A SINGLE-SHOT BEAM CHARACTERIZATION DEVICE BASED ON THE PEPPER-POT PRINCIPLE*

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Abstract

For characterizing the ampere-scale microsecond single-pulse ion beam, a pepper-pot based beam profile measurement device was developed at Peking University (PKU). It is a combination of Faraday cup technique with pepper-pot measuring facility. The total beam current is measured by a Faraday cup and there is an array of pepper-pot holes at the bottom of the Faraday cup, which takes sample beamlets from the whole beam profile for beam distribution measurement. A Faraday cup array, that locates 3 mm away from the pepper-pot mask, is used to measure beamlet currents, so that the distribution and the transverse size of the main beam can be determined. To suppressing the secondary electrons two pairs of permanent magnets are mounted at the entrance of the main Faraday cup and in front of the Faraday cup array, respectively. In this paper we present the details of the physical and mechanical design, and the future developments on pepper-pot devices are discussed, too.

INTRODUCTION

The beam distribution on its profile is a basic parameter that characterizes the ion beam extracted from the ion source and greatly influences the beam transmission. A device to measure the beam distribution of an ampere-scale microsecond single-pulse ion beam and its peak beam current has been investigated at PKU recently. The main parameters of the ion beam to be measured and their varying range are listed in Table 1.

Table 1: Main Parameters to be Measured by the Pepper-Pot Device

Parameters	Value
Beam type	Single pulse
Pulse length	4 μs
Beam diameter	< 30 mm
Beam energy	20~150 keV
Peak beam current	0.1~10 A

More generally the beam emittance can be measured by different Emittance Measurement Units (EMUs), such as the pepper-pot device [1-3], the slit-wire type facility [4-6] and the Allison scanner [7-8], which can also give out the beam distribution information. But the slit-wire EMU and the Allison Scanner are unsuitable here because they need longer time to finish the mechanical scan during a measurement. The pepper-pot EMU is a candidate for single-shot micro-second beam profile measurements. However, The pepper-pot EMU can not be used for the total ion beam current measurement and the cost to manufacture such a facility is very high. To measure the ampere-scale microsecond single-shot ion beam with a lower cost, we propound a beam profile and total current measurement device based on the pepper-pot principle and Faraday cup technique. It is named as pepper-pot beam profile measurement device (see Fig. 1). Its test will be performed on the low energy beam transport (LEBT) test bench at PKU.

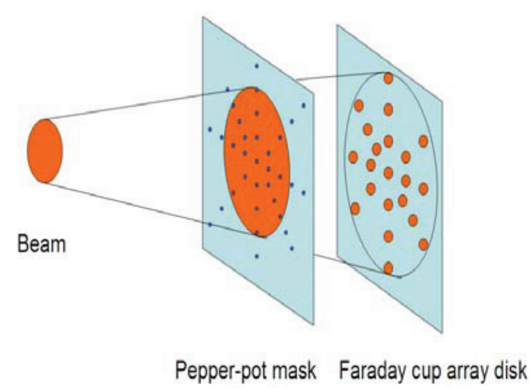

Figure 1: The beam profile measurement principle.

MECHANICAL DESIGN

The schematic diagram of this pepper-pot beam profile measurement device is shown in Fig. 2. It consists of a main Faraday cup with a pepper-pot mask on its bottom, a Faraday cup array disk, two pairs of permanent magnets and an outer casing. The grounded outer casing is a shielding to reduce the measurement background introduced by secondary electrons and other stray ions in the vacuum chamber.

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Main Faraday Cup with Pepper-Pot Mask

The main Faraday cup is used to collect the total beam current and its bottom pepper-pot mask with identical holes can sample the total beam to form multiple beamlets for the beam distribution measurement. The Faraday cup array disk locates downstream from the pepper-pot mask, and every pair of pepper-pot hole and the corresponding array cup is aligned so each beamlet current can be measured by the corresponding array cup, as shown in Fig. 2. To meet the beam size, the inner diameter of the direct Faraday cup is 30 mm.

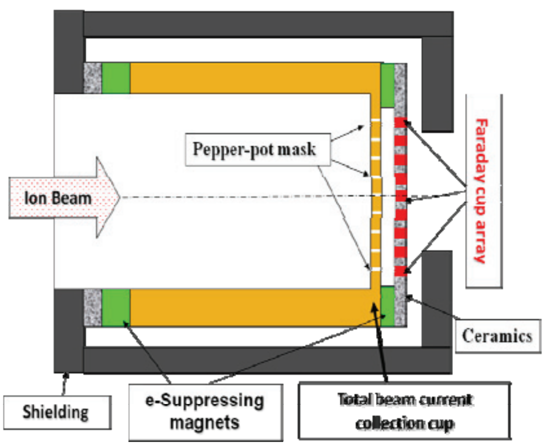

Figure 2: Schematic diagram of the pepper-pot beam profile measurement device.

The structure of the pepper-pot mask, which is made of molybdenum, is illustrated in Fig. 3. The thickness of the pepper-pot mask should be small enough to prevent any smearing effects due to beam scattering [1]. Hence, each hole on the 2 mm thick mask has a 60° cone apex angle and the actual thickness of the hole wall is 0.5 mm. To measure different divergence and different current ion beams, we choose 0.8 mm and 0.5 mm as the pepper-pot hole diameter. As shown in Fig. 3, there are 25 holes on the pepper-pot mask.

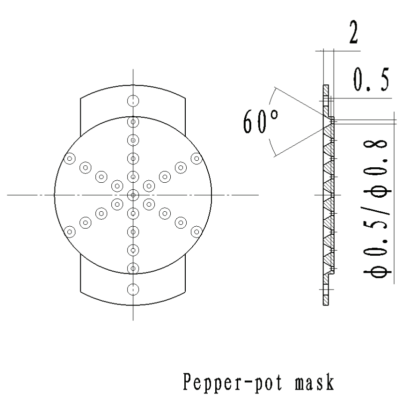

Figure 3: The pepper-pot mask.

Faraday Cup Array Disk

As a beam profile detector, 25 small Faraday cups, that correspond to the pepper-pot holes one by one, form a Faraday cup array. They are embedded into a 3 mm thick aluminium oxide ceramic disk for supporting and insulation. Considering the divergence of the ion beam, the size of array Faraday cups should be larger than the size of pepper-pot hole aperture [1]. In order to avoid the beam overlap between neighbouring beamlets, the distance between the pepper-pot mask and the Faraday cup array should be set as shorter as possible. Here the gap is 3 mm. By calculating, an ion beam with about 180 mrad divergent angle can be detected on the collector disk by an array of 2 mm diameter Faraday cups.

Secondary Electrons Suppression

According to theoretical analysis, the beam current and beam distribution measurements without secondary electrons suppression will be larger than its real value. For the pepper-pot device, we choose two pairs of permanent magnets to suppress the secondary electrons. As the ion beam energy is less than 150 keV, the energy of the secondary electrons is generally tens of eV [9]. Using the formula of $r = mv/eB$ we know that a 200 Gauss of magnetic field is big enough to capture the secondary electrons with the cyclotron radius less than 2 mm. Therefore, two pairs of permanent magnets with an axial field larger than 200G will be used at the entrance of the main Faraday cup and in front of the Faraday cup array.

DATA ACQUISITION AND ANALYSIS

We have developed a complete set of data acquisition and analysis system for the High Intensity Beam Emittance Measurement Units (HIBEMU) at Peking University [5], but they are used to measure CW or long pulsed beams with the pulse width longer than 1 ms. For a □s ion beam, this acquisition system is not suitable. Two methods of measuring microsecond ion beams can be chosen for us. One is using sampled resistances and a computer with a data acquisition card of hundreds of MHz which contains more than 25 signal channels. The other method that uses many storage oscilloscopes to measure the signal of each Faraday cup is also available at the laboratory.

COMMISSIONING TESTING

The pepper-pot measurement device will be tested on the Low Energy Beam Transport (LEBT) test bench (Fig. 4) [10]. Data obtained from the pepper-pot beam profile measurement will be compared with the results acquired by the Allison scanner EMU2 [8] (beam profile) and the FC2.

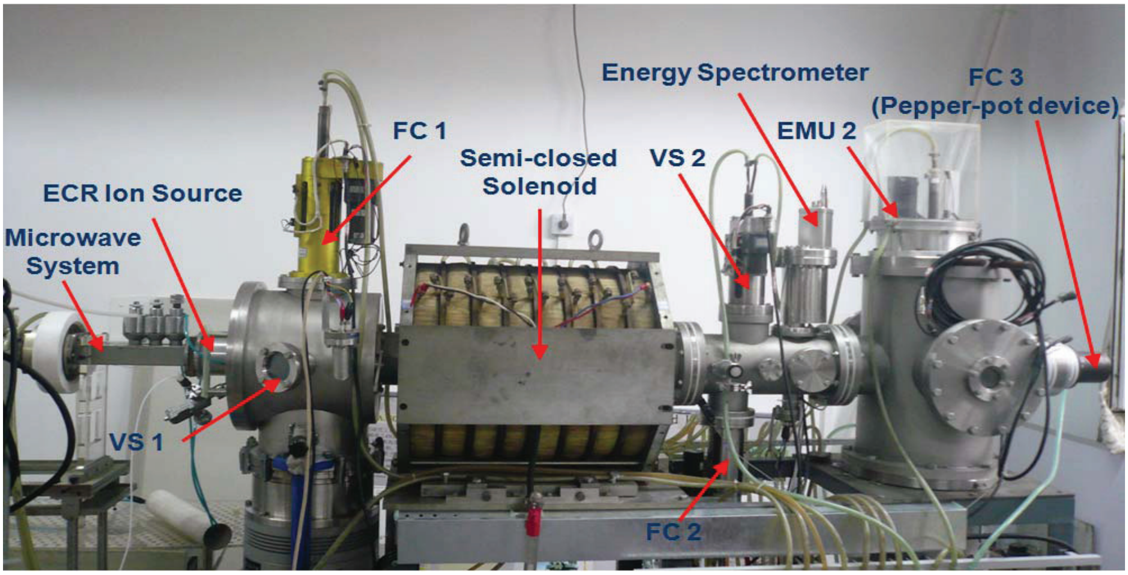

Figure 4: Low Energy Beam Transport (LEBT) Test Bench.

SUMMARY

In this paper, we present the details of the design of a pepper-pot beam profile measurement device, which can detect the beam current and beam distribution of an ampere-scale microsecond single-shot ion beam. It is under fabrication now. The commissioning test will be performed on the LEBT test bench at Peking University. The results will be reported in the future.

REFERENCES

[1] M. Ripert, A. Peters, “Target Materials for A Low Energy Pepper-pot Emittance Device”, Proceedings of DIPAC09, Basel, Switzerland, TUPD36, P. 378-380 (2009).

[2] M. Hamabe, T. Kuroda, M. Sasao, M. Nishiura, M. Wada and S. K. Guharay, “A Comparative Study of Emittance Measurements Using Different Techniques”, Rev. Sci. Instrum. Volume 71, Number 2, 2000.

[3] M. Strohmeier, J. Y. Benitez, D. Leitner, D. Winklehner, D. S. Todd, C. M. Lyneis and M. Bantel, “Emittance Measurements at The LBNL ECR and AECR-U Ion Source Using a Pepper-pot Emittance Screen”, proceedings of BIW10,Santa Fe, New Mexico, US, TUPSM061, P. 302 (2010).

[4] X. F. Guan, X. Z. Shi, Y. H. Zhang, et al. “Emittance measurements basing on probe-slit method for a high current grid-controlled pulse electron gun”, High Power Laser and Particle Beams, 1992, 4(2): 215-222.

[5] P. N. Lu, S. X. Peng, Z. Y. Guo, Z. X. Yuan, H. T. Ren, J. Zhao, M. Zhang, J. E. Chen and Y. R. Lu, “Development of High Intensity Beam Emittance Measurement Unit”, SCIENCE CHINA Physics, Mechanics & Astronomy, 132011-575 (2011).

[6] P. N. Lu, S. X. Peng, Z. X. Yuan, J. Zhao, H. T. Ren, Z. Y. Guo, and Y. R. Lu, “Four-Dimensional Transverse Emittance Meter at Peking University” (this proceeding).

[7] P. W. Allison, J. D. Sherman, D. B. Holtkamp, “An emittance scanner for intense low-energy ion beams”, IEEE Transactions on Nuclear Science, 1983, 30(4): 2204-2206.

[8] R. Xu, Y. B. Zou, S. L. Gao, Z. Y. Guo, S. X. Peng, F. Qian, and J. Zhao, High Power Laser and Particle Beams 19, 1216 (2007).

[9] P. A. Wolff, “Theory of Secondary Electron Cascade in Metals”, Phys. Rev. 95, 56–66 (1954).

[10] H. T. Ren, S. X. Peng, M. Zhang, Q. F. Zhou, Z. Z. Song, Z. X. Yuan, P. N. Lu, R. Xu, J. Zhao, J. X. Yu, Y. R. Lu, Z. Y. Guo and J. E. Chen, “The Deuteron Injector Progress of the PKUNIFTY Project”, Rev. Sci. Instrum. 81, 02B714 (2010).