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Development of microwave ion source and low energy beam transport system for high current cyclotron

V.S. Pandit *, P. Sing Babu, A. Goswami, S. Srivastava, A. Misra, Mou Chatterjee, P.Y. Nabhiraj, R.C. Yadav, S. Bhattacharya, S. Roy, C. Nandi, G. Pal, S.K. Thakur

Variable Energy Cyclotron Centre, 1-AF Bidhannagar, Kolkata 700064, India

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ABSTRACT

A 2.45 GHz microwave ion source and a low energy beam transport system have been developed to study the high intensity proton beam injection into a 10 MeV, 5 mA compact cyclotron. We have extracted proton beam more than 10 mA at 80 kV as measured by the DCCT after the extraction and a well collimated beam of 7 mA (through 1 cm × 1 cm slit) at the faraday cup 1.5 m away from the source. The transport of protons from the ion source in the presence of H_2^+, H_3^+ species has been studied using PIC simulations through our transport line which consists of two solenoids. We have also installed a small dipole magnet with similar field as that of the cyclotron along with vacuum chamber, spiral inflector and few diagnostic elements at the end of the beam line. In the preliminary testing of inflection, we achieved 1 mA beam on the faraday cup at the exit of inflector with ~60% transmission efficiency.

Introduction

There are several accelerator projects planned to produce high power beams with currents in the milliampere range for various applications. The major challenge at the low energy part of such systems is to form a good quality beam from a high current source, transport and match it to the subsequent accelerating structure. In order to achieve small transverse emittance and to avoid formation of beam halo during transport, extensive simulations with experiments are required. At the Variable Energy Cyclotron Centre at Kolkata a 10 MeV, 5 mA four sector compact proton cyclotron is being developed to study the space charge dominated beam behaviour during injection and acceleration [1]. This development is a part of the considerably larger activity presently undergoing in the field of high intensity accelerator development for ADSS (Accelerator driven subcritical system) applications. Proton beam at 80 keV from a 2.45 GHz microwave ion source will be first collimated by slits to remove the 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. There are certain critical issues related with the injection and acceleration of high intensity beams in a cyclotron such as beam losses during injection, control of space charge defocusing forces, matching of beam at the spiral inflector and in the central region etc. which are not yet resolved and need to be studied in detail. The main objective of this development is to carry out detail study of high current beam injection and acceleration in a compact cyclotron.

The 2.45 GHz microwave ion sources are widely used nowadays to produce several mA of proton beam for various applications [2–8]. These sources are based on the principle of off resonance microwave discharge. The main features of such sources are high yield, high proton fraction and long term stability and reliability which meet the requirement of a driver for an ADS system. We have developed a 2.45 GHz microwave ion source and the injection system to study the transport and injection related problems. We have already extracted proton beam more than 10 mA at 80 kV as measured by the DCCT (direct-current current transformer) after the extraction and a well collimated beam of 7 mA (through 1 cm × 1 cm slit) at the faraday cup 1.5 m away from the source. We have studied the transport of protons from the microwave ion source in the presence of H_2^+, H_3^+ species through our transport line which consists of two solenoids. We have also performed PIC (Particle-In-Cell) simulations to understand the evolution of beam in the transport line. Presently ion source is under testing for performance improvement. A small magnet having similar field configuration as that of the central region magnetic field of the 10 MeV cyclotron has been installed together with the vacuum chamber, spiral inflector and few diagnostic elements. In the preliminary testing of inflection, we have got 1 mA beam inflected successfully with ~60% transmission and further testing is in progress.

* Corresponding author. Tel.: +91 33 2337 1230; fax: +91 33 2334 6871.
E-mail addresses: pandit@vecc.gov.in, vspandit12@gmail.com (V.S. Pandit).

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Description of ion source and injection system

The design of the ion source is based on the principle of microwave discharge off resonance. The detailed design and performance results of such type of ion sources are discussed in many Refs. [2–5]. The main advantage of the microwave source is the low emittance, stable high yield with large proton fraction. The ion source consists of a plasma chamber, two adjustable solenoids and a triode ion extraction system. 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 to the chamber through a WR340 waveguide followed by circulator and dummy load assembly to absorb the reflected power, a three stub tuning unit, a 90° bend, a WR340–WR240 transition, an auto tuner and finally water cooled ridged wave-guide. In order to protect the thermal fracture of microwave window from the back streaming electrons and source plasma heating a 5 mm thick boron nitride plate placed behind the water-cooled plasma chamber. A RF quartz window is also placed for vacuum sealing just before the 90° bend in the waveguide. The extraction geometry of this source is a traditional three-electrode system with provision for adjustment of inter-electrode gap to minimize the distortions in the phase space and to adjust the focusing. The diameter of the apertures in the plasma electrode, accelerating electrode and de-accelerating electrode are 6 mm, 8 mm and 8 mm respectively. The optimization of the extraction system was performed using the PBGUN code. Ion source with adjustable solenoids, power supplies of solenoids, microwave generator, a high precision gas flow system etc., all are kept at the high voltage deck at $\sim$100 kV. This deck is separated from the ground through polypropylene insulators. A two-segment ceramic insulators (Al_2O_3) column, which also supports the beam extraction electrodes, separates the high voltage deck and the beam line at the ground potential. Power to the various subsystems on the deck is supplied using a 150 kV, 30 kW isolation transformer. Ion source with various components on high voltage deck is shown in Fig. 1.

Since all subsystems of the ion source are placed on the high voltage deck, an isolated control system is used for remote monitoring and operation of various subsystems. Control units for adjusting current in the solenoids, movement of solenoids, tuning of microwave power, adjustment of gas flow etc. are placed on the high voltage deck and control and monitoring of the various voltages and currents are done with a PC at ground potential. The system architecture is made modular with dedicated control nodes for individual subsystem. Adjustment and monitoring are done with a PC at ground potential through optical fiber. The control system uses Advantech ADAM modules. 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 100 kV high voltage deck, frequent sparks used to cause communication failure and sometimes damage to the components of the control system. A protection circuit is implemented to reduce these effects.

Fig. 2 shows the layout of the injection system. It is specially designed with provisions for various adjustments to get good quality beam and for off line testing of buncher and inflector. The injection beam line consists of two identical solenoids (40 cm, 4 kG) along with some diagnostic elements such as slits, Faraday cups, beam viewers etc. The beam from the ion source is expected to contain a substantial fraction ($\sim$10–30%) of molecular hydrogen ion. We have installed two motor controlled independent slits, one set for the *x*-plane and other set for the *y*-plane between the two solenoids to control the size of the beam and to reject molecular hydrogen beam. A water cooled fix slit of diameter 4 cm is also used after the first solenoid and before the waist position of proton to restrict unwanted beam and to reduce the beam load on the movable slits. Beam current measuring equipments used in the beam line are a DCCT near the source, a water-cooled Faraday cup (up to 10 mA only) with secondary electron suppresser after the slit and a water cooled Faraday cup cum beam dump at the end of the transport line. Three turbo pumps having pumping speed of 520 l/s are used to evacuate the entire system; two of them are near the extraction zone. We have achieved vacuum of the order of 1.5×10^{-7} mbar near the extraction zone and in the beam line. A remote monitoring system is used to monitor the Faraday cup and slit currents and pressure in the beam line.

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 in the extraction zone. Earlier plan was to operate the source at 100 kV. During the testing we observed that ion source is more stable and reliable against sparks and electric

Fig. 1. 2.45 GHz microwave ion source on the 100 kV high voltage deck. (1) DCCT; (2) turbo pumps; (3) ceramic insulators to isolate HV deck; (4) solenoid coils; (5) H_2 gas cylinder; (6) motor assembly to move solenoids; (7) auto tuner; (8) magnetron and its power supply; (9) solenoid power supplies; (10) isolation transformer.

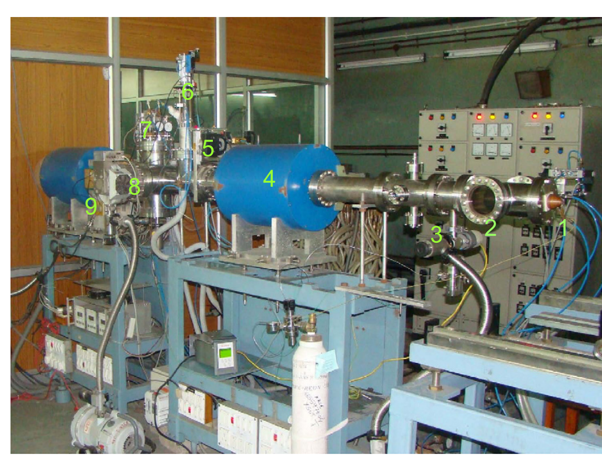

Fig. 2. Solenoid based low energy beam transport line. (1) Water cooled Faraday cup cum beam dump; (2) beam viewing port; (3) gas injection port; (4) solenoid S2; (5) gate valve; (6) water cooled Faraday cup; (7) water cooled slit system; (8) turbo pump; (9) *x*–*y* steering magnet.