CHARACTERIZATION OF 2.45 GHz ECR ION SOURCE BENCH FOR ACCELERATOR-BASED 14-MeV NEUTRON GENERATOR

Sudhirsinh Vala†[1,2], Ratnesh Kumar, Mitul Abhangi[1], Rajesh Kumar[1,2] and Mainak Banyopadhyay[1,2]
[1] Institute for Plasma Research, Bhat, Gandhinagar, 382428, Gujarat, India
[2] Homi Bhabha National Institute (HBNI), Anushaktinagar, Mumbai, 400094, India

Abstract

The 2.45 GHz Electron Cyclotron Resonance Ion Source (ECRIS) has been indigenously developed. This development of ECRIS aims to provide high brightness, stable, and reliable D+ ion beam of 20 mA beam current in a continuous (CW) mode operation for an accelerator-based D-T neutron generator. The ECR ion source setup consists of a microwave system, a magnet system, a double wall water-cooled plasma chamber, a high voltage platform, a three-electrode ion extraction system, and a vacuum system. The ECR ion source test setup is installed, and deuterium plasma is generated. A three-electrode extraction system is designed and fabricated for the ion beam extraction. A ~10 mA deuterium ion beam is extracted from the ECR ion source. The paper covers the detailed experimental setup of ion beam characterization and diagnostics used for measurement of beam profile, beam current, and beam emittance measurements. It also covers the latest results of beam emittance measurements.

INTRODUCTION

The 2.45 GHz ECR ion source is one of the main components of the 14-MeV neutron source. It plays an important role in the operation of the neutron source, particularly in the stability, reliability, and performance of the entire system. Therefore, it gives us the motivation to us for developing the 2.45 GHz ECR ion source for the upcoming neutron source facility at IPR. In the last three decades, many international laboratories had worked on the development of a 2.45 GHz ion source and achieved good performance. The list of some of the high current 2.45 GHz ECRIS is shown in Table 1. The designs of the referred (Table 1) 2.45 GHz ECR ion sources have been studied for the development of 2.45GHz ECRIS for a 14-MeV neutron generator. The 2.45 GHz ECRIS has been designed and developed based on three Coaxial NdFeB permanent magnet Ring type of magnetic system and three-electrode extraction system to produce the 20 mA deuterium ion beam. The results of the deuterium ion beam extraction and emittance measurements were published in this paper.

The 14-MeV neutron generator and deuterium ion irradiation facility is being developed at the Institute for Plasma Research. It will be used for the fusion neutronics activities to support the Indian as well as international fusion program. The neutron is generated by a D-T fusion reaction in which the accelerated deuterium ion beam hits the tritium target and produces the neutrons in order of 10^{12} per second [1].The facility consists of a 2.45 GHz ECR ion source, low energy beam transport system, 300 kV electrostatic acceleration system, medium energy beam transport system, rotating tritium target, vacuum system, and tritium handling & recovery system. The footprint layout of the facility is shown in Fig-1. The entire 14-MeV neutron generator facility will be installed in the 15m x 15m x 9m neutron generator hall, which has 1.8 m thick concrete wall and 0.5 m roof for biological shielding [2]

Table 1: Parameter of the 2.45 GHz ECR Ion Sources

Parameter of 2.45 GHz Source	**SILHI (SPIRAL - 2) FRANCE**	**CEA/Saclay (IFMIF) FRANCE**	**PKUNIFTY CHINA**	**LBNL USA**
Power	1200	2000 W	800 W	700 W
Magnet System	Three Coaxial NdFeB	Two solenoid configuration	Three Coaxial NdFeB	Two solenoid configuration
Beam Optics/ extraction system	5 electrode 50 kV max,	5 electrode 55 kV max,	3 electrode 50 kV max,	3 electrode 60 kV max,
Extraction aperture	3 mm	9mm	5mm	3mm
Emittance(π mm mrad)	< 0.1	0.25	0.2	0.04
Max Beam Current	10 (D)	140(D)	100(D)	44(D)

The deuterium beam is generated by the 2.45 GHz ECR ion source bench. It further transports to the low energy beam transport system, where other ion spices (D2+, D3+) of the deuterium beam will be separated from D+ ion beam by using the dipole magnet and diagnosed through the Beam Diagnostic System (BDS). The only D+ ion beam will transport for further acceleration. The ion beam properties will be measured by an integrated BDS which con-sists of a beam profile monitor, a X-Y slit, and a Faraday cup. To achieve the quality of the deuterium beam for ac-celeration, it will again focus through the quadrupole triplet and further accelerated up to 300 keV through an electro-static accelerator system. The properties of the accelerated deuterium beam are measured for the second time by a sim-ilar integrated BDS and the focused by quadrupole triplet to the switching magnet. Inside the switching magnet, the deuterium beam is splitted into three separate beamlines (-45°, 0°, +45°). The zero-degree beamline will be used for 14MeV neutron production by bombarding the deuterium

---

† sudhir@ipr.res.in

ISBN: 978-3-95450-226-4 ISSN: 2222-5692 doi:10.18429/JACoW-ECRIS2020-TUZZO01

beam on a rotating water-cooled Tritium target (TiT). The other two numbers of ± 45° beamline used for the deuterium ion beam irradiation experiments. The Tritium Handling and Recovery System (THRS) will be integrated with the exhaust of the beamline system to recover the sputtered tritium from the tritium target during the bom-bardment [3].

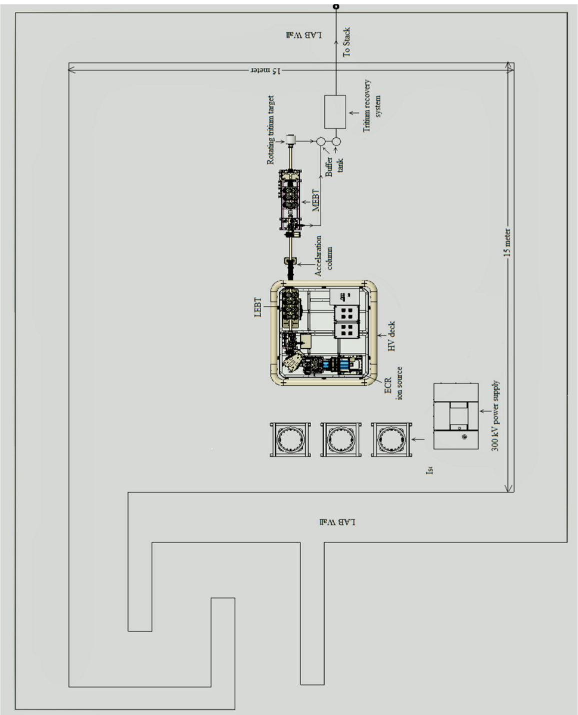

Figure 1. Layout of the 14-MeV neutron generator.

EXPERIMENTAL SETUP

Figure 2 shows the photograph of the experimental setup for the beam characterization experiments. It consists of the 2.45 GHz magnetron based microwave source followed by three stub tuner, 50kV DC high voltage break, 3-step ridge waveguide, plasma chamber with three coaxial NdFeB permanent magnet ring type of magnetic system, three electrodes extraction system, magnetic lens, vacuum chamber, dual Allison emittance scanner, and Faraday cup. A Pfeiffer make (EVR 116) mass-flow controller is used to feed deuterium gas into the plasma chamber to create deuterium plasma.

The three-electrode extraction system consists of a plasma electrode, accel electrode, and decel electrode to extract the deuterium ion beam, which has a 6 mm, 8mm, and 8 mm aperture diameter, respectively. The plasma electrode is kept at positive potential up to 30 kV, accel electrode, and decel electrode at negative potential up to 3 kV and ground potential, respectively. The extracted deuterium ion beam is focused by the magnetic lens, which had a 0.350 T magnetic field with a length of 255mm and 40 mm half aperture. Earlier, we were using an Einzel lens for the focusing of the ion beam, which is now replaced with a magnetic lens for better focusing on the high current ion beam [4]. The emittance and current are measured using a dual Allison emittance scanner system and a Faraday cup, respectively.

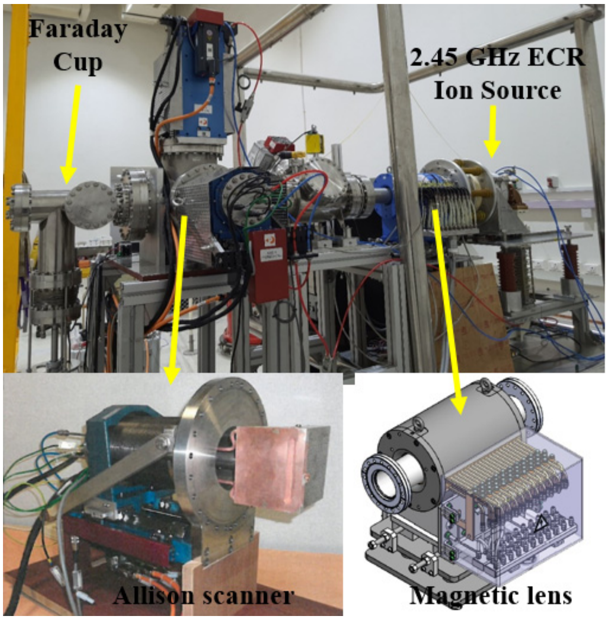

Figure 2: Photo graphic view of experimental setup.

Before the D ion beam generation, the system was evacuated to a base pressure ~ 10^{-6} mbar. The deuterium plasma was produce using 100 to 400 watt of microwave power with a gas flow rate of 1 to 5 x 10^{-4} mbar l/sec. The ion beam current is measured as a function of the extraction voltage for different MW power. The X-Y emittance is measured at various solenoid current in the magnetic lens system for beam focusing.

RESULTS & DISCUSSIONS

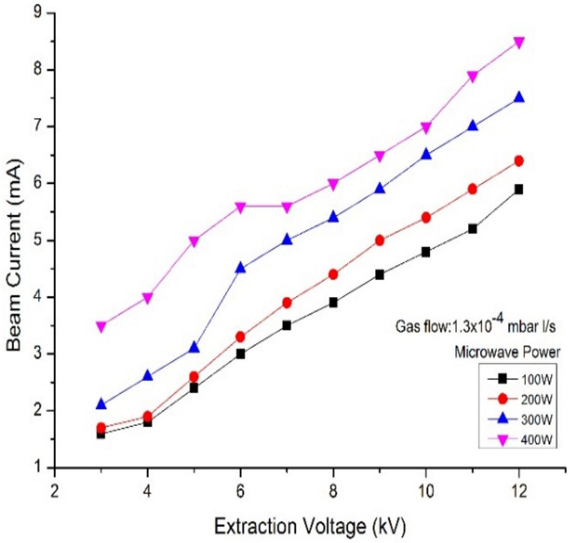

Figure 3 Measurement of deuterium ion beam current as a function of extraction voltage & microwave power.

The ECR ion source has been tuned for the extraction of the deuterium ion beam. The beam current as a function of the extraction voltage for different microwave power is

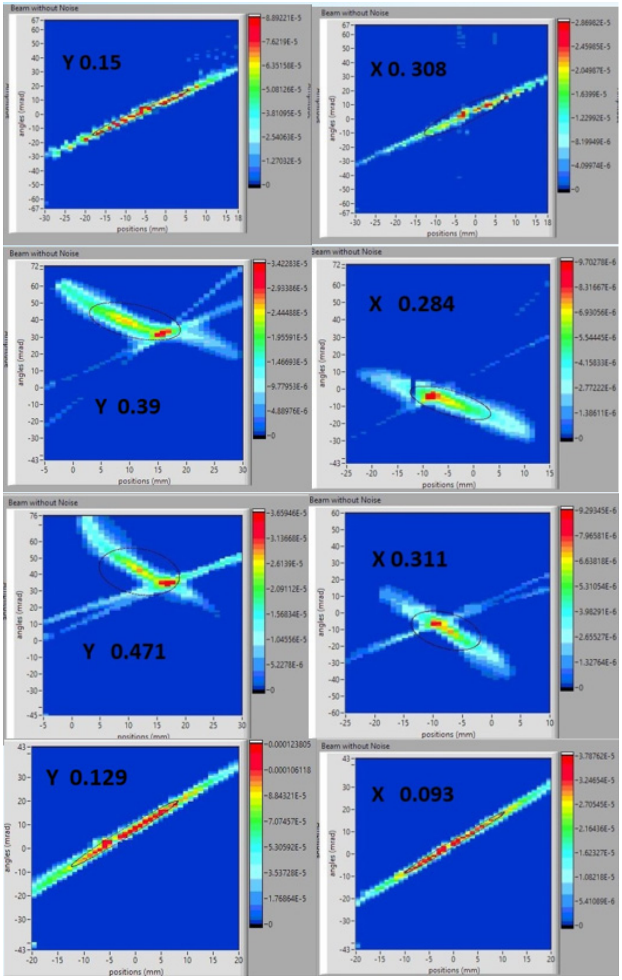

Figure 3. Beam emittance with various solenoid current with fix extraction voltage of 15 kV.

shown in Fig. 3. The preliminary emittance measurement has been done in both X and Y plans. The extraction voltage and acceleration voltage are fixed at 15 kV and -0.8 kV, respectively during the emittance measurement. The results of the emittance measurements are shown in Fig. 4 at various solenoid current. It is observed that there is a variation between the X-plan and Y-plan emittance measurements. The value of normalizing emittance for 90% beam envelop is between 0.093 to 0.308 π.mm.mrad and 0.129 to 0.471π.mm.mrad for X-plan and Y- plan, respectively. The analysis of the results of the emittance measurement is going on.

SUMMARY

For the better focusing of the ion beam into the LEBT, the Einzel lens has been replaced with the magnetic lens (Solenoid).To measure the beam emittance dual Allison emittance scanner has been integrated into the test bench. The beam characterization experiments have been performed. The beam emittance, as well as beam profile, have been measured as a function of solenoid current. The normalized emittance is between 0.093 to 0.308 π.mm.mrad and 0.129 to 0.471π.mm.mrad for X-plan and Y- plan, respectively. The beam diameter is < 20 mm.

REFERENCES

[1] S. Vala, *et al.*, "Development and performance of a 14-MeV neutron generator", *Nucl. Instrum. Methods Phys. Res., Sect. A*, Vol. 959, p. 163495, 2020. `doi:10.1016/j.nima.2020.163495`

[2] H. L. Swami *et al.*, "Occupational radiation exposure control analyses of 14 MeV neutron generator facility: A neutronic assessment for the biological and local shield design", *Nuclear Engineering and Technology*, vol. 52, p. 17841791, Aug. 2020, `doi:10.1016/j.net.2020.01.006`

[3] S. Vala *et al., "*Rotating tritium target for intense 14-MeV neutron source", *Fusion Engineering and Design*, vol. 123, p. 7781, June 2017. `doi:10.1016/j.fusengdes.2017.05.117`

[4] S. J. Vala, M. Abhangi, M. Bandyopadhyay, R. Kumar, and R. K. Kumar, "Development of Test Bench of 2.45 GHz ECR Ion Source for RFQ Accelerator", in *Proc. 23th International Workshop on ECR Ion Sources (ECRIS'18)*, Catania, Italy, Sep. 2018, pp. 198-201. `doi:10.18429/JACoW-ECRIS2018-THC2`