A NON-INTERCEPTING BEAM EMITTANCE MEASUREMENT DEVICE BASED ON NEUTRAL BEAM FLUORESCENCE METHOD AT PKU*

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Abstract

A new concept to attain ion beam emittance through measuring the forward neutral beam without intercepting the beam transportion was proposed at PKU. The forward neutral beam produced by space charge compensation and seperated from the transporting ion beam with the help of a deflecting magnetic field, carries the entire emittance information of the original particle beam and becomes a fast and non-interceptive beam diagnostic tool. This idea was tested on PKU ion source test bench and the experimental results show that the neutral beam fluorescence method is feasible. Based on these qualification results, a formal non-intercepting emittance measurement device was designed. It is a 90 degree full-scale dipole analysis magnet combined with the classical pepper-pot technique. Testing and commissioning of the device have been performed on the PKU test bench. Details of design and comissioning results will be presented in this paper.

INTRODUCTION

The knowledge of transverse phase space such as beam emittance is of essential importance for beam matching and beam loss in high-intensity high-brightness particle accelerators. Conventional emittance measurement techniques are generally classified into the slit-wire method, the pepper-pot method and the Allison-type scanner. At Peking University, several Emittance Measurement Units (EMUs) of these kinds have been developed for high intensity ion beams [1-3]. However, all these techniques are interceptive systems and cannot be able to meet the on-line, real time, non-interceptive measurement requirements of the large high-intensity LINAC such as accelerator driven clean nuclear system (ADS), spallation neutron source (SNS).

For this purpose, some non-interceptive beam emittance measurement devices have been developed recently, i.e., Optical Diffraction Radiation Interference (ODRI) method [4] for high brightness electron beams, laser wire based method [5] for high energy H- beam, and the residual gas illumination method [6] for high intensity proton or deuteron beams. A new non-interceptive emittance measurement approach based on neutral beam fluorescence was proposed at PKU and a proof-of-principle demonstration was conducted in Ref. [7]. Based on the principle experimental results, a formal non-intercepting emmitance measurement device has been developed and installed in the PKU ion source test bench. It is a 90 degree full-scale dipole analysis magnet combining with the classical pepper-pot technique. The device enables a measurement of the transverse emittance in both directions with non-intercepting.

In this paper, we describe the details about design, and commissioning results of the non-interceptive emittance measurement system based on neutral beam fluorescence method. In order to verify the new device, comparison experiments with slit-wire emittance monitor have also been presented in this paper.

EXPERIMENTAL SETUP

Measurement Principle

Figure 1 shows a diagram of the non-interceptive beam emittance measurement system based on neutral beam fluorescence. It is in principle a pepper-pot style emittance device combining with a dipole analysis magnet. When the particle beam, for example the H^+ beam, interacts with residual/extra injected gas, a certain number of the ions are meutralized in the space charge compensation (SCC) zone [8] and then separated from the charged beam path by the deflecting magnetic field. These hydrogen (H^0) atoms preserve the angular distribution of the original H^+ beam. Therefore, the measurement of the neutral beam (H^0) divergence can lead to the determination of the proton beam divergence.

The measurement of the neutral beam (H^0) angular distribution is performed by a classic pepper-pot device. The pepper-pot sampling plate intercepts the forward H^0 beam to form multiple beamlets by a array of small holes. These beamlets transmitted through these holes illuminate the fluorescence screen located at a certain distance. By

*Work supported by the National Science Foundation of China (Grant Nos. 91126004, 11075008, 11175009) and China Postdoctoral Science Foundation (Grant No. 2013M530483).
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ISBN 978-3-95450-127-4

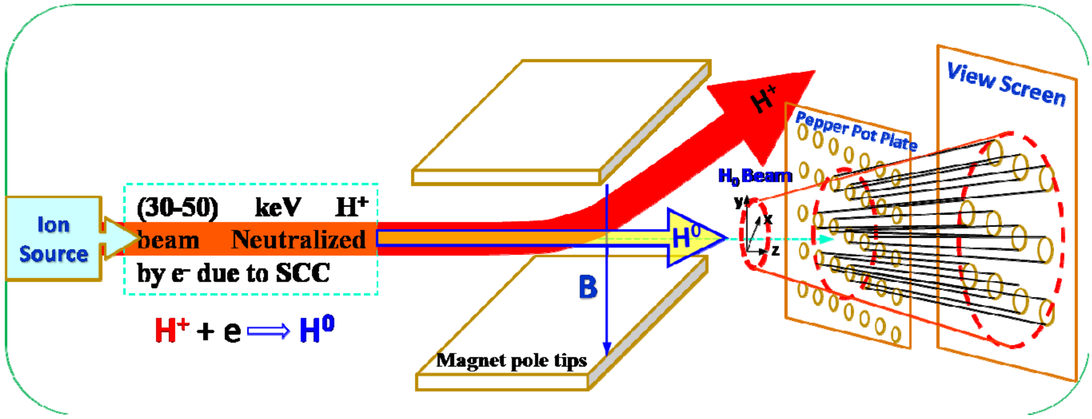

Figure 1: Outline of beam emittance monitor based on neutral beam fluorescence.

meauring the images of these neutral beamlets on the fluorescence screen by a CCD camera, the disribution of the H^0 beam which corresponds to the divergence of the H^+ beam can be obtained. Finally, analysis and calculation of the spot size of the images can show the two-dimensional transverse emittance. Because the scattered images of these beamlets cannot give all detailed information o of the distribution of H^0 beam before data processing, an approximation method with grid data function is used to reconstruct the H^0 beam transverse profile.

System Layout

The new emittance measurement device was installed and tested on the PKU ion source test bench (shown in Fig. 2) [8]. The test bench consist of a compact 2.45 GHz Permanent Magnet Electron Cyclotron Resonance (PKU PMECR) ion source with its microwave system, a tri-electrode extraction system and a vacuum chamber for beam diagnostic device. In order to verify the results acquired by the neutral beam fluorescence based emittance measurement device, a multi-slit single-wire (MSSW) beam emittance monitor is installed in the vacuum chamber. The space charge compensation happens in the chamber with extra injected gas.

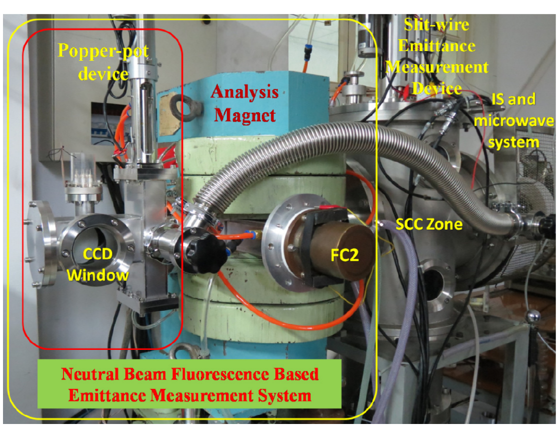

Figure 2: PKU ion source test bench and new emittance measurement system.

The neutral beam fluorescence based emittance measurement system is located about 550 mm away from the PMECR ion source. As shown in Fig. 2, the new system consists a 90 degree full-scale dipole analysis magnet and a conventional pepper-pot unit along the straight line direction. The dipole installed right behind the SCC zone is used to bend the H^+ beam and separate the neutralized hydrogen beam (H^0) from the main beam trajectory. The pepper-pot plate containing 61 identical holes (diameter of 0.2 mm) with thickness of 0.2 mm is installed in the straight beam line, about 680 mm downstream to the MSSW emittance monitor. The distance between the plate and the fluorescence screen is 120 mm. The Faraday Cup (FC2) at the end of the dipole is used to collect the bending ion beam.

TESTS AND COMMISSIONING

During the commissioning, the background vacuum is 9.5×10^{-5} Pa and the compensation vacuum is 5.2×10^{-3} Pa with extra Argon gas. The initial test of the system was conducted using a 30 mA/50 keV proton beam with 10% duty factor (1 ms, 100 Hz). Fig. 3 shows an output image of the neutral beamlets obtained by the CCD camera after subtracting background noise. In this image, all the H^0 beamlets on veritcal direction were acquired by the fluorescence screen, while on the horizontal direction there was a lack of several H^0 beamlets because of the limitation of the screen size. Therefore this image can only provide the information for the vertical emittance calculation of the H^+ beam.

A data analysis program written with Matlab was performed to calculate the transverse emittance of the ion beam. A grid data function was chosen to reveal the entire beam emittance distribution with the scattered spots of H^0 beamlets in the image (shown in Fig. 3). Fig. 4 shows the measurement result for the vertical emittance distribution (vertical) of the proton beam. The measured normalized rms emittance is 0.0973 π mm mrad. Under the same conditions, the measurement result (on the vertical direction) by the MSSW emittance monitor is shown in Fig. 5 and the measured normalized rms emittance is 0.0826 π mm mrad.

ISBN 978-3-95450-127-4

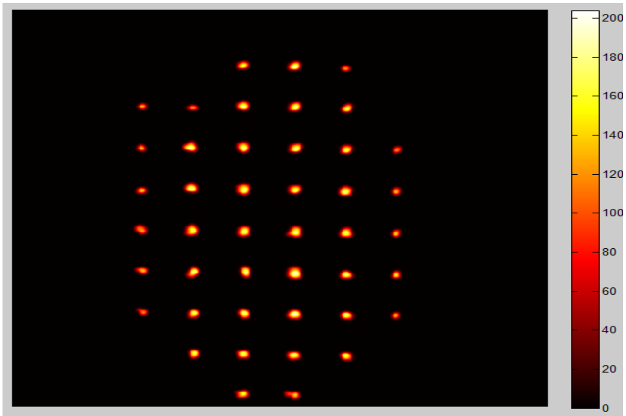

Figure 3: Image of H^0 beamlets on the fluorescence screen.

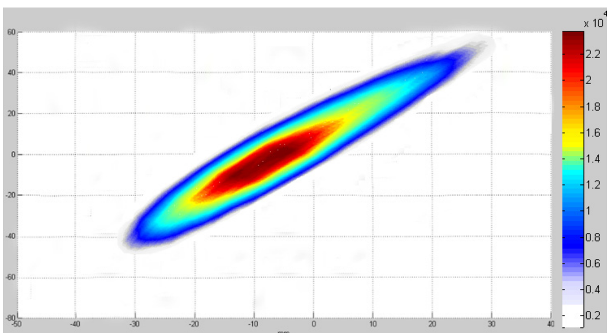

Figure 4: Measured emittance distribution (vertical) using the neutral beam fluorescence based emittance measurement system.

According to the comparison between Fig. 4 and Fig. 5, the measurement result of the new system is basically consistent with the output of the MSSW emittance monitor. The reasons for the higher emittance value measured by this new system are mainly focusing on two factors. First one is the space charge effect during the beam transmission between two measurement devices, which can lead to emittance growth. The second one is the measuring error caused by larger distance between neighboring sample holes. In the pepper-pot plate of the new device, the distance between two neighboring holes is 7 mm, great lager than 2 mm in the multi-slit plate of MSSW emittance monitor.

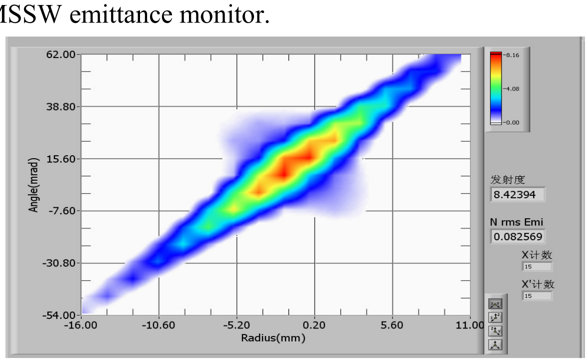

Figure 5: Measured emittance distribution (vertical) using the MSSW emittance monitor.

The spatial resolution of a pepper-pot emittance monitor is determined by the requirement that different beamlets do not overlap in the fluorescent target [9]. Under this precondition, the distance between sample holes should be as small as possible to reduce the measuring error.

CONCLUSION

We have described the system configuration, commissioning results, and error analysis of the neutral beam fluorescence based emittance measurement device at the PKU ion source test bench. The system has demonstrated a high speed, high accuracy and non-interceptive transverse emittance measurement method for the H+ beam. And meanwhile it is greatly helpful for further study of the space charge compensation in the intense ion beam at low energy. In order to measure beam emittance in both vertical and horizontal directions, the size of fluorescence screen should be improved in the future.

REFERENCES

[1] Xu R, *et al.*, "Allison Scanner for High-current Ion Beam Emittance Measurements" (in Chinese), High Power Laser Part Beams, 19(7): 1216–1220, (2007).

[2] P. N. Lv, *et al.*, "Development of High Intensity Beam Emittance Measurement Unit", SCIENCE CHINA (Physics, Mechanics & Astronomy), Vol.54 Suppl. 2: s287–s291, (2011).

[3] H. T. Ren, S. X. Peng, J. Zhao, *et al.* "A PEPPER-POT BASED DEVICE FOR DIAGNOSTICS OF THE SINGLE-SHOT BEAM", Proceedings of IPAC2013, Shanghai, China, THOAB102, 3093-3095.

[4] A. Cianchi, *et al.*, NON-INTERCEPTING EMITTANCE MEASUREMENTS BY MEANS OF OPTICAL DIFFRACTION RADIATION INTERFERENCE FOR HIGH BRIGHTNESS ELECTRON BEAM, Proceedings of IPAC2012, New Orleans, Louisiana, USA, MOPPR024, 831-833.

[5] Y. Liu, A. Aleksandrov, C. Long, Nonintrusive emittance measurement of 1 GeV H- beam, Nuclear Instruments and Methods in Physics Research A 675 (2012) 97–102.

[6] R. Ferdinand *et al.*, "Non interceptive Emittance Measurements of a High-Intensity Beam at Low Energy", LINAC 98 conf., Chicago.

[7] J. Zhao, H.T. Ren, S.X. Peng, et al., DESIGN OF A NON-INTERCEPTING BEAM DIAGNOSTIC DEVICE USING NEUTRAL BEAM FLUORESCENCE METHOD, Proceedings of IPAC2013, Shanghai, China, MOPME035, 547-549.

[8] M. Zhang, S. X. Peng, H. T. Ren, Z. Z. Song, Z. X. Yuan, Q. F. Zhou, P. N. Lu, R. Xu, J. Zhao, J. X. Yu, J. E. Chen, Z. Y. Guo, and Y. R. Lu, Upgrade of permanent ECR ion source and its extraction system，Rev. Sci. Instrum. 81, 02B715 (2010).

[9] H.R. Kremers, *et al.*, "A pepper-pot emittance meter for low-energy heavy-ion beams", Review of Scientific Instruments Vol.84, Issue 2, (2013).

ISBN 978-3-95450-127-4