Microwave Ion Source and Injection System for a High Current Compact Cyclotron

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Abstract. A 2.45 GHz microwave ion source (80 kV, 20 mA) has been developed at VECC along with solenoid based low energy beam transport line to study the space charge dominated beam injection in a compact cyclotron using an electrostatic spiral inflector. The source is operating and is presently under testing for performance improvement. We have already installed a small dipole magnet, vacuum chamber with spiral inflector and few diagnostic elements. The operating experience and current status of the microwave ion source and low energy beam transport system will be discussed.

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INTRODUCTION

At the Variable Energy Cyclotron Centre, we are developing a 10 MeV, 5 mA four sector compact proton cyclotron. A 2.45 GHz microwave ion source will produce protons beam at 80 keV. The extracted beam will be first collimated by slits to remove undesired components (H_2^+, H_3^+ etc.), bunched using a sinusoidal buncher and will be injected axially in the central region of the cyclotron by a spiral inflector. Microwave ion source and low energy beam transport system (LEBT) for the compact cyclotron have been designed, fabricated indigenously, installed and commissioned. Presently it is under testing for beam characterization and inflection study. We have already installed a small dipole magnet, vacuum chamber with spiral inflector and few diagnostic elements and study on the inflection of high beam current has been taken up. The fabrication of the sinusoidal buncher is near completion. The operating experience and current status of the microwave ion source and low energy beam transport system will be discussed in this paper.

MICROWAVE ION SOURCE AND LEBT

The microwave ion source (shown in Fig. 1) consists of a plasma chamber, two movable solenoids to produce desired axial magnetic field and triode ion extraction system [1, 2]. The diameter of the apertures in the plasma, accelerating and de-accelerating electrodes is 7 mm, 8 mm and 8 mm respectively. The plasma chamber is a double walled water-cooled cylindrical stainless steel chamber of 100 mm length and 90 mm diameter. The microwave power from the 2.45 GHz, 1.2 kW magnetron is coupled through a three stubs tuning unit, an auto tuner and water cooled ridged wave-guide. Ion source along with adjustable solenoids, its power supplies, microwave generator, gas cylinder and a high precision gas flow system etc., all are kept at 100 kV high voltage deck. Deck is isolated from the ground through polypropylene insulators. A two-segment ceramic insulators (Al_2O_3) column, which supports the beam extraction electrodes, isolates the high voltage deck and the beam line at the ground potential. A 150 kV, 30 kW isolation transformer is used to supply power to the various subsystems on the high voltage deck.

The injection beam line (shown in Fig. 1) consists of two solenoid magnets, adjustable slits, one fixed slit, faraday cup and beam profile monitoring box and a beam dump cum faraday cup at the end of the beam line. The beam from the ion source is expected to contain a substantial fraction (~10 to 20 %) of molecular hydrogen ion. We have provided a slit at the waist position of the proton beam after the first solenoid to reject most of the molecular hydrogen beam [3]. Beam current measuring equipments used in the beam line are; a water-cooled faraday cup (up to 10 mA only) with secondary electron suppresser and a DCCT. We have used three turbo pumps each having pumping speed of 520 l/s to evacuate the entire system. A pressure of the order of 3.5 x 10^{-7} mbar has been achieved in the beam line.

Control system for adjusting current in the solenoids, movement of solenoids, tuning of microwave power, adjustment of gas flow etc. is placed on the high voltage deck. A PC at ground potential is used to control and monitor through optical fiber. The control system uses Advantech ADAM modules in modular form with dedicated control nodes for individual sub-systems. The PC based supervisory console is connected with the control nodes in RS485 multi-drop fashion through an indigenously developed optical fiber based serial link for electrical isolation. As the control system is installed on a high voltage deck, frequent sparks used to cause communication failure and sometimes damage to the components. A protection circuit has been implemented to reduce these effects. A similar remote monitoring system with protection circuit, using National Instruments Field Point (NIFP) modules, has also been developed to monitor the faraday cup and slit currents.

FIGURE 1. 2.45 GHz microwave ion source on the high voltage deck (left) and solenoid based low energy beam transport line (right).

OPERATIONAL EXPERIENCE

Initial promising operations were halted several times due to failure of the electronic components at the high voltage deck induced by HV sparking. To solve these problems we grounded most of the floating conductors inside the deck and connected a high resistance between isolation transformer and the deck. We placed appropriate filters and tested the system up to 90 kV with negligible leakage current (200 μA).

There was a serious problem in microwave coupling to the plasma. We observed very high reflected power and lots of heating in the ridged wave-guide. Locally made control of manual tuner did not work properly. In order to optimize the coupling between microwave generator and the plasma chamber of the source we designed and fabricated a new water cooled four step binomial maximally flat transformer to realize a progressive match between the impedance of WR284 waveguide (663.7 ohm) and the impedance of plasma filled chamber (~ 110 ohm). The initial design was done analytically and finally the ridge spacing and ridge lengths were optimized using computer code HFSS to maximize electric field in the centre of the plasma chamber. We have also inserted an auto tuner in the system.

We faced lots of glow discharge and internal arcing during initial operation in the extraction region. In order to improve the vacuum in this region we machined several holes in both biased and ground electrodes and added one more turbo pump having pumping speed of 520 l/s closed to the extraction electrode. These modifications improved the performance against the magnetic discharge in the extraction region. We are also planning to add some iron sheets in the extraction region to reduce the field in the extraction zone.

The thermal fracture of microwave window from the back streaming electrons and source plasma heating was another problem. We have now placed a 5 mm thick boron nitride plate behind the water-cooled plasma chamber. A RF quartz window is now placed for vacuum sealing just before the 90 deg bent in the waveguide. This will save the system in case of fracture of boron nitride microwave window. Now the system is performing very well.

STATUS OF THE ION SOURCE

We have operated the ion source with a stable beam current around 6.4 mA on the faraday cup through 1 cm × 1 cm slit just before the faraday cup and 8.5 mA on DCCT at 400 W of microwave power at an extraction voltage of 80 kV. We transported this beam up to the last beam dump near the diagnostic chamber. We observed increase in the beam current (I > 10 mA) at the DCCT with increase in microwave power. At present we are testing the source for performance and beam quality improvement. Beam spot of 80 keV, 5 mA on alumina plate is shown in Fig. 2. In order to study the inflection and transmission of the high beam current through the spiral inflector [4, 5], we have designed and fabricated a small magnet (shown in Fig. 2) having a similar characteristics as the central region of 10 MeV cyclotron. Magnet has already been assembled. The vacuum chamber with inflector inside it is placed between the poles of the magnet and connected with the beam line.

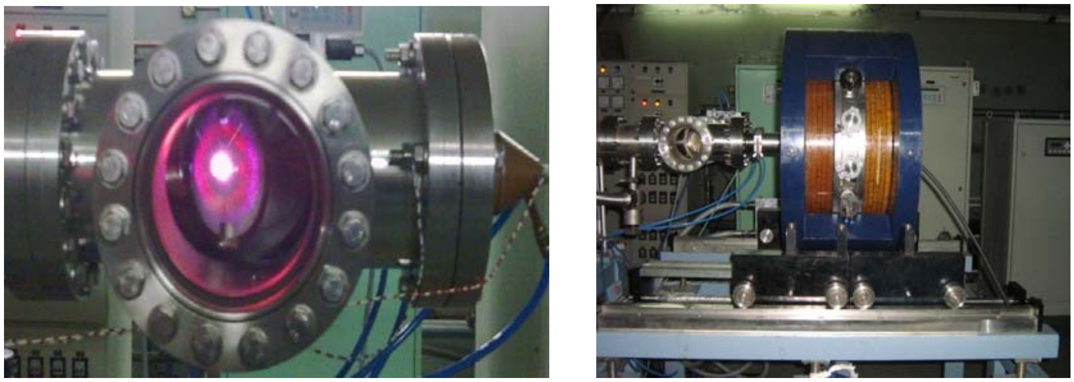

FIGURE. 2 Beam spot of 80 keV, 5 mA proton on water cooled alumina plate placed at the end of beam line near beam dump (left). Magnet with inflector at the end of the beam line (right).

The preliminary testing of beam transmission at low beam current is going on. During the testing of beam transmission through the inflector we observed lots of glow discharge and loading on the power supply of the inflector voltage. A long duration of baking of the electrodes improved the situation, however, experiments with high beam currents (>1 mA) needs further improvement in the vacuum within the chamber. A beam transmission of 50% has been achieved and efforts are on to improve the transmission efficiency. We would like to point out here that we need first to optimize the beam transmission at low current to avoid any damage to the electrodes of the inflector. A sinusoidal buncher will be used to bunch the beam before injection into the cyclotron. Details of the design of the buncher and simulation studies on high current beam bunching are presented in ref. [6]. The fabrication of the buncher together with a fast faraday cup is near completion. These components will be installed very soon after the second solenoid to study the behavior of beam bunching at high current.

The ion source has been tested for reliability and performance in terms of the long term stability. We have operated the source continuously for several hours with current more than 5 mA on the Faraday cup. There were only 3-4 small sparks in the extraction zone during the continuous eight hours of operation which stopped the beam due to tripping of the high voltage. The beam was recovered within 2 minutes after the trip.

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