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TRANSVERSE BEAM EMITTANCE MEASUREMENTS WITH MULTI-SLIT AND MOVING-SLIT DEVICES FOR LEREC*

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Abstract

Low Energy RHIC electron cooling (LEReC) is the first bunched electron cooler, designed to cool low energy ion beams at RHIC. The beam quality, including the transverse beam emittance, is critical for the success of cooling. The transverse electron beam emittance was characterized with a multi-slit and moving-slit device at various locations in the beamline. The beam emittance measurement and analysis are presented in this report.

INTRODUCTION

LEReC [1], a linear electron accelerator (Figure 1), is designed to cool RHIC ion beams and therefore improve luminosities at beam energies below 10 GeV/n [2]. Electron bunches are generated by a 400 kV DC electron photocathode gun; these bunches then go through a chain of cavities, which includes a 1.2/1.6 MeV 704 MHz superconducting booster cavity, a 2.1 GHz normal-conducting copper cavity to linearize beam energy chirp, a 704 MHz normal-conducting cavity to reduce energy spread of individual bunches and a 9 MHz normal-conducting cavity to reduce energy droop along bunch train due to beam loading. Each electron macro-bunch, consisting of 30 micro-bunches of 40 ps length at 704 MHz repetition frequency, will overlap with a RHIC ion bunch at 9 MHz frequency. The electron beam first propagates with the ion beam in one of the RHIC rings (Yellow) collinearly with the same speed, then turns around and propagates with the ion beam in the other RHIC ring (Blue). With extremely small energy spread (5E-4), the electron beam reduces the ion beam energy spread when interacting with it by coulomb friction force. The design electron beam current is 30-55 mA for beam energy 1.6-2.6 MeV, with bunch charge of 130-200 pC and normalized emittance <2.5 µm [1].

Matching the electron beam transverse emittance to that of the ion beam is crucial for cooling. With low energy and high bunch charge, the electron beam emittance is dominated by space charge effect. Therefore, emittance measurement devices made of slit/slits [3] were chosen in the LEReC accelerator to measure beam emittance along the beamline. The multi-slit and moving-slit sample several transverse slices of the beam which then project to downstream profile monitors. The space charge effect is substantially reduced due to reduction of charge density by the sampling of the slit/slits.

MATERIAL AND METHOD FOR BEAM EMITTANCE MEASUREMENT

A multi-slit device (Figure 2) [4], installed after the Booster cavity with a YAG profile monitor 2 m downstream, measures beam emittance in the DC gun test line. There are 10 horizontal and 10 vertical slits on the same mask, respectively for vertical and horizontal beam emittance measurement. The slit width is 150 µm, with slit spacing 1.346 mm. The mask was made of Tungsten plate of 1.5 mm thickness. The multi-slit mask is thick enough to stop most of the electrons at 1.6 MeV beam energy. This is designed to avoid background on the downstream profile monitor due to scattered electrons.

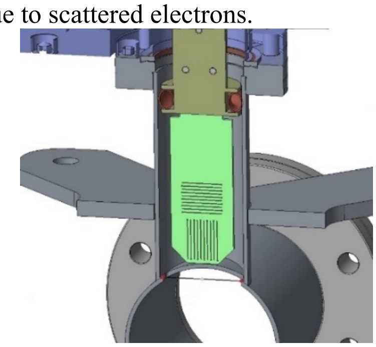

Figure 2: Drawing of multi-slit device at retracted position, with vertical slits at the bottom and horizontal slits at the top part of the mask.

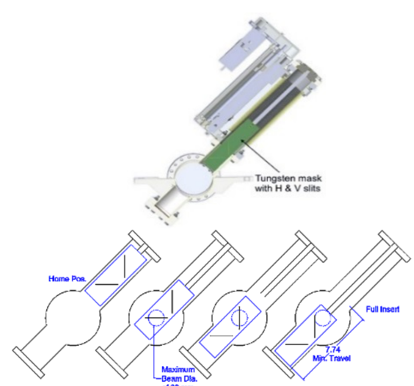

Figure 3: Schematics of moving-slit device. The image on top shows the assembly and the orientation, with a view along the beam path. The lower image illustrates the sampling process, first horizontal and then vertical with the mask driven in by a stepper motor.

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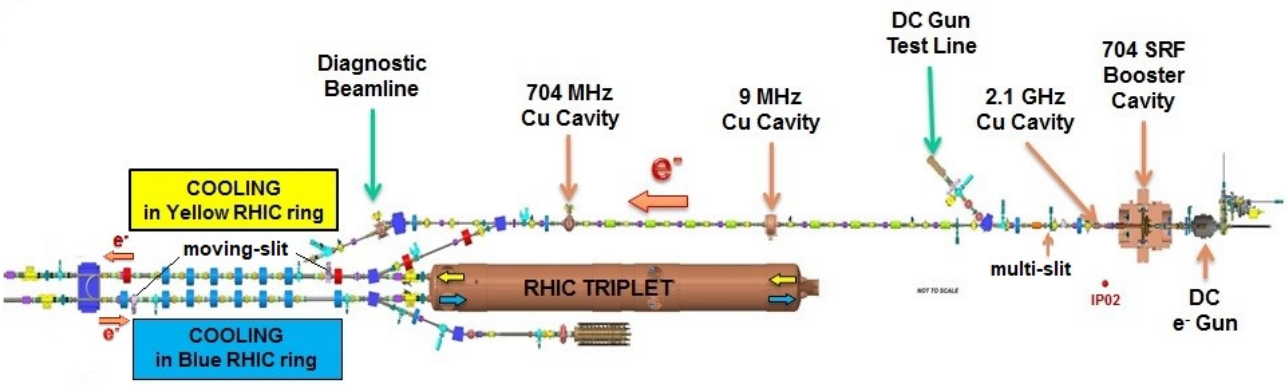

Figure 1: Schematics of Low Energy RHIC electron Cooling accelerator. Low energy electron beam is transported through beamline with solenoids, merged to cooling section in Yellow RHIC ring first, turned around and merged to cooling section in Blue RHIC ring to cool ion beams in both rings.

Two moving-slit devices (Figure 3), placed after the first merging dipole magnet in Yellow RHIC ring and the 180-degree dipole magnet, measure the beam emittance in the cooling sections. The moving-slit, driven by a step motor into the beam path at a 45-degree angle, samples horizontal beam slices and then vertical slices. Up to 40 beam slices can be generated by each scan on the downstream YAG profile monitor for horizontal and vertical measurements. The slit width is 150 µm. The distance from the moving-slit to the downstream profile monitor is 2 m and there are no magnetic elements between the moving-slit and the downstream profile monitor. The potential advantage of this device is to sample more transverse slices for better precision emittance measurement.

MEASUREMENT RESULTS AND ANALYSIS

The emittance measurement with the multi-slit in the DC gun test line is presented here. Multiple beam slices, sampled from the beam by the multi-slit, propagate in a drift space to the downstream profile monitor. The beam slices would expand in the drift space, with length designed based on model parameters, but not overlap with each other on the downstream profile monitor. The width of each beam slice on the profile monitor represents the divergence of each beam slice. The recorded profile was projected to horizontal or vertical plane. The projection was fitted to a multi-Gaussian distribution, providing information of the amplitudes and RMS width of the peaks. Then the beam emittance was calculated based on the fitting results [5]. With 32 pC bunch charge, the geometrical horizontal beam emittance was measured to be 0.512±0.015 µm. The image processing and emittance calculation was performed by an in-house program called imageViewer [6].

Beam charge dependence of beam emittance (Figure 6) has been studied with the multi-slit device. The single bunch charge was scanned from 13 to 32 pC by varying the laser intensity for these measurements. The solenoid between the multi-slit and downstream profile monitor was turned off during the measurements. These beam emittance measurements for different bunch charge were taken with the same optics setting. In the future, these measurements will be performed while changing the beam optics accordingly. By doing this, beam emittance growth due to non-optimal beam optics can be avoided.

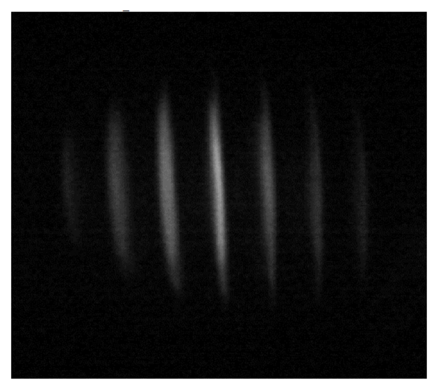

Figure 4: Images taken on the downstream profile monitor with vertical slits of the multi-slit inserted in the beam path.

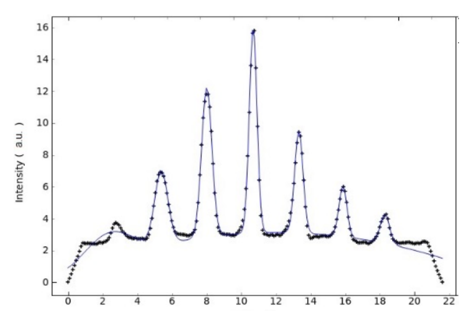

Figure 5: Multiple peak intensity distribution (data points in stars), generated by projecting image of beam slices (Figure 4) along the slice image direction, and its multi-Gaussian peak fitting (solid curve).

Beam emittance measurement results with multi-slit showed a strong dependence on the number of beam slices used in the emittance calculation. With smaller bunch

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charge, the outer slices will be excluded by imageViewer if their intensity is comparable to noise level. These beam slices have larger slice emittance than the center ones. Therefore, their accidental exclusion resulted in smaller beam emittance number and larger error bar at lowest bunch charge (Figure 6).

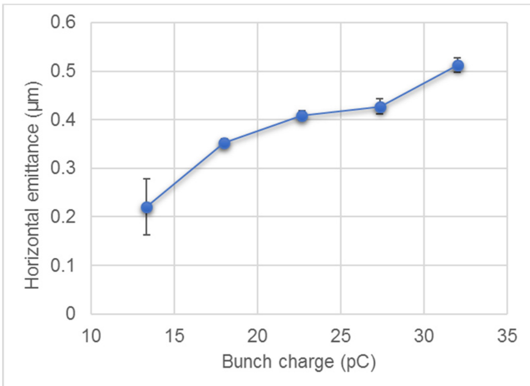

Figure 6: Bunch charge dependence of the horizontal beam emittance measured with multi-slit device. The error bars show the statistic measurement errors.

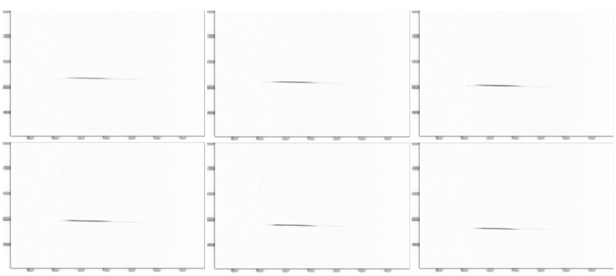

Figure 7: Selected individual beam slice images taken on the profile monitor while sampling the beam with moving horizontal slit.

The preliminary results from commissioning of the moving-slit are presented here. Multiple profiles on the downstream profile monitor (Figure 7) have been taken while the moving-slit was driven through the beam path. The projection of these profiles were combined (Figure 8) to show the samples from the beam. With the same algorithm [5], the emittance was calculated based on the fitting parameters of these peaks. The advantages of moving-slit emittance measurement are that the method produces a greater number of beam slices than with multi-slit device and these slices do not interfere with each other.

It was found that the system is very sensitive to beam orbit. Not only should the beam be centered on the BPM near the moving-slit, but also on the profile monitor. Initial tuning of beam orbit along the moving-slit device is necessary before starting the scanning begins. Due to residual beam offsets, a programmable scanning range was implemented. It is also suspected that beam scraping, which would also affect measured profiles, happened upstream. Therefore, beam optics tuning for good transmission is crucial as well.

One problem associated with the moving-slit device is that the space between the slit and the downstream profile monitor is short (2 m). The spacing was limited by the available drift space from one solenoid to the next. With a short drift space, the beam slice will not diverge enough on the profile monitor which results in less precision in the measurement of the beam divergence.

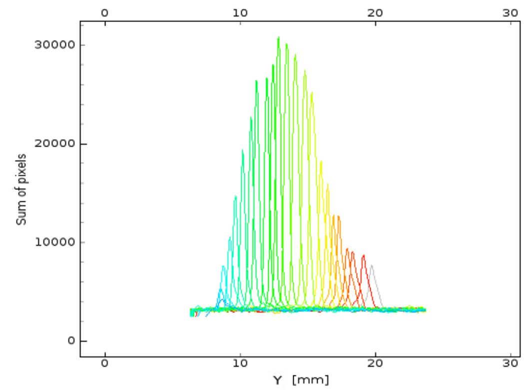

Figure 8: Combination of projection of (~30) individual beam slices, taken at each step while scanning the horizontal slit through the beam. The measured geometrical vertical RMS emittance is 0.49 µm.

Slanted beam slices have been observed in beam emittance measurements in the Yellow cooling section intermittently. This has not been understood and further investigation is needed. It is suspected that there is leakage magnetic field from solenoids, either the one upstream of the slit, or the ones in the Blue cooling section close to the moving-slit measurement device.

SUMMARY AND OUTLOOK

In this report, the emittance measurement devices, measurement methodology, measurement results and analysis were reported. We obtained reasonable measurement results with the multi-slit device. The preliminary results from commissioning the moving-slit are also presented in this report.

The work reported here provides a perspective for future work on beam emittance measurement. Beam emittance will be characterized as a function of beam currents and beam optics configuration. The dependence of beam emittance on the beam position in the booster cavity will be investigated as well. The final goal is to measure the electron beam emittance at design bunch charge and match it with that of the ion beam.

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