HTS-ECRIS AND LOW ENERGY BEAM TRANSPORT SYSTEM OF THE HIGH CURRENT INJECTOR

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Abstract

A new type of high performance electron cyclotron resonance ion source (ECRIS) called PKDELIS capable of operation at 14.5 and 18 GHz using high temperature superconducting (HTS) coils designed and developed jointly by IUAC, Delhi (earlier called NSC), Pantechnik, Caen and ISN, Grenoble is presently in operation. The source is very suitable for operation on a 400 kV high voltage platform for injecting beams from the High Current Injector (HCI) into the superconducting linear accelerator booster. Since the emittance of the source is large, the complete transport system is being made as short as possible, at the cost of some of the important beam diagnostics elements. A new type of extraction system is being developed in-house to improve the extraction conditions and better vacuum close to the beam formation region. A large aperture, 'third order' corrected analysing magnet has been fabricated for analysing the beams from the source. Typical axial and radial bremstraahlung spectra have been measured. The axial direction shows a single electron temperature component while the radial direction shows 'two electron' temperature components.

INTRODUCTION

The beam energy delivered by the 15 UD Pelletron accelerator at IUAC is above the Coulomb barrier for masses below 40. To augment the beam energy, a superconducting LINAC [2] is being installed to provide beams of ~ 5 MeV/A for the medium heavy ions. The input of LINAC demands high current, high charge state pulsed beam (150 ps). Since the pulsed beam available from the existing Pelletron is of low intensity (~ a few nA average current) and low charge state, an Electron Cyclotron Resonance (ECR) ion source based High Current Injector (HCI) is being installed to provide relatively high current (a few pμA) heavy ion beams for the LINAC.

A cryogen-free high temperature superconducting (HTS) coil based electron cyclotron resonance ion source has been developed and is being used as a part of high current injector for the superconducting linear accelerator at the Inter University Accelerator Centre. This kind of ion source is an off-shoot from the HYPERNANOGAN ECR ion sources developed by Pantechnik, France, where the resistive coils have been replaced using HTS coils [3]. By using HTS coils, the original injection field of 1.3 T has been increased to 1.8 T. The source is configured to be operated on a 400 kV high voltage platform. Power and cooling requirements for the sub-systems are designed to be minimal. Due to the use of HTS coils for the magnets, a reduction factor of 10 results in the power saving costs. In addition, the cooling requirements are also reduced tremendously. This type of ion source is first of it's kind designed to deliver highly charged ions ranging from a few keV to a few MeV depending on the extraction voltage and charge states extracted from the ion source. The source is designed to deliver A/q beams having a maximum value of 10 to be accelerated through the superconducting linear accelerator system of IUAC. A view of the high temperature superconducting ECR ion source is shown in figure 1.

DESIGN ASPECTS OF THE SOURCE

Unlike low temperature superconducting (LTS) materials, HTS coils do not require actively-cooled shields and the temperature can be controlled by standard industrial refrigeration systems. The systems are simpler to design, contruct and compact in form. LTS coils operate closer to their critical temperature as compared to HTS coils. Therefore, HTS coils can withstand wider temperature change without losing their superconducting properties. Also, the critical current density of HTS materials falls slowly as a function of temperature. In addition, the cooling costs are drastically reduced when compared to operation at lower temperatures of about 4 K. The requirements of cooling water on a high voltage platform is also negligible.

Figure 1. View of the High Temperature Superconducting ECR Ion Source, PKDELIS

The heart of the source is built using high strength Bi-2223 HTS tapes for the coils. High strength conductors were chosen instead of high current conductors to withstand the huge forces acting on the coils. Each coil consists of 10 pancakes connected in series wound on a single copper former. The current capacity of the tape is rapidly reduced by the application of magnetic field, particularly in a direction perpendicular to the plane of the conductor. Since the performance of the tape is more critical when the magnetic field is perpendicular to the tape than when parallel to it, the maximum operating field of 1.8 T corresponding to a maximum current of 181 A determines the maximum radial field on the tape of about 1.4 T. This in turn determines that the maximum operating temperature of the coil which should be below 30 K.

SOURCE OPERATION

Figure 2 shows a schematic of the source coupled with the analysing system. The complete beamline is made as short as possible in order to minimise the beam losses due to the large emittances at the cost of a few diagnostic elements. During normal operations, we have observed beam losses due to space charge effects at low extraction voltages of 10 to 30 kV [4]. The transmission of these beams is being improved upon. In addition, x-ray measurements have been explored to understand the source performance. Typical axial bremstraahlung spectra measured at a distance of approximately one metre from the ECR plasma in the zero degree view port of the analysing magnet at a fixed rf power of 300 W is shown in figure 3.

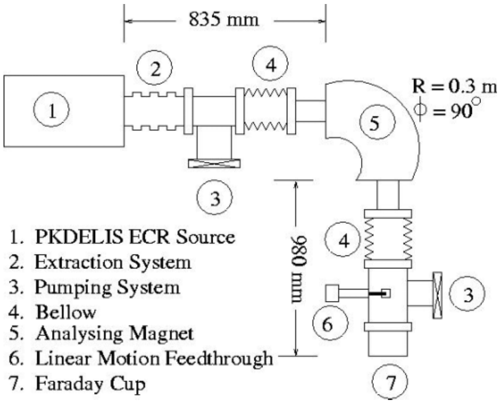
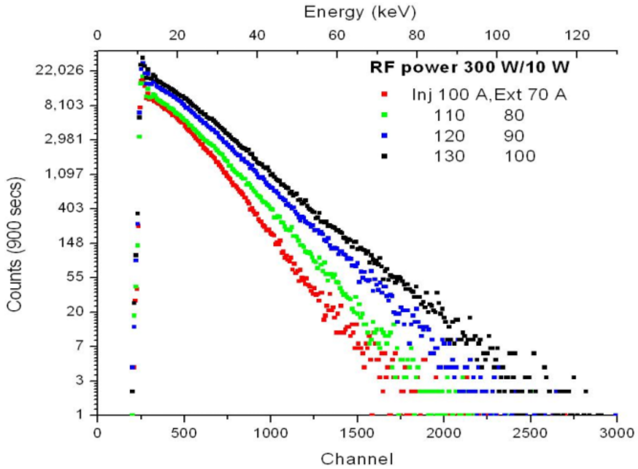


Figure 2: Schematic view of the source coupled with the analysing system.

A small Si pin diode detector (AMPTEK) was used with proper collimation to obtain the x-rays only from the plasma. From these measurements, we found that as the mirror ratio is increased on the injection and extraction sides, the slope of the distribution changed considerably. The legend in figure 3 shows the values of the injection and extraction coil currents used to change the mirror ratio at fixed rf forward power level of 300 W. This shows that a single electron temperature component is found to increase with higher mirror ratios. All measurements were performed for a fixed time period of 900 seconds. The energies of the x-rays which span from a few tens of keV to a few hundred keV show that at these power levels the energies of the x-rays correspond to the available electron energies. We expect that at higher power levels higher energy electrons would be produced, but these measurements could not be completed due to problems with the DC waveguide break at higher levels of RF power. We have also measured the bremstraahlung in the radial direction. These measurements however show a 'two-component' electron temperature. This requires more detailed measurements to further understand the behaviour of the plasma.



Note: Detector mounted at analysing magnet port

Figure 3. Axial bremstraahlung measurements from PKDELIS ECR plasma.

LOW ENERGY BEAM TRANSPORT

The LEBT of the High Current Injector consists of the High Temperature Superconducting ECR source PKDELIS, multi-electrode extraction system/solenoid/magnetic quadrupole doublet, 90^o analysing Magnet, 400 kV high voltage accelerating column and a few focussing devices to transfer the beam from ECR to RFQ entrance. In the low energy beam transport (LEBT) system of the HCI, the beam extraction and transport becomes more and more challenging. From beam measurements, we have observed losses in the beam mainly due to beam blow-up at low extraction voltages of about 10 to 30 kV. From IGUN simulations, it has been found that the source beam emittance is of the order of ~ 200 π .mm.mrad and matches close to the measured values. In addition, due to the high currents (~ 10 mA) extracted, the extraction system needs proper cooling requirements and possibility of movement of the electrodes for tuning various A/q beams which have different focussing properties under the influence of a strong axial magnetic field. A new type of extraction system with movable electrodes and with provision for water cooling is being developed. A large acceptance analysing magnet has been designed to analyse ions from the ECR source. This magnet will be placed on the high voltage platform to reduce beam loading of the high voltage power supply. The combined function magnet has been designed to incorporate higher order terms to reduce the higher order aberrations. Since the technical challenge of transporting low energy, high current ions lies mainly in the low energy section of the injector, utmost care has been taken in the design of the LEBT. The ions from the ECR source are first extracted around 30 kV and A/q analysed by a large acceptance analysing magnet and further accelerated using deck voltage with a maximum allowable voltage of 400 kV. The energy of this beam will be further accelerated by a Radio Frequency Quadrupole accelerator (RFQ), Drift Tube Linac (DTL) and low β cavity resonators to match the existing LINAC beam-input energy requirements. A new beam hall is being constructed on the east side of the present beam hall I to house these facilities. A schematic layout of the building and tentative layout of beam line is shown in figure 4. The ion optical design has been carried out considering the beam input parameters of maximum A/q = 10 and beam emittance of 200 π mm.mrad [5]. A second order corrected beam optics on the 400 kV high voltage platform and upto the RFQ entrance is shown in figure 5 for E/q= 380 kV.

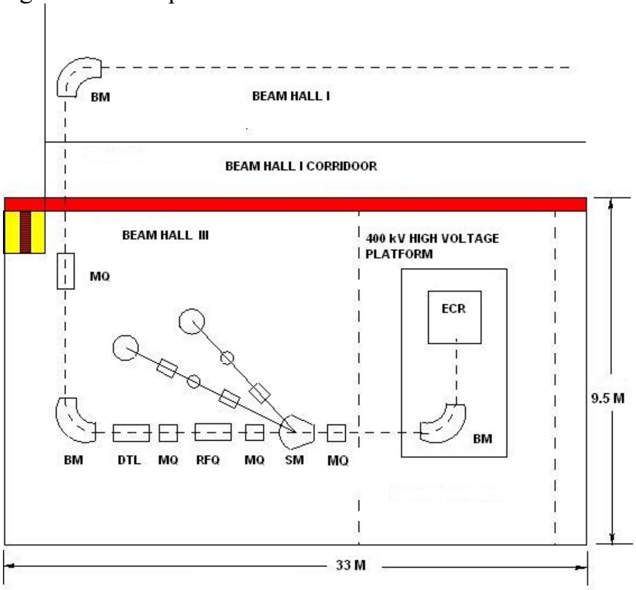


Figure 4: Schematic layout of new beam hall III.

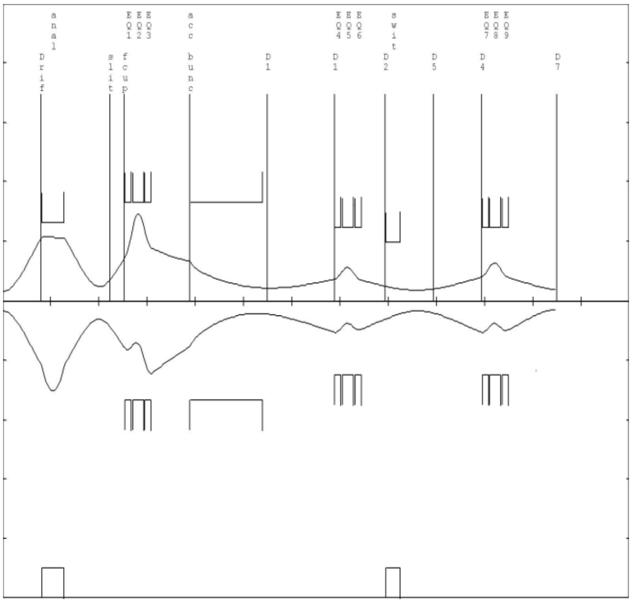


Figure 5: Second order corrected beam envelope from ECR source upto RFQ entrance for E/q = 380 kV.

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