DESIGN OF A NON-INTERCEPTING BEAM DIAGNOSTIC DEVICE USING NEUTRAL BEAM FLUORESCENCE METHOD

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Abstract

The forward neutral beam from deflecting magntic field carries some characteristic properties of high intensity particle beams, such as profile, emittance etc. Therefore a reliable measurement of neutral beam fluorescence can be used to develop a fast and non-interceptive beam diagnostic tool. A non-intercepting beam emittance (profile) monitor using neutral beam fluorescence method has being constructed at Peking University. The monitor is designed to measure the transverse emittance in both directions on a low energy intense proton beams at the ion source (IS) test bench. The neutral particles are produced in the space charge compensation (SCC) zone. The mechanical design has been completed. The implementation, measurement, and comparison to multi-slit single-wire type emittance monitor will be carried out in the near future. The details of design and some preliminary results of measurement will be presented in this paper.

INTRODUCTION

Beam emittance is one of the most important characteristic properties of high-intensity beams that might limit the performance of the accelerator. Therefore a reliable measurement and determination of beam emittance is most helpful for controlling and improving the beam quality, better beam match, low beam losses during acceleration, and improving the whole accelerator chain to achieve the best performance [1].

Five High Intensity Beam Emittance Measurement Units (HIBEMUs) have been developed at Peking University, named HIBEMU-1~5[2-6]. HIBEMU-1,2,4,5 are based on multi-slit single-wire(MSSW) method, while HIBEMU-3 is an Allison scanner. All the HIBEMUs are interceptive system. They are unable 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).

In recent years, some non-interceptive beam diagnostics methods are used to measure the emittance of high energy intensity beam [7], such as interferometer method [8], optical diffraction radiation and undulator radiation. For low energy high intensity beam, emittance measurement based on the residual gas ionization is a very powerful non-interceptive beam diagnostic tool [9].

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The forward neutral beam neutralized and separated from the beam path carries some characteristic properties of the original particle beam [10]. Therefore a hight-accuracy measurement of neutral beam fluorescence can be used to develop a fast and non-interceptive beam diagnostic tool. It can avoid the high amount of heat produced the high power beams during the interceptive emittance measurement. More importantly, it is consistent with the increasing non-destructive beam diagnostic need for the high-intensity and high energy beams accelerators like ADS and SNS.

In this paper, we describe a non-intercepting beam emittance monitor based on neutral beam fluorescence at the ion source test bench. The neutral particles are produced in the space charge compensation (SCC) zone. It is designed to give the transverse emittance of two directions by the classical pepper-pot technique.

FEASIBILITY TEST

In order to verify the feasibility of the method, we have completed a principle experiment. A multiple slits plate and a quartz glass target coated with fluorescent powder were laid behind the analysis magnet of the IS test bench (see Fig. 1). By comparison with the brightness of slits image on quartz fluorescent target with or with no deflecting magntic field, we can get the angular distribution of the neutral hydrogen (H^0) beam.

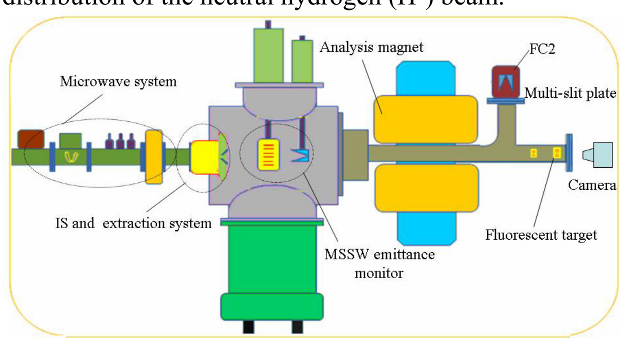

Figure 1: Layout of the IS test bench.

IS test bench consists of a compact 2.45 GHz Permanent Magnet Electron Cyclotron Resonance (PKU PMECR) ion source with its microwave system, a tri-electrode extraction system, a vacuum chamber for beam diagnostic device and a 90 degree dipole analysis magnet with a Faraday cup (FC2). In the vacuum chamber, a Faraday cup (FC1, alternative with the MSSW emittance monitor), a multi-slit single-wire (MSSW) beam emittance monitor and an extra gas injection valve are

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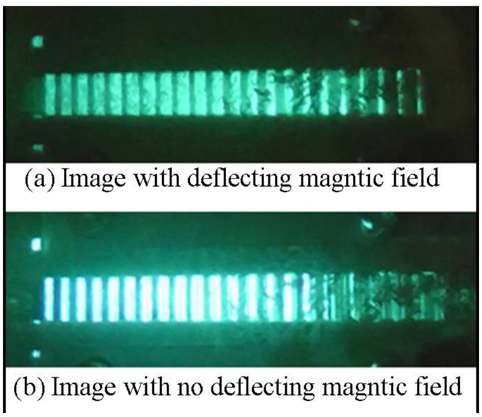
installed. An extra injected gas makes the chamber being a space charge compensation (SCC) zone. The background vacuum is 1.0×10^{-5} Pa. The ion source and extraction system has the ability to produce a maximum 100 mA hydrogen beam at 50 keV with H+ factor of 90%.

During the principle experiment, a 40KeV 13mA CW hydrogen beam was extracted form the IS and the FC1 was installed on the beam line. When the FC1 was raised up from the beam line, the images of fluorescent target with or without deflecting magntic field are shown in Fig. 2.



(a) Image with deflecting magntic field

(b) Image with no deflecting magntic field

Figure 2: Image of quartz fluorescent target.

In space charge compensation (SCC) zone, a certain number of the ions are neutralized by residual/extra injected gas ionization [11]. These hydrogen (H^0) atoms preserve the angular distribution of the original hydrogen beam, which can be verified in Fig. 2. Image (a) of Fig. 2 can be considered as a neutral beam (H^0) fluorescence image since all charged particles such as H^+, H_2^+, H_3^+ are deflected from the beam path by the deflecting magntic field. Image (b) is produced by the full beam including the charged and neutral particles. Compare the two images, the number of fluorescent stripes is approximate the same except the level of brightness.

DESIGN OF DEVICE

Above experimental results show that the neutral beam fluorescence method is feasible. In order to reliably measure the two-dimensional transverse emittance, we designed a measurement device using the classical pepper-pot technique, the outline is shown in Fig.3. The new mechanical design with a 90 degree full-scale dipole analysis magnet is shown in Fig. 4.

The forward neutral beam (H^0) neutralized by gas ionization in SCC zone and separated from the charged beam by a deflecting magntic field is intercepted by a pepper-pot sampling plate with a linear array of holes. The beamlets transmitted by these holes illuminate the fluorescent target located at a fixed distance downstream of the pepper-pot plate. The pinhole diameter is 0.1 mm and the distance between the plate and the target is 100 mm. The image on the target is acquired by a CCD camera.

The spatial resolution of a pepper-pot emittance monitor is determined by the requirement that different beamlets do not overlap in the fluorescent target, while the angular resolution is determined by the resolution of the CCD camera and image processing algorithm. Practical experience shows that often problems arise because of inhomogeneity, nonlinear response and aging of the fluorescent material [12].

Analysis and calculation of the spot size of the image can show the two-dimensional transverse emittance. As a reference measurement, a MSSW emittance monitor is installed in SCC zone. It can define the measure error of neutral beam fluorescence method by comparing the result between both measurement method. Furthermore, it is helpful for better understanding of the space charge compensation of intense ion beams at low energy.

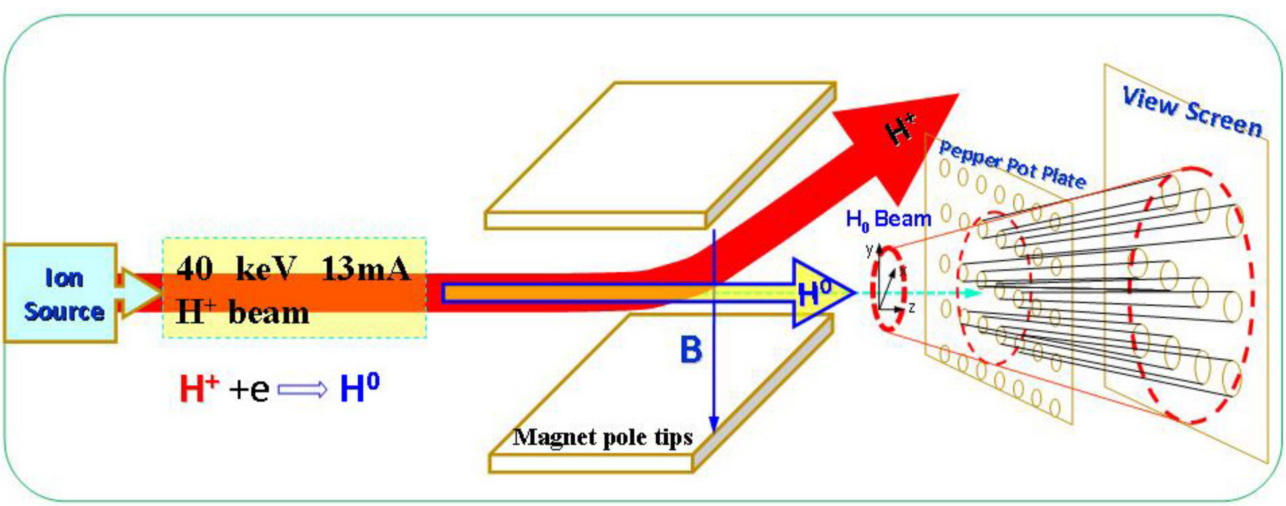


Figure 3: Outline of beam emittance monitor based on neutral beam fluorescence.

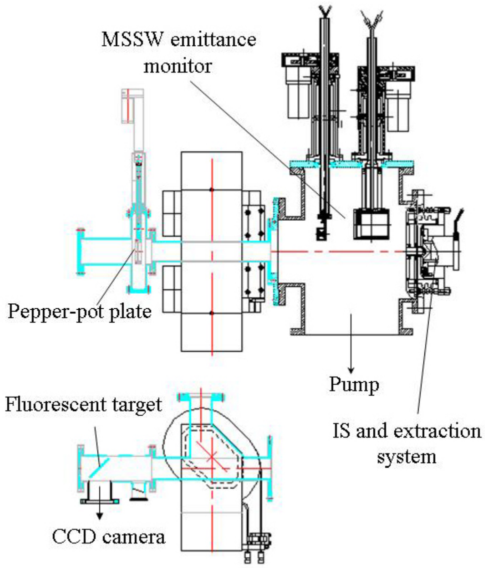


Figure 4: Mechanical design of measurement device.

CONCLUSION

Beam emittance monitor based on neutral beam fluorescence method gives possibility to measure the two-dimensional transverse emittance of low energy intense beam. It can be used to develop a fast and non-interceptive beam diagnostic tool.

Now the mechanical design has been completed. The implementation, measurement, and comparison to MSSW emittance monitor will be carried out in the near future.

REFERENCES

[1] Z. Y. Guo, et al., "Measurement Techniques of High-Current Ion Beam Emittance"(in Chinese), Chinese Physics C (HEP & NP), Vol 32, P148-150, 2008.

[2] W.Z. Wu, et al., "Development of an Emittance Measurement Unit for High-current Ion Beam." (in Chinese) Atomic Energy Science and Technology, Vol. 38. Suppl: 66-74, 2004.

[3] J.C. Ming, et al., "Emittance Measurement of High-current Pulse Ion Beam." (in Chinese), Nuclear Techniques, Vol.29(2), 105-107, 2006.

[4] 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.

[5] S. X. Peng, et al., "Methods to Reduce the System Error for High Power MSSW Emittance Metor", IBIC2012, Tsukuba, 2012, TUPB64, http://www. JACoW.org.

[6] 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.

[7] I. Pinayev, "Lepton Beam Emittance Instrumentation", BIW2006, 112-123.

[8] J. Chen, et al., "The Synchrotron Radiation Diagnostic Beam line of SSRF", IBIC2012, Tsukuba, 2012, MOPB70, http://www. JACoW.org.

[9] R. Ferdinand, et al., "Non-Interceptive Emittance Measurement of a High Intensity Beam at Low Energy", Linac98, Chicago, 1998, TH4059, http://www. JACoW.org.

[10] Y. Liu, et al., "Nonintrusive emittance measurement of 1GeV H- beam", Nuclear Instruments and Methods in Physics Research A 675, 97–102, 2012.

[11] S. X. Peng, et al., "Key elements of space charge compensation on a low energy high intensity beam injector", Rev Sci Instrum, 84(3):033304, 2013.

[12] 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.