5). The multi-wire grid based system with a wire spacing of 2.5 mm can measure the beam in both directions in the range of -4 to 4 cm with its center adjusted to be the same as the center of the beam line. However, because of the limited number of channels available to the present multiplexers used for signal processing, only 24 of the 32 channels are used for each direction, reducing the measurable range to -2.5 to 2.5 cm for each direction.

Electrical current signals generated on the wires when the beam hits the multi-wire grid are transferred to the two multiplexers, which select a single channel's signal and pass it to the oscilloscope. All channels are scanned in sequence. A resistor (R in Fig. 5) is used here to convert the electrical current into voltage which can be amplified with an amplifier then recorded by the oscilloscope.

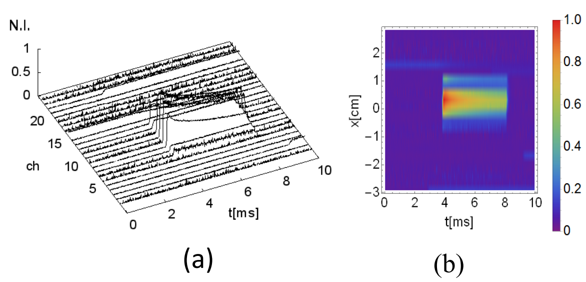


Figure 6: Signal processing.

Fig. 6 shows the process to obtain horizontal-longitudinal (x-t) beam profile by combining individual signals. Fig. 6 (a) shows all the wires' signals in the horizontal direction (each direction has 24 channels as discussed, horizontal direction in this example) in the same sequence as their physical layout. Fig. 6 (b) shows the normalized intensity projection of (a) to the horizontal-longitudinal (x-t) plane. Vertical-longitudinal (y-t) profile can be obtained in the same way. Due to the fact that the Monitor Unit is the same as the existing multi-wire grid profile monitor which is intrinsically a quasi-2D profile monitor, the modified profile monitor, with additional profile in the longitudinal profile, is a quasi-3D profile monitor.

Tested beam

An $A/Q=4$ ion beam is used in this experiment, where A is the mass number of the particle and Q is the charge state. When the Einzel Lens works just as a focusing device, the long beam is transported to the LEBT line. The beam intensity profiles of the long beam measured with FC1 are shown in Fig. 7 and the beam parameters are listed in Table 2.

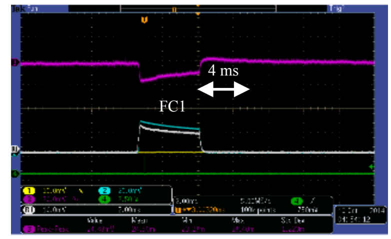


Figure 7: 4 ms beam measured at FC1 (Fig. 2).

Table 2: Beam Parameters

Energy	200 keV
A/Q	4
Intensity	~130 μA
β	0.01

MOMENTUM DEVIATION AND BEAM LOADING EFFECTS

Results of the profile monitor

At the position of PR1, where the dispersion function is almost zero (Fig. 3), it is impossible to obtain the longitudinal momentum deviation. This argument is confirmed by the experimental results of PR1 as shown in Fig. 8 in which the beam center along the longitudinal direction stays the same. However, at the position of PR2, the dispersion function is more than 2 m, which indicates that 1% difference in momentum deviation will results in a 2cm's excursion of the beam center. Accordingly, PR2's measurement shows that the front of the beam is bending towards the $-x$ direction as shown in Fig. 9.

Fig. 9 suggests that the front part of the beam has a larger momentum deviation, or higher energy than the rear part of the beam. The beam gains energy at two places before entering the LEBT line. The first one is the extraction gap of the ECRIS (Fig. 1). The second one is the post-acceleration column.

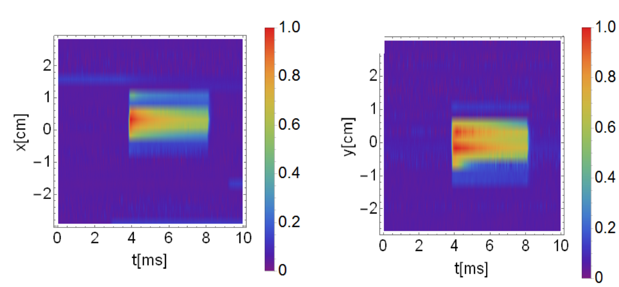


Figure 8: Beam profile measured at PR1.

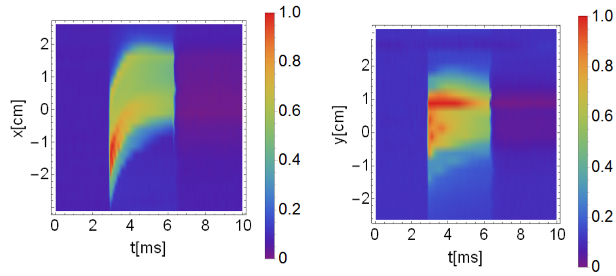


Figure 9: Beam profile measured at PR2, bending beam.

There are also some other differences between Fig. 8 and Fig. 9. For example, in either horizontal or vertical direction, the beam size measured at PR2 is larger than that measured at PR1. Supposed that the transverse emittance stays constant when the beam is transported from PR1 to PR2, these results suggests that the beam has larger beta functions in both directions. As expected, the beam doesn't bend in the vertical direction.

Extraction region and compensation: Experiment and Simulation

If the voltage between the cathode and anode changes during the process when the beam passes this gap, it will result in longitudinal energy difference of the beam. High voltage probe has been used to directly measure the voltage trend during the beam extraction process. The results are shown as in (a) of Fig. 10. The extraction voltage is 14 kV, when no beam generated from the ECRIS, this voltage is constant. However, when the beam is generated and extracted through the gap, this voltage will drop about 0.4 kV as shown in the figure. This phenomenon is called "beam loading effect".

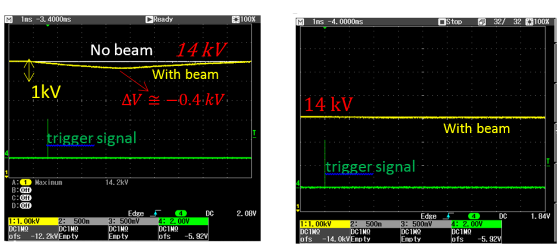


Figure 10: Beam loading effect and its compensation with a stabilizer.

In order to compensate this effect, a simple circuit featuring capacitance has been added to stabilize the extraction voltage. We call this circuit a "stabilizer". After adding the stabilizer for the ECRIS, the beam loading effect has become negligible as shown in (b) of Fig. 10. The equivalent circuit for ECRIS including the stabilizer is shown in Fig. 11. The simulation result with and without stabilizer are shown in Fig. 12. In the simulation the beam current intensity profile has been assumed to be the same as measured with FC, which is also plotted in Fig. 12.

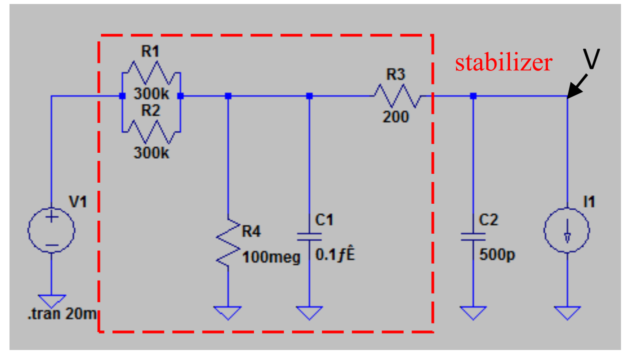


Figure 11: Equivalent circuit of ECRIS including stabilizer.

With the stabilizer, the voltage drop is negnigible. Even without the stabilizer, the energy diffence is about 0.4 kV at most. However, as shown in Fig. 13, after adding the stabilizer, the front part of the beam still bends towards the $-x$ direction. Compared with Fig. 9, the bending amplitude is smaller. As discussed, the excursion of the center can be used to evaluate the energy difference. A comparison of the beam center in Fig. 9 and Fig. 13 is compared in Fig. 14, in which the secondary vertical axis indicates the corresponding momentum deviation if we take the longitudinal middle of the beam as reference. Fig. 14 suggests that there exists another source and it contributes more to the longitduinal beam energy difference.

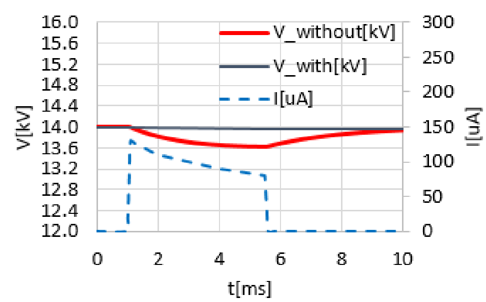
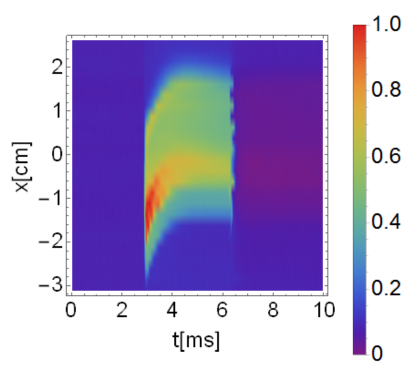


Figure 12: Simulation results of the ECRIS extraction region.



Figgure 13: Beam profile measured at PR2, ECRIS with stabilizer.

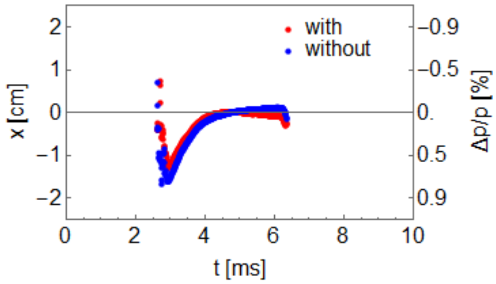


Figure 14: comparison of the beam center in Fig. 9 (without stabilizer) and Fig. 13 (with stabilizer).

Post-acceleration column: simulation

Unfortunately, it is difficult to directly measure the voltage trend for the 186 kV high voltage on the post acceleration column as we did for the extraction voltage. But the beam loading effect at this region can be studied through electrical circuit simulation. From the discussion of the beam loading effect at the extraction region, the simulation results have a good agreement with the experimental results. Fig. 15 shows the equivalent circuit of the HVT (without the "stabilizer" part). Fig.16 shows the simulation result, which indicates that the voltage drop when the beam pass this region is about 1kV.

A stabilizer circuit has been used to compensate the beam loading effect for the ECRIS extraction region. In Fig. 15 a possible design of the stabilizer for the same purpose has been proposed and its simulation result shows that it can suppress the voltage drop to less than 20 V, which is negligible. The experimental confirmation with the downstream profile monitor will be done in near future.

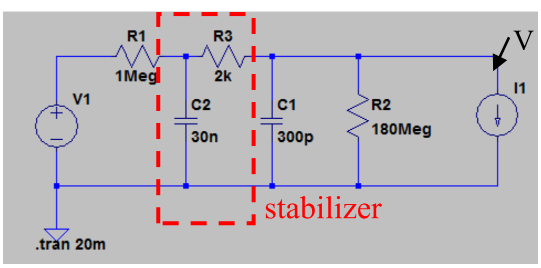


Figure 15: Equivalent circuit of the HVT with proposed stabilizer.

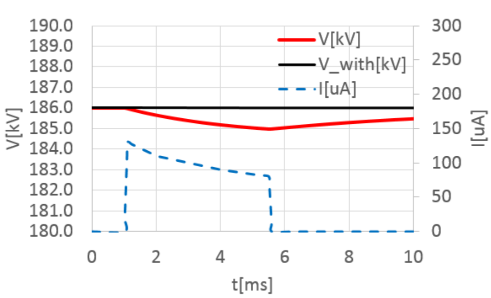


Figure 16: Simulation result of the post-acceleration column region.

With beam parameters from Table 2, the relationship between voltage difference and the resulted momentum deviation can be calculated. The calculation result is compared with the experimentum result in Fig. 17. Two experimental data points are plotted in this figure, the momenum deviations are taken from Fig. 14 and the voltages are 1.05 kV and 1.45 kV respectively, corresponding to the two cases with and without stabilizer.

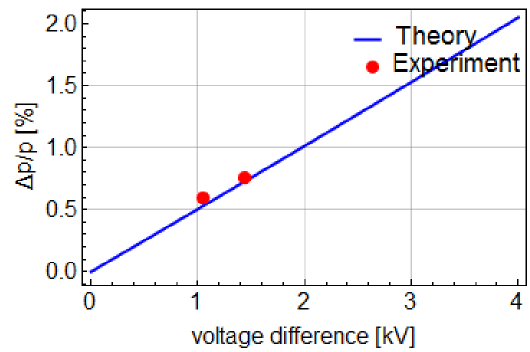


Figure 17: Momentum deviation in terms of the voltage difference.

SUMMARY

In this paper, the longitudinal momentum deviations within the beam for a 4 ms long beam has been evaluated with the measurement results of the quasi-3D profile monitor, which has been newly developed based on the multi-wire grid profile monitor. For the long beam, the beam loading effects at the ECRIS extraction region and the post-acceleration column contribute to the longitudinal momentum deviation. The high voltage measurement and electrical circuit simulation both confirmed the beam loading effect at the ECRIS extraction region. A stabilizer have been used to compensate the beam loading effect at this region. The beam loading effect on the post-acceleration column have also been confirmed with simulation and a compensation circuit design was provided for near future experiment. In summary, using the quasi-3D profile monitor located at a position with a proper dispersion function value, the longitudinal momentum deviation can be evaluated experimentally.

REFERENCE

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