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Emittance and proton fraction measurement in High current electron cyclotron resonance proton ion source

P. Roychowdhury *, H. Kewlani, L. Mishra, S. Gharat, R.K. Rajawat

Accelerator and Pulse Power Division Bhabha Atomic Research Centre Trombay, Mumbai 400085, India

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ABSTRACT

The beam characterization studies in terms of emittance and proton fraction have been carried out in the high current Electron Cyclotron Resonance (ECR) proton ion source developed for Low Energy High Intensity Proton Accelerator (LEHIPA). The beam emittance was measured using two slit emittance measurement units (EMU). The emittance was measured at three locations (1) after beam extraction at ion source end, (2) after focusing the beam using solenoid magnet and (3) after focusing and separating H^+ using solenoid magnet and analyzing magnet. The beam emittance measured in all three cases was found to be less than 0.2π mm-mrad (rms-normalized). The proton fraction in the beam measured using analyzing magnet was found to be more than 90%. The variations of beam emittance and proton fraction have been studied as a function of microwave power and neutral gas pressure.

1. Introduction

A high current Electron Cyclotron resonance (ECR) proton ion source has been designed and developed for Low Energy High Intensity Proton Accelerator (LEHIPA) at Bhabha Atomic Research Centre (BARC) [1–3]. LEHIPA consists of H^+ ion source at 50 keV to be accelerated to 3 MeV by Radio Frequency Quadrupole (RFQ) and to 20 MeV by an Alvarez type DTL. The design parameters and the status of the ion source are shown in Table 1. The microwave discharge in the ion source under ECR conditions is capable of generating high density plasma at low pressure and ion beam current of tens of milli-amperes have been extracted from these plasmas. The ECR ion source consists of a cylindrical plasma chamber that is surrounded by magnetic field in axial direction. The ionization of neutral gas molecules is created by low energy plasma electrons. The applied magnetic field provides the electron cyclotron motion for the resonance heating and confinement of plasma. The ion beam is extracted by biasing the extraction electrodes when the plasma is stabilized. The studies on plasma characterization, beam extraction and stable operation of the ion source have been reported earlier [2,3]. In this paper we report the measurement of two crucial beam parameters i.e. beam emittance and proton fraction. The emittance was measured using a two slit emittance meter and proton fraction was measured using a magnetic mass analyzer. The variation of these parameters with microwave power and gas pressure was studied.

2. Method of emittance measurement

Transverse emittance is one of the fundamental beam characteristics in any ion source and beam transport line. It is a measure of transverse trace space occupied by the beam. There are various methods of measuring beam emittance e.g. slit–slit, slit and collector, electric sweep, quadrupole scan, pepper pot etc. [4–14]. In our study we have used a slit–slit emittance measurement method.

The Emittance Measurement Unit (EMU) apparatus designed and developed in our laboratory consists of two identical stepping-motor driven slit and slit-detector devices for determining the transverse emittance of the ion beam in x and y directions, respectively. Each slit is made of tantalum 0.2 mm wide and 80 mm length and separated by 300 mm. The slits are water-cooled. An electron suppressed Faraday cup is attached to the second slit. The Faraday cup current on the second slit is recorded on M/S Keithley 6485 current meter and stored in PC. The design parameters of the emittance meter are shown in Table 2.

The instrumentation of the two slit emittance meter [15] was based on microcontroller. The sixteen bit microcontroller was chosen for this application. For providing precision motion of the slits, the stepper motor (150 kg.cm torque) of 1.8° step size and a ball screw of 5 mm pitch mechanism were employed. Using the micro-step driver and the above mechanism, the precision motion of 5 μm was achieved for both the slits. Two linear incremental encoders of 5 μm resolutions were employed to know the exact positions of the two slits. For limiting the motion of the slits, two limit switches were installed on the emittance meter.

* Corresponding author.
E-mail address: pradipr@barc.gov.in (P. Roychowdhury).

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A quantitative measure of the quality of ion beams is given by the root-mean-square emittance

$$\varepsilon_{y-rms} = \left(<y^2> <y'^2> - <yy'>^2 \right)^{1/2} \quad (1)$$

Table 1
Parameters of ECR proton ion source.

Parameters	Design Specifications	Present Status Achieved
Beam current (mA)	50	40
Beam energy (keV)	50	50
Incident RF power @ 2.45 GHz	500–1000	500–1100
Axial magnetic field (G)	875–1000	800–900
Duty factor (%)	100 (CW)	100 (CW) and 1–99% (pulsed)
Gas pressure (10^{-3} mbar)	1–10	1–5
Emission aperture radius (mm)	4	4
Extraction gap (mm)	17	17
Proton fraction (%)	80	>90 @ 25 keV
RMS normalized beam emittance (π mm-mrad)	0.2	0.05–0.23 @ 25 keV

Table 2
Design parameters of emittance meter.

Parameters	Values
Slit aperture width (mm)	0.2
Slit aperture length (mm)	80
Distance between slits *D* (mm)	300
Position resolution (mm)	0.1
Maximum linear stoke (mm)	± 75
Angular resolution (mrad)	± 0.33
Maximum angular range (mrad)	± 250

In Eq. (1), $<y^2>$, $<y'^2>$, and $<yy'>^2$ are the moments of particle distribution in y–y' trace space (equivalent in case of x–x') [16,17]. We assumed that the particle distributions in the y–y' and x–x' phase space had the same distributions because we only measured the particle distribution in the y–y' phase space, and, in general the distribution is symmetric in the beam from the ECR proton ion source.

The computer programs have been developed to control the measurement as well as to evaluate and visualize data. To start the measurement, many parameters have to be specified. First, the beam profile is measured by moving two slits together. This mode is provided to get a rough estimation of the beam characteristics. Second, for one location of first slit, the second slit scans the beamlet to get an idea of the extent of the scan. Third, complete emittance scan using emittance measuring program.

On the basis of stored data, the evaluation program first converts and stores the measured rough data in a matrix. Here each number represents the normalized intensity, measured in a small area in phase plane defined by Δy, the step width of the slit movement, and $\Delta y'$, the divergence determined by the detector positions behind the slit. The matrix contains some thousands of numbers, where some cells are filled up with very small numbers, generated by electronic noise instead of representing a real emittance pattern. The evaluation program then removes these strange points by setting all numbers in the matrix below a given threshold to zero and evaluates the emittance value based on the program written as per reference 18.

3. Experimental set up

The schematic of LEHIPA ECR proton ion source operating at 2.45 GHz and used in this study is shown in Fig. 1. The ion source consisted of 90 mm diameter, 100 mm length cylindrical water-cooled stainless steel plasma chamber followed by ion extraction

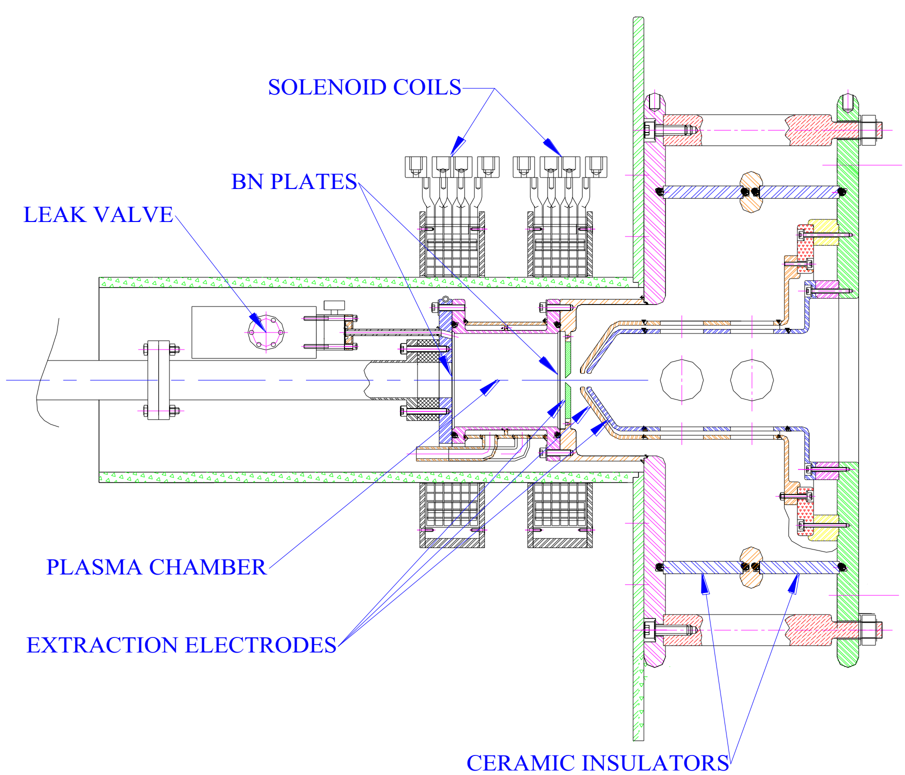

Fig. 1. Schematic of three electrode ECR proton ion source.