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TRANSVERSE EMITTANCE MEASUREMENT FOR LOW ENERGY ION BEAMS USING QUADRUPOLE SCAN METHOD

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Abstract

Low energy ion beam facility (LEIBF) at IUAC consists of all permanent magnet 10 GHz electron cyclotron resonance (ECR) ion source (NANOGAN) along with 400 kV high voltage accelerating platform, a switching cum analysing magnet and electrostatic quadrupoles. Intense low energy ion beams puts tremendous challenge to transport from ion source to target with minimum emittance growth and beam losses. The normalized emittance of analysed ion beam is measured using electrostatic quadrupole scan method for various source parameters like RF power and injection pressure of gas etc. It is attributed to beam rotation induced by ECR axial magnetic field, effect of ion temperature in plasma, nonlinear electric fields and space charge etc. which play a significant role in emittance growth.

INTRODUCTION TO LEIBF

The new low energy ion beam facility (LEIBF) [1] at the Inter-University Accelerator Centre (IUAC) is a facility dedicated to provide multiply charged ion beams at a wide range of energies (a few keV to a few tens of MeV) for experiments in Atomic, Molecular and Materials Sciences. This facility consists of an all permanent magnet (NdFeB) 10 GHz electron cyclotron resonance (ECR) ion source (NANOGAN) [2] installed on a high voltage platform (400 kV) for obtaining multiply charged intense ions and the analysed beam is transported to the three beam lines along 75deg., 90deg. and 105 deg. angles using a switching cum analysing magnet. The beam tuning parameters of various ion beams are verified experimentally within first order linear beam optics analysis. The emittance is measured for various parameters of NANOGAN using quadrupole scan method in 90 deg. beam line. Standard beam dynamics and 3D field computation codes have been used to design beam transport element. The whole system has been installed and tested and facility is being used by scientific users.

ECR ION SOURCE AND LOW ENERGY BEAM TRANSPORT

The ECR ion source [3, 4] acts as prominent injector into heavy ion accelerators as they can produce the broad range of intense ions in multiple charge states for maximum energy gain in linear accelerators. Simultaneously, they are also used as a compact facility in low energy regime to perform implantation experiments on target samples. The magnetic confinement necessary to sustain the ECR plasma makes the ion density distribution across the extraction aperture inhomogeneous and charge state dependent. Thus it is necessary to characterize the extracted beam in terms of its emittance and transmission along the beam lines. The ion beam parameters from the exit of ECR ion source taken for beam optics simulations are given in Table 1.

Table 1: Ion Beam Parameters

Parameters	Values
Emittance ε (π mm-mrad)	100
Extraction Energy (E) keV/q	30
Max. ME/q^2 along 75°, 90° and 105° lines (MeV.amu)	44.68, 30.37 22.96

The beam is extracted using 30kV dc potential and focussed by a combination of electrostatic quadrupole doublet (EQD), 400kV accelerating section (AS) and an electrostatic quadrupole triplet (EQT) directly to object point of switching magnet (SW). The beam optics for the whole facility in 90 deg. line is shown in Fig. 1 using code TRANSPORT [5]. Different colour envelopes corresponds to different charge states of Ar ion beam. Based on this beam optics, the whole facility is installed and commissioned. Transverse emittance measurements of analysed beam have been performed using electrostatic quadrupole scan method.

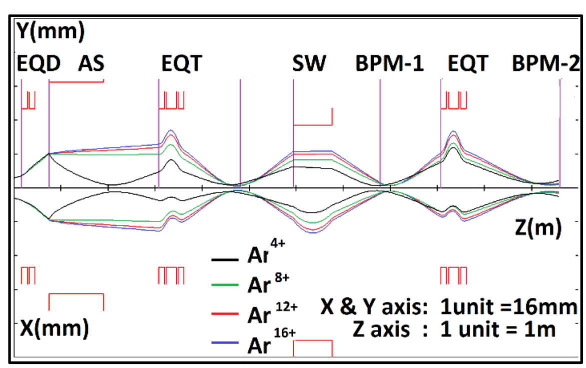

Figure 1: Beam optics of LEIBF in 90° line using TRANSPORT code for charge states of Ar ion beam at the energy of q*210 keV.

QUADRUPOLE SCAN METHOD

The two beam profile monitors before and after the EQT in 90 deg. line are used to measure the emittance using quadupole scan method [6, 7]. It is based upon linear transformations of beam phase space and

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conservation of emittance in the quadrupole manipulation of ion beam. Consider a system of BPM-1-EQT-BPM-2 after the switching magnet in 90 deg. beam line as shown in Fig. 2 also. Argon beam is extracted at a voltage of 12 kV and accelerated by 88 kV to get the 100 keV Ar^{1+} ion beam. The focusing of the beam is symmetrical in horizontal and vertical plane so that the measurements are made for both planes to measure individual transverse emittances. The BPM-2 measures the beam profiles in horizontal and vertical planes. These profiles are digitized and fitted with a Gaussian profile to get the FWHM at several gradients of EQT for different beam sizes around the minimized beam size. This FWHM of beam profiles is finally plotted with respect to the quadrupole gradient around the minimized spot size on target. A quadratic function is fitted to these points and the function is compared to the standard theoretical expression of beam size (σ_{11}) in quadupole scan method in terms of quadrupole gradient (K) as follows.

$$\sigma_{11}(K) = aK^2 - 2abK + ab^2 + c$$

The fitting parameters a, b and c are extracted from quadratic function which represents the measured FWHM of beam profiles at the BPM-2 after EQT. Emittance is then given as simply by the relation.

$$\varepsilon = \frac{\sqrt{ac}}{L^2}$$

Where L=2m, is the distance between EQT and BPM-2. The beam is tuned in non steering mode for emittance measurements. The error involved in the measurements is estimated to be within 1% coming mainly from the measurement of beam size by beam profile monitors and the stability of power supplies of various beam optical components.

Effect of RF Power

Emittance measurement i being performed with respect to RF power by fixing other parameters of beam tuning from ion source. Theoretically, the ion temperature [8] is expected to increase with rf power. The emittance measurements also shows an increase for all charge states along with beam intensity due to increase in plasma temperature with more RF power as shown in Fig. 2 but saturate to equilibrium charge state and decreases further. Here, the dotted lines show the beam current variation and solid lines represent the emittance. During the measurements, the RF power levels were in the range from 20W to 80W and the beam currents are not optimized but are chosen for a stable operation and repeatability in the measurements. In all cases, we are getting lower emittance for higher charge state ions. Due to the more confinement of the high charged ions in ECR ion source, they are created closer to its axis and hence extracted from small effective extraction aperture which gives in smaller emittance values of multiply charged ions.

Effect of Injection Pressure of Gas

Emittance properties of low energy ions has been measured by varying the gaseous pressure at the injection side of ECR ion source [9, 10] keeping other parameters constant. Beam current increases with plasma density due to more ionisations up to the injection pressure of 0.0175 mbar and then it decreases as shown in Fig. 3. The beam emittance decreases with the gaseous density due to reduction in ion temperature resulting from more collisional momentum transfer transversely. The probability of collisions among the ions increases with gaseous pressure upto a certain limit but once the plasma become overdense in terms of ion density at a pressure around 0.025 mbar, emittance shots up to a high value along with decrease in beam current due to change in plasma mode.

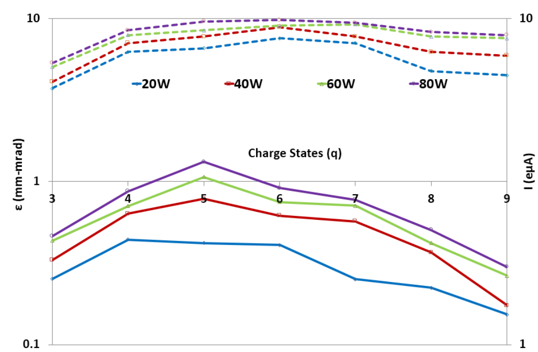

Figure 2: Argon ion spectrum at different RF powers.

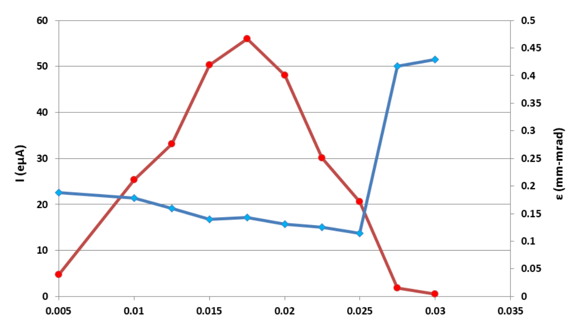

Figure 3: Emittance versus injection pressure of the Ar gas.

Effect of Negatively Bias Electrode

Emittance behaviour is studied for change in bias voltage of the electrode inserted into plasma when other parameters of ECR source are held constant. The bias voltage has to be negative so that electrode donates the cold electrons. Plasma potential in ECR ion source can range over few tens of volts. But it should be neutralised by any means so as to make plasma stabilised towards unwanted instabilities and oscillations. Positive plasma

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potential is compensated dynamically by the negative bias voltage [11, 12] of the electrode inserted into plasma which supplies more and more number of electrons to raise the electron density in plasma chamber and the ion beam intensity at the extraction side. So, the beam current increases first due to increase in number of ionisation events but then decreases due to being over dense in terms of electron density as shown in Fig. 4. The emittance is almost constant throughout the change of negative bias voltage of electrode as the injection of electrons does not affect the ion temperature due to less collisional crossection of ion with electron as compared to ion-ion collisional crossection.

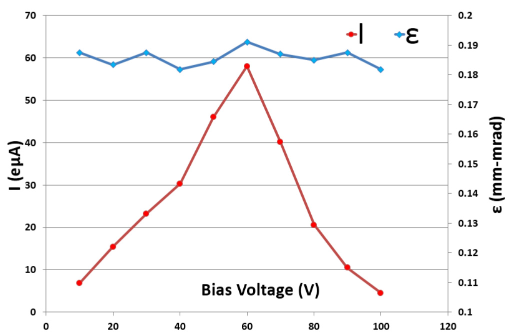

Figure 4: Emittance versus bias voltage of inserting electrode into ECR plasma.

CONCLUSION

The emittance measurement helps in tuning the ion source parameters to minimize the spot size on target samples with maximum beam current. It ranges from 0.1 mm-mrad to 0.5 mm-mrad for different ion source parameters The beam optics of whole facility lead to design and installation of beam optical components at proper locations and facility is in use by scientific community.

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