FOUR-DIMENSIONAL TRANSVERSE EMITTANCE MEASUREMENT UNIT FOR HIGH INTENSITY ION BEAMS*

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Abstract

To measure the emittance of a 2 MeV 40 mA pulsed D^+ ion beam with the repeat frequency of 100 Hz and the pulse width of 0.1 – 1 ms at the exit of Radio Frequency Quadrupole (RFQ) accelerator, a four-dimensional transverse emittance measurement unit has been developed at Peking University (PKU). This unit is based on Multi-Slit-Single-Wire (MSSW) method, and named as High Intensity Beam Emittance Measurement Unit (HIBEMU) -4. In this paper, we will introduce its mechanical design and application, present the data processing method and the test results using a 1MeV 3mA (average) O^+ beam with a duty factor of 1/6. At the end of this paper, some discussion will be given on the possible improvements to realize complete sampling and to avoid data overlapping.

INTRODUCTION

The emittance measurement for high intensity ion beams is always a challenging task as the beam power may overheat the facilities and the high intensity beam produces lots of secondary particles which introduce massy noises. At PKU a Neutron Imaging Facility (PKUNIFTY) is under construction. The RFQ will deliver a 2 MeV 40 mA 1/10 duty factor pulsed D^+ ion beam for this project. To check the output beam of RFQ and to optimize the design and operation of High Energy Beam Transport (HEBT), the beam emittance at the exit of RFQ must be measured. In the past decade, three sets of two dimensional (one directional) HIBEMU devices have been developed at PKU mainly for the diagnostic of ion beams extracted from ion source and in LEBT, where the ion beam is symmetrical about axis [1-3]. However, the measurement for the mentioned D^+ beam requires a four dimensional device because the profiles of the ion beams output from RFQ are different in X and Y planes. In addition more efficient water cooling is required, too.

We compared the characteristics of MSSW, Allison scanner and popper-pot devices and the MSSW type device was chosen as our prototype because of its compact layout, low cost hardware and relative short measurement time. This new emittance measurement unit (EMU), which is named as HIBEMU-4, consists of a couple of X-Y orthogonal and coplanar MSSW EMU's.

We paid special attention to the Faraday cup cooling, data processing and noise suppressing technique. Commissioning results indicate that HIBEMU-4 is a device with enough endurance against to the bombardment of high intensity ion beam. Also its user-oriented software and flexible installation make it universally applicable to measure different beams.

EMU DESIGN

The core of HIBEMU-4 consists of two front Faraday cups in the front and two rear Faraday cups behind. The front cups are used to collect the total beam current and to sample the sub-beams with multi-slits at their bottom for emittance measurement, and the rear cups are used to scan through the sub-beams for the beam divergence measurement. A structural diagram of HIBEMU-4 is shown in Fig. 1.

The two front cups are bound together and can be driven by a common motor with three stops. The inner diameter and the length of the front cups are 70 mm and 84 mm respectively. There is a long slot at the bottom of each front cup, which is covered by a 0.3 mm thick molybdenum plate. There are 35 sampling slits on the plate, and the size of each slit is 5 mm×0.2 mm. The interval gap between every two adjacent slits is 2 mm. The slot directions on the bottom of two front cups are orthogonal and correspond to the X and Y directions respectively, as shown in Fig. 1 (b). The three stops of the motor correspond to the X-cup, the Y-cup and no cup on the beam axis. So the ion beam can be sampled as a series of sub-beams arranged in a line along either X or Y directions depending on the cup position.

The rear cups locate at 100 mm away downstream from the slits on the bottom of front cups. Traditionally for MSSW method a metal wire parallel to the sampling slits is used to scan through the sub-beams to get the beam divergence message. But for intense beam the scattering particles will introduce strong background to the measurement. So the Faraday cup with a narrow slit in front is used to replace the wire. The receiving slit has a dimension of 16 mm×0.2 mm, and the two rear cups can be driven by motor to scan in X or Y direction, respectively, coordinate to the sampling slits on the X or Y front cups. These two rare cups are identical to guarantee the consistency of measurements in two

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directions. For a measurement each rear cup will scan a distance of 100 mm in 40 seconds and record 2 M sets of data.

To avoid overheating, all of the cups are sufficiently cooled down by high speed flowing water and all bellows are set outside the vacuum box. To reduce noises from secondary electrons, magnets are used at the entrance of each cup and all signal wires inside the vacuum box are threaded through ceramic sleeves.

At the beginning of a measurement the software checks the initial state to make sure that all cups are outside the beam track. Then the front X Faraday cup moves to the centre of the beam pipe, and the corresponding rear cup starts its round-trip scanning. After the measurement in X direction the Y cup locating and scanning will also be performed. At last all cups will move outside the beam track waiting for the next measurement.

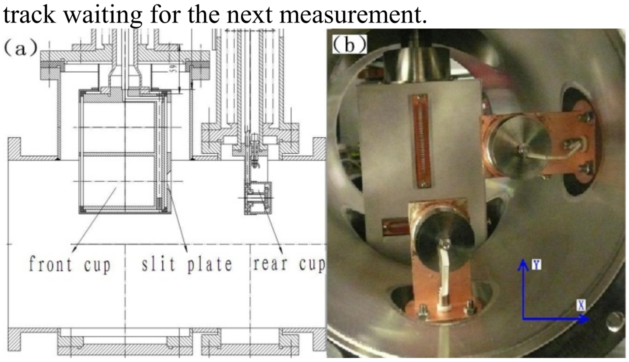

Figure 1: Mechanical design of HIBEMU-4. (a) Lateral view. (b) Back view.

HIBEMU-4 can be used to measure the emittance of a wide variety of ion beams. Table 1 lists its working parameters.

Table 1: Working Parameters of HIBEMU-4.

Parameters	Value
Installation Angle	any
Beam Power	< 10 kw
Beam Diameter	< 70mm
Divergence Angle	< 100mrad
Cw	ok
Frequency	> 50hz
Pulse Width	>100μs
Vacuum	better than 1.0×10-4pa

A Labview code is compiled for device control and data processing. This code puts emphases on reducing human errors in data processing, especially for noisy data. The processing steps, including noise diminishing, background removing, peak-searching and grouping, are displayed in images to help users to estimate the rationality and to make timely revises. Detailed data processing results are shown in Section III.

Automatic calculations used to process ideal data are tested repeatedly using data from HIBEMU-2[2], and a bias of less than 0.01πmm.mrad was found in normalized rms emittance calculation.

COMMISSIONING EXPERIMENTS AND FACILITY DEMERITS

The emittance of a 1MeV 3mA 1/6 duty factor O^+ beam at the exit of 1 MeV RFQ accelerator was measured with HIBEMU-4. The experimental results in X direction are hard to process as the measurement was performed near the beam waist of X direction, where data overlap is too serious, as shown in Fig. 2(a). This problem cannot be solved by the design of EMU, instead the measurement section has to be reselected avoiding the beam waist.

In Y direction, first we got data with slight overlap and high-frequency noises (Fig. 2(a)). Effects of noise reduction and peak searching are shown in Fig. 2(c) and (d) respectively. After that the computer grouped the data according to slits. The grouping standard is universal but will make mistakes at the overlapped parts. So manual options are necessary for correction (Fig. 2(e)). Finally a phase diagram was drawn (Fig. 2(f)) and the rms emittance was calculated to be about 0.49πmm.mrad.

The experimental results prove that HIBEMU-4 is able to endure high intensity beams, and the data analysis processing method has the ability of handling noisy data. However，the measurement accuracy is limited by the data overlap and adequate water cooling determines the short-slit design on front cups which will bring about 8% error for Gaussian distributed beams[4].

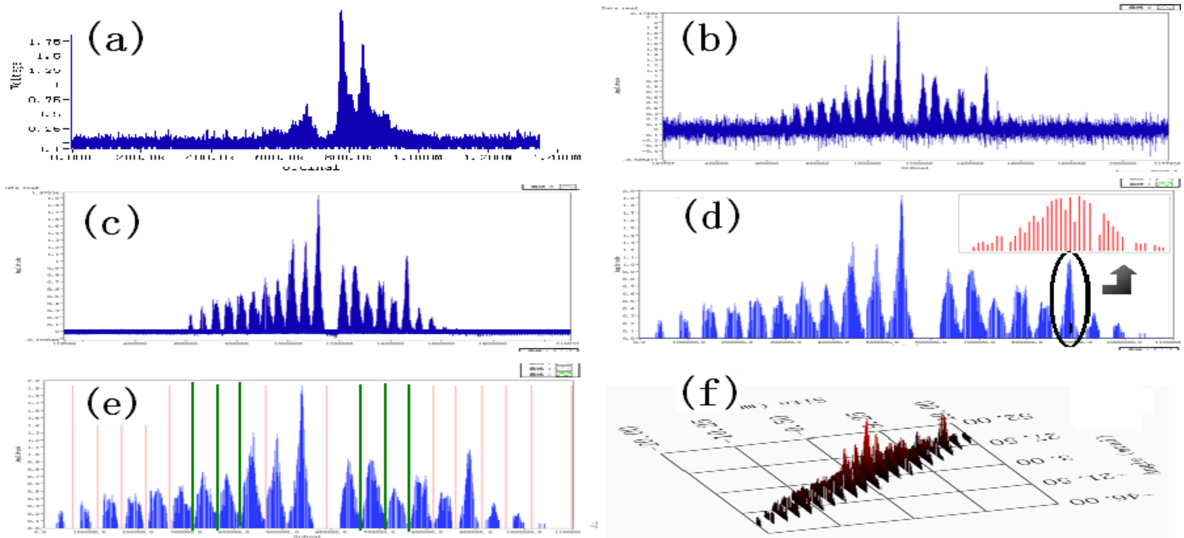

Figure 2: (a) Initial X data with serious data overlap. (b) Initial Y data. (c) Results of noise reduction. (d) Results of peak searching, the background has been removed. The lost pulse shown in the detailed image may mislead the computer in subsequent grouping. (e) Grouping results. Red lines are automatic results, green lines are manual correction. (f) Phase diagram composed of 327 peak-data points.

In order to solve the above problems two new designs were proposed. One is the movable slit cup used to fetch the equilibrium between peak isolation and data quantity. The other is a screen cup moving together with the rear cup which will extremely diminish the heating time from 40 s to 8 s in a measurement. A sketch map of new designs is shown in Fig. 3.

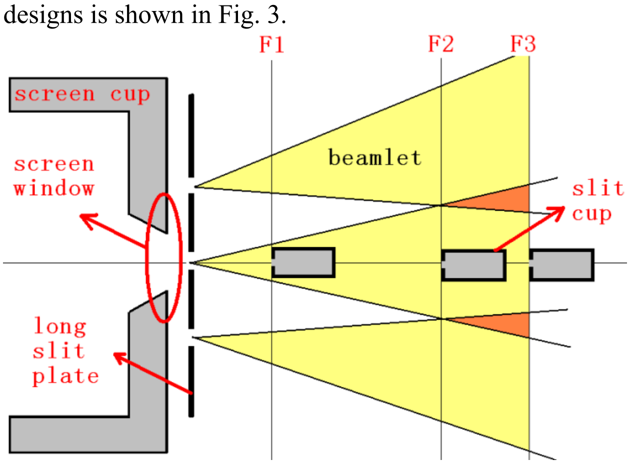

Figure 3: New designs for MSSW emittance meter. The screen cup and the slit cup are relatively static. F1~3 are three planes. On F1 parts of scanning range is wasted. On F3 data get overlapped. And F2 is the best choice. Movable slit cup is necessary to find F2 in different beams.

SUMMARY

HIBEMU-4 has the advantages of high endurance of beam power, short measurement time, low dependence of auxiliary devices and adjustability of installation. Generally it is a conservative design which used plentiful mature technologies to meet the conflicting requirements of both data rationality and high power of beams. Besides, the data process method has been tested using former data. The new design aiming to sample the beam completely and to avoid data overlap is right now under mechanical design.

REFERENCES

[1] Wu Wenzhong, Guo Zhiyu, Yu Jinxiang, et al. "Development of an emittance measurement unit for high-current ion beam." Atomic Energy Science and Technology, 2004, Vol. 38. Suppl 66-74 (in Chinese).

[2] Ming Jianchuan, Yuan zhongxi, Peng Shixiang, et al. "Emittance measurement of high-current pulse ion beam." Nuclear Techniques, Vol.29(2),105-107 2006 (in Chinese).

[3] Xu Rong, Zou Yubin, Gao Shuli, et al. "Allison scanner for high current ion beam emittance measurements." High Power Laser and Particle Beams. Vo1.19, No.7, 1216-1220, Ju1.2007(in Chinese).

[4] Zou Yubin, Guo Zhiyu. "Simulating study on systematic errors in measurements of high-current ion beam emittance with slit-wire method." Nuclear Techniques, 2004, 27(10), 744-748 (in Chinese).