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BEAM CHARACTERIZATION OF FIVE ELECTRODE ECR ION SOURCE

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Abstract

A five electrode ECR Ion Source (ECRIS) is developed for the Low Energy High-Intensity Proton Accelerator (LEHIPA) at BARC. The ECRIS is operated at the energy of 50 keV with a beam current of 20 mA. The ECRIS characterization is done for the beam current, beam emittance, and proton fraction in continuous and pulse beam operation. The pulsed beam operation of the ion source starting from 500 µs to 200 ms of pulse on time with a repetition rate of 1 to 10 Hz. The transverse beam emittance measurement is done by using an Allison scanner. The beam emittance characterization experiments are conducted by varying applied microwave power to the plasma, operating gas pressure of plasma, and puller voltage. The measured beam emittance is in the range of 0.3 π.mm.mrad to 0.4 π.mm.mrad for 50 keV beam. In this paper, beam emittance experiment setup, its instrumentation and results are discussed.

INTRODUCTION

At BARC research activities are going on for proton linac as a part of Accelerator Driven System (ADS) program [1]. The 20 MeV Low Energy High Intensity Proton Accelerator (LEHIPA) [2] is the front end of it. The major components of LEHIPA are 50 keV ion source, 3 MeV Radio Frequency Quadrupole (RFQ) and 20 MeV Drift Tube Linac (DTL) as shown in Fig. 1. Presently a three electrode ECRIS is operational in LEHIPA [3]. A five electrode ECRIS has been designed and developed and characterization is going on. The beam characterization results of this five electrode ECRIS is discussed in this paper. The main requirements of this ion source are emittance of 0.2 π.mm.mrad , proton fraction of more than 90%, beam current of 10-30 mA with CW and pulsed operation.

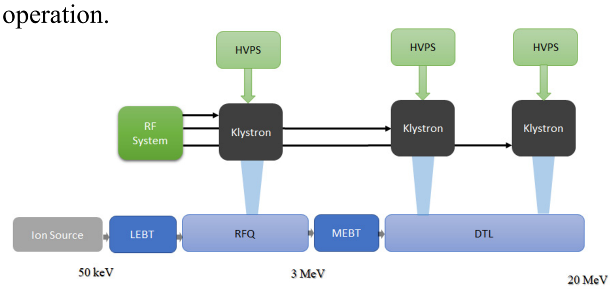

Figure 1: Schematic of LEHIPA, Low energy beam transport (LEBT), medium energy beam transport (MEBT), High voltage power supply (HVPS).

FIVE ELECTRODE ECRIS

The five electrode ECRIS is designed and developed for 50 keV, 30 mA. The details of the five electrode ECRIS is shown in Fig. 2. A 2.45 GHz, 2 kW microwave generator (make: SAIREM) [4] which operates both in CW and pulsed mode is used for plasma generation. The waveguide line consists of circulator, directional coupler, automatic stub-tuner, high voltage break (made of waveguide choke and teflon sheet), quartz window and ridge waveguide.

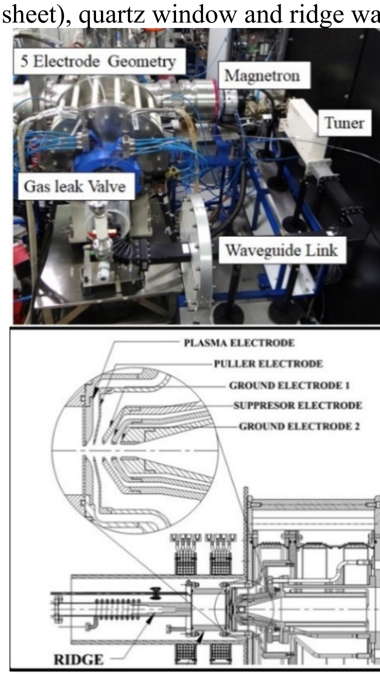

Figure 2: Five electrode ECRIS picture (above) and details of the 5-electrode assembly (below).

The plasma chamber made from SS 304 is of 90 mm diameter and 100 mm in length. The extraction geometry consists of five electrodes which are the plasma, puller, first ground, suppressor and second ground electrodes respectively (Fig. 2). The emittance of extracted beam can be controlled by puller electrode potential, microwave power, operating hydrogen gas pressure, and magnetic field of ECR solenoids. The two electro magnet solenoid coils used for ECR phenomena are placed generated at the entry and exit point of plasma chamber with the magnetic fields varied from 875 Gauss to 1200 Gauss. The base vacuum in the ion source is 8 $*10^{-7}$ mbar. A precision leak valve is used for the injection of hydrogen gas to the plasma chamber. The operating pressure of the ECRIS is $5*10^{-6}$ mbar to 2 $*10^{-5}$ mbar.

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BEAM EMITTANCE MEASUREMENT

Beam emittance is the area occupied by beam particles in three dimensional phase space (x-x', y-y', and z-z') [5]. We are interested in transverse emittance (x-x' plane and y-y' plane) of the beam from the ion source. There are several methods for transverse emittance measurement, among which allison scanner [6, 7] technique is used in our ECRIS. In Fig. 3 the layout of emittance measurement setup is shown. The ion source is followed by a movable faraday cup; focusing solenoid [8], DC Current Transformer (DCCT), 90-degree bending magnet [8], and the allison scanner. The function of focusing solenoid and 90 degree bend is to focus and filter the 50 keV H^+ ion beam.

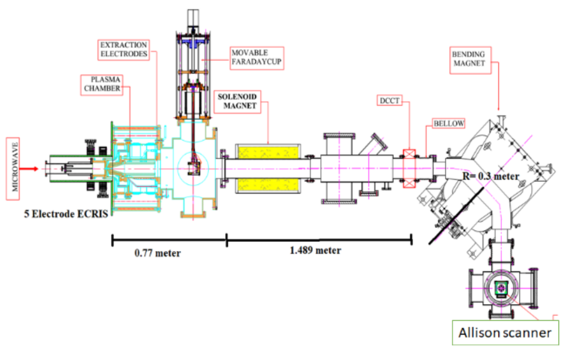

Figure 3: Emittance measurement layout.

Allision Scanner

The 3D model of Allison scanner is shown in Fig. 4. The allison scanner is made in-house, and it consists of two 80 mm long deflector plates with 4 mm gap in between; two tantalum slits of width, 0.3 mm each and a faraday cup after the second slit. The design parameters of allison scanner is shown in Table 1.

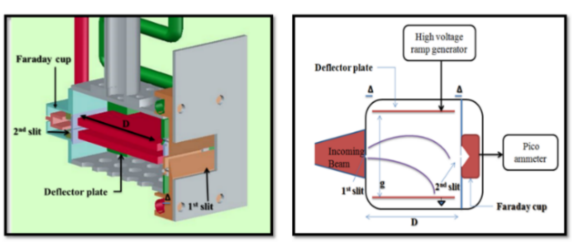

Figure 4: Allison scanner.

Table 1: Allison Scanner Design Parameters

Parameters	Value
Slit 1 (S1)	0.3 mm
Slit 2 (S2)	0.3 mm
Gap (g)	4 mm
Deflection Length (D)	80 mm
Gap (Δ)	5 mm
x_m'	$\pm$83 mrad
V_{max}	1000 V

This allison scanner is designed for 50 keV ion beam. The beam position, x is defined by the transverse slit location. A linear encoder records the beam position data. The beam divergence, given by x'= Vp/E ((D-2δ)/4g) is obtained with the voltage scan on deflector plates [6]. The voltage scan of -1 kV to +1 kV in a duration of 100 ms. For each slit position, the deflection voltage along with Faraday cup current data are recorded. Throughout the experiment the beam current is monitored on DCCT [9].

EXPERIMENTAL RESULTS

During the Allision scan emittance measurement experiments a 200 ms, 2 Hz beam pulse was used. The peak beam current was 6 mA at 5 keV. In Fig. 5 the beam pulse as observed in faraday cup is shown. The forward and reflected power levels of microwave are also shown in Fig. 5. The emittance experiments are performed during the stable period of beam pulse (last 100 ms). The emittance measurements are carried out by varying three parameters, puller electrode potential, operating gas pressure, and step size of allision scan.

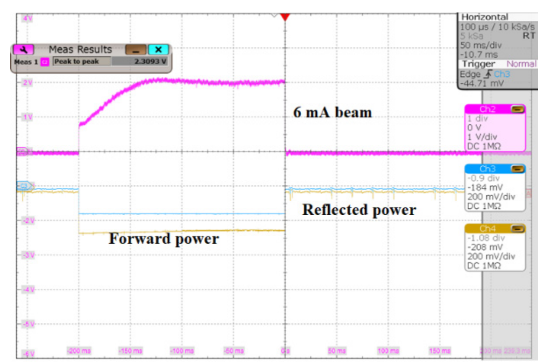

Figure 5: Beam pulse on faraday cup.

Variation of Puller Electrode Potential

Figure 6 shows the plot of transverse emittance at different values of puller electrode potential. The puller electrode potential was varied from 33 kV to 45 kV. The operating gas pressure of $8*10^{-6}$ mbar and microwave power of 920 W were maintained during the measurements. As shown in Fig. 6 the emittance curve shows a minimum of 0.38 π.mm.mrad at puller electrode potential of 42 kV which is very close to the design potential of 40 kV.

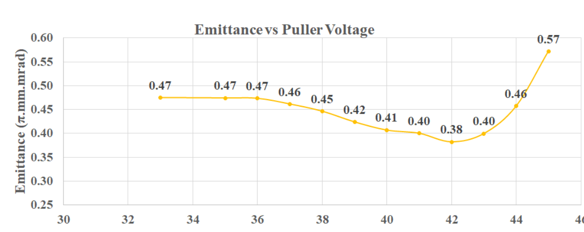

Figure 6: Plot of emittance vs puller electrode potential.

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Variation of Operating Gas Pressure

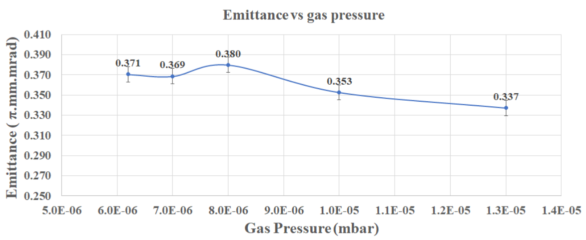

Figure 7: Result plot emittance vs operating gas pressure.

The effect of operating gas pressure on beam emittance is studied next. During these measurements, puller electrode potential was kept at 42 kV and other plasma parameters similar to earlier experiment. The result plot is shown in Fig. 7. As gas pressure is increased from $6*10^{-6}$ mbar to $1.3*10^{-5}$ mbar, the emittance has improved from 0.37 π.mm.mrad to 0.33 π.mm.mrad. Further experiments are planned at different gas pressures along with optimization of ECR magnet coils and microwave power to obtain emittance close to the design value of 0.2 π.mm.mrad.

Variation of Step Size of Emittance Scan

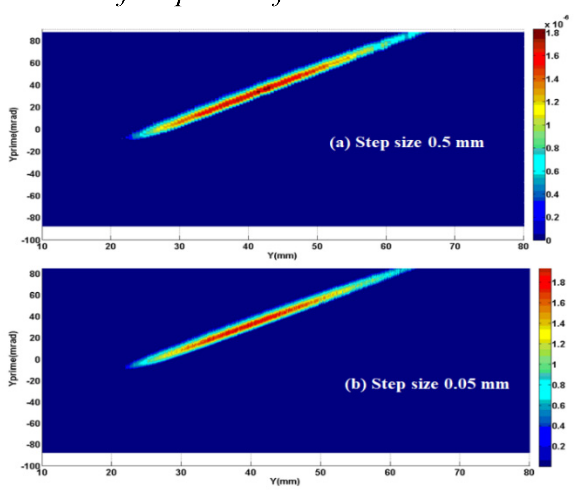

Figure 8: Emittance plot for step size 0.5 mm and 0.05 mm.

The effect of transverse position scan step size on emittance values is also studied. The plasma and beam parameters kept at the optimized values. The position step size of allison scan measurement is varied from 20 µm to 500 µm. In Fig. 8 two emittance plots are shown for step size of 0.5 mm and in the other one 0.05 mm. With 0.5 mm step size, the time taken for emittance measurement is 90 s, while plot is discrete in nature and the measured emittance is 0.3614 π.mm.mrad. For 0.05 mm step size, the scan time increases to 780 s, but the emittance plot has become smoother with the measured emittance improved to 0.3451 π.mm.mrad. In Fig. 9 the plot of emittance vs step size is shown. By taking fine step from 0.5 mm to 0.02 mm emittance is improved by 5%.

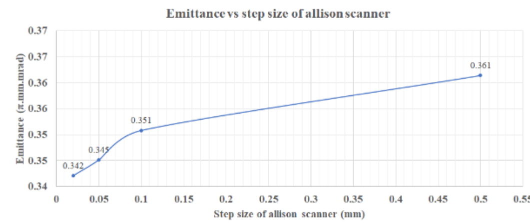

Figure 9: Result plot emittance vs step size of scanner.

CONCLUSION

A five electrode ECRIS has been developed for LEHIPA. A 50 keV beam with mA beam current has been obtained. The beam emittance measurements of a five electrode ECRIS has been performed at different operating parameters like puller electrode potential, operating gas pressure, and step size of slit scan. For 50 keV H^+ beam emittance is in the range of 0.3 π.mm.mrad to 0.4 π.mm.mrad. Further experiments are being carried out at different gas pressures along with optimization of ECR magnet coils and microwave power to get emittance close to the design value of 0.2 π.mm.mrad.

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