DEVELOPMENTS FOR BEAM INTENSITY INCREASE AND BEAM QUALITY IMPROVEMENT IN THE RCNP CYCLOTRONS

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Abstract

An upgrade program of the RCNP cyclotron facility for increase of beam intensity and improvement of beam quality is in progress to meet requirements from research in nuclear physics and industrial applications using secondarily produced particles such as neutrons, muons and radioisotopes. A 2.45 GHz ECR proton source using a set of permanent magnets was developed for high intensity proton beam production. The proton beam intensity more than 0.5 mA at an extraction energy of 15 keV has been obtained with a high proton ratio more than 80 %. The quality of the pre-accelerated beam from the K140 injector AVF cyclotron has been improved by a flat-top acceleration system using the 7th harmonic voltage to enhance the beam transmission to the K400 ring cyclotron. Transversal resonant mode of a dee electrode with a span angle of 180 degrees was also investigated to confirm feasibility of the 4th harmonic FT acceleration in the frequency region from 50 to 60 MHz.

INTRODUCTION

The cyclotron facilities of Research Center for Nuclear Physics(RCNP), Osaka University, have been utilized mainly for research in nuclear physics and radio chemistry since 1976. A K400 ring cyclotron can provide a variety of ion beams with maximum energy of 400 MeV for protons, 420 MeV for $^3He^{2+}$ ions and 100 MeV/n for heavy ions [1]. A maximum current of the 400 MeV proton beam is limited to around 1 μA. In recent years, demands for an intense proton beam and a high quality light ion beam are increasing. The intense proton beam is required for production of high-intensity secondary particle beams such as neutrons and pions/muons. Neutrons, produced by a spallation reaction of 400 MeV protons with a thick lead or tungsten target, are used for developing an ultra-cold neutron(UCN) source and for testing single event effects in semiconductor devices. The primary intense proton beam will be also provided for a new muon source using a thick graphite target placed in a superconducting solenoid magnet for pion capture. The muon source will be used for the research in elementary particle physics and interdisciplinary science. In order to meet the requirement of the intense proton beam, a 2.45 GHz ECR proton source of permanent-magnet type has been developed to increase the intensity to more than 5μA.

On the other hand, a halo-free high-quality light-ion beam with energy spread less than 0.1% is requested for a precise nuclear physics experiment using the Grand-Raiden spectrometer. A flat-top(FT) acceleration system [2] was developed for a K140 injector AVF cyclotron, and a flat-top accelerated beam is being developed to improve the intensity and quality of the injection beam for the ring cyclotron.

In this paper, development of the intense 2.45 GHz ECR proton source and its installation to the injection beam line of the AVF cyclotron are reported. The present status of the flat-top accelerated beam development is also described.

INTENSE PROTON SOURCE

Design of the 2.45 GHz ECR Proton Source

A high intensity light ion source of 2.45 GHz ECR type using a set of ring-shaped permanent magnets was developed at CEA-Saclay to produce a 100 keV CW proton beam with the intensity more than 100 mA [3]. The design of our 2.45 GHz ECR proton source is similar to the CEA-Saclay source, but the extraction system was optimized for 15 keV protons to match with the injection system of the RCNP AVF cyclotron. The proton source has three rings of permanent magnets, NMX-48BH (NEOMAX Engineering Co., Ltd.), with an inner radius of 75 mm to form the ECR field of 875 G for 2.45 GHz. The ring magnet consists of 12 pieces of blocks with a radial thickness of 35 mm and an axial width of 50 or 60 mm. A 2.45 GHz microwave and a hydrogen gas are axially fed into a plasma chamber made of copper. The fabricated 2.45 GHz ECR proton source is shown in Fig. 1. An extraction system of the ECR proton source is composed of five electrodes. The size of the electrode hole is 5 mm in diameter to obtain a low-emittance proton beam. The shape of the electrodes and the distance between the neighbouring electrodes were optimized using a simulation code IGUN. An example of extracted beam trajectories is shown in Fig. 2.

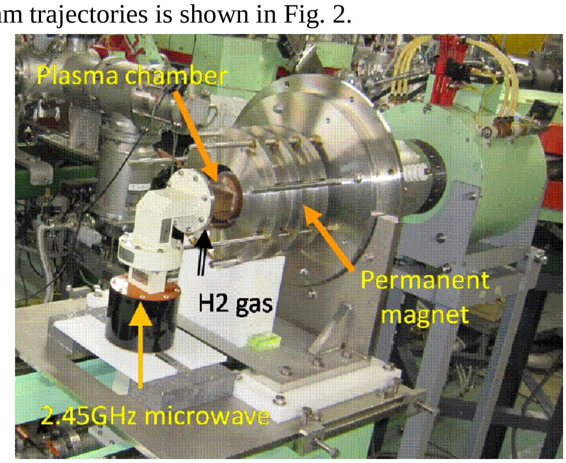

Figure 1: 2.45 GHz ECR proton source.

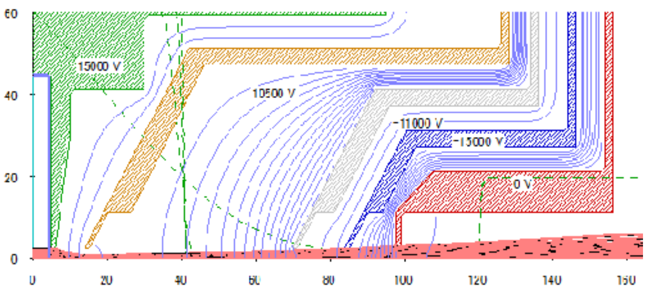

Figure 2: An example of particle trajectories in the extraction region, simulated using IGUN. Transmission of 95 % is expected for 15 keV protons.

Performance Test

We obtained a 0.5 mA 15 keV proton beam by supplying a 60 W microwave. The ratio of protons and H_2^+ ions was 0.85/0.15. The high proton ratio was similar to that at CEA-Saclay. Optimum microwave frequency to obtain the maximum beam current was investigated by using a travelling wave tube amplifiler. More than 0.7 mA proton beams were extracted from the proton source in the frequency range between 2.52 and 2.55 GHz. The result indicated the feasibility of further optimization of the magnet layout and the extraction electrode configuration.

Installation in the Injection Beam Line

The injection beam line was extended for installation of the proton source. A glazer lens followed by a 90 degree bending magnet was placed at the exit of the ion source to focus the proton beam at the entrance of the bending magnet. The LEBT for the new proton source is jointed at the second 90 degree bending magnet as shown in Fig. 3. We have already succeeded in injection of the proton beam into the AVF cyclotron.

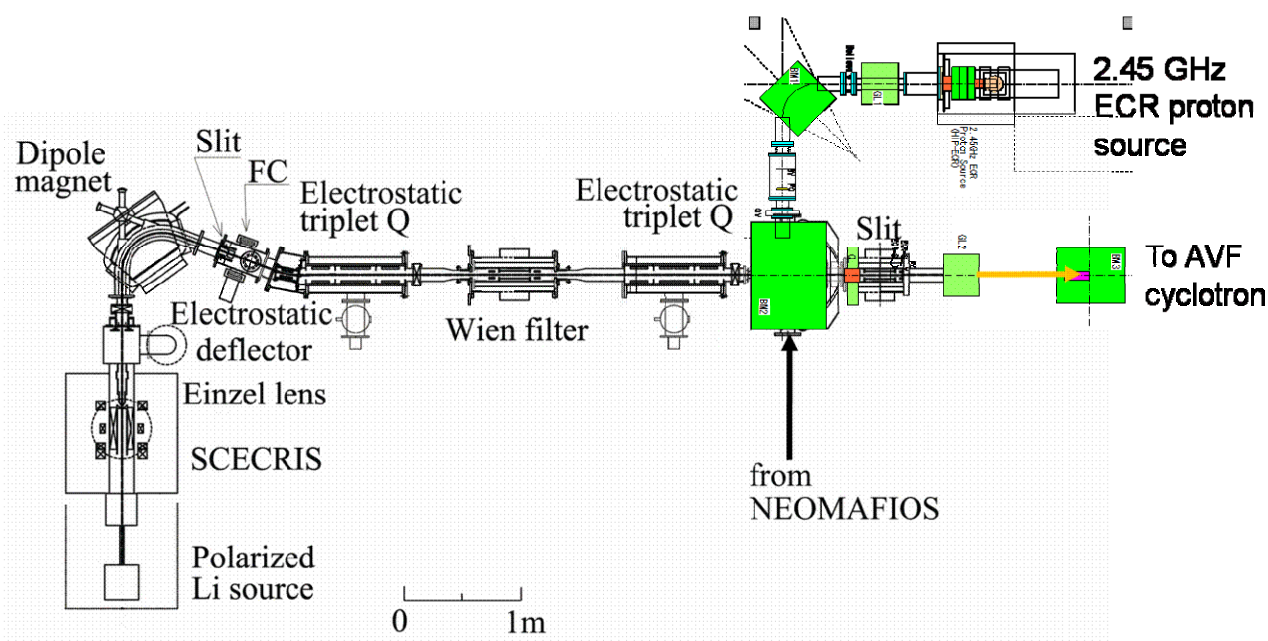

Figure 3: LEBT for the 2.45 GHz ECR proton source.

DEVELOPMENT OF THE FLAT-TOP ACCELERATED BEAM

The flat-top acceleration technique using the 7th harmonic frequency of 70.814 MHz was applied to a 44 MeV deuteron beam. The energy spread of 42 keV FWHM and the horizontal beam emittance of 15 π mm mrad, obtained by acceleration using a fundamental frequency of 10.116 MHz, were improved to 32 keV FWHM and 9 π mm mrad. The improvement of the beam quality by the FT acceleration was obviously observed. The beam transmission from the AVF cyclotron to the ring cyclotron was also increased from 43 % to 75 %.

A transverse resonant mode was investigated by two dee voltage pickup signals from the electrodes placed at the both ends of a single dee electrode with a span angle of 180 degrees. We observed opposite polarity of the two pickup signals, showing the existence of the transverse resonant mode. Therefore, the FT acceleration using the 5th harmonic frequency cannot be realised in the harmonic frequency range between 50 to 60 MHz. Further development is required to overcome the interference.

The 4th harmonic voltage was generated in the harmonic frequency range to achieve the FT acceleration using the transverse resonant mode as a trial. We have observed frequency dependence of the harmonic voltage distribution along the acceleration gap. More analysis is required for ideal FT acceleration.

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