DEVELOPMENT OF HIGH-QUALITY INTENSE PROTON BEAM AT THE RCNP CYCLOTRON FACILITY

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Abstract

An upgrade program for increase of beam intensity and improvement of beam quality is in progress at the cyclotron facility of Research Center for Nuclear Physics(RCNP). A 2.45 GHz ECR proton source was modified to increase 392 MeV proton beam intensity. Rated output power of a microwave power supply was increased from 200 W to 2 kW. A water-cooled waveguide system for high power microwave transfer is being installed for the proton source. A 15 keV proton beam with intensity of 0.6 mA was stably produced for output microwave power of 200 W. Emittance of 50 to 100 π mm-mrad was obtained for 0.05 to 0.1 mA proton beams in the LEBT system. Beam transmission, defined by the ratio of the beam intensity between a Faraday cup placed in the axial injection beam line and an inflector electrode of the AVF cyclotron, was improved from 25 % for a 0.07 mA proton beam to more than 90 % for 0.03 mA, which indicated that the beam transmission was limited by the acceptance of the axial injection beam line. A new active gradient corrector is being designed for horizontal beam focusing in the extraction region of the AVF cyclotron and for reducing a beam loss at the vacuum chamber in the extraction region. An asymmetric dee voltage distribution at an acceleration gap is being analyzed for improvement of a flat-top acceleration system of the AVF cyclotron.

INTRODUCTION

Two variable-energy multi-particle cyclotrons, a K400 ring cyclotron and a K140 AVF cyclotron, provide light and heavy ion beams for nuclear physics experiments. In recent years, beam time for utilization of secondarily produced particles such as neutrons and muons has been increasing gradually and the demand for the intense primary proton beam rises.

In the development of ultra-cold neutron (UCN) source, highest UCN density of around 20 UCN/cm^3 was achieved by using a 1.1 μA 392 MeV proton beam, bombarding a thick lead target. White neutrons, produced by a spallation neutron reaction between the 1.1 μA 392 MeV proton beam and a thick tungsten target, are provided for elucidation of single event upset phenomena occurred in semiconductor devices. Development of a new muon source has been started using a 20 cm long graphite target placed in the center of a 3.5 T superconducting solenoid magnet to capture pions and surface muons emitted from the target with a large solid angle. AN intense primary 392 MeV proton beam with intensity of more than 5 μA is required to realize the highest CW muon source [1].

Modification of a 2.45 GHz ECR proton source of permanent magnet type has started to increase the intensity of the proton beam with high brightness and low emittance to more than 1 mA. Such a high quality intense beam will enhance beam transmission and reduce beam loss and activation in the equipment of the AVF cyclotron and a beam line to the ring cyclotron. A field-gradient corrector with a pair of active coils is being designed to improve beam extraction efficiency and to avoid extra activation of equipment. In addition, the electric field distribution along the acceleration gap at the fundamental and the fifth-harmonic frequencies is being analysed by HFSS and MW-Studio codes to improve the flat-top acceleration system of the AVF cyclotron. In this paper the present status of development for the high quality intense proton beam production is reported.

2.45 GHz ECR PROTON SOURCE

Originally a 200 W microwave power supply was used for production of a 15 keV proton beam [2]. The beam current of 0.5 to 0.6 mA was obtained for a microwave output power of 50 to 150 W. Generation of a high quality beam by cutting down the beam with a set of beam slits results in decrease of beam intensity. Enhancement of beam brightness is required for minimization of the beam cut and production of a high quality intense beam. The beam intensity is expected to be increased with the microwave power rising. The microwave power supply was replaced by a switching power generator (Alter SM840E) and a 2 kW air-cooled magnetron head (Alter TMA20). After the replacement of the microwave power supply, a proton beam current of 0.6 mA was confirmed for output power of 200 W.

The waveguide system will be also renewed for high power microwave transmission. A vacuum window and a water-cooled high voltage isolator is being mounted to a plasma chamber. A dual directional coupler and a stub tuner were connected between the power supply and the high voltage isolator.

In order to improve thermal conduction of the four gap electrodes forming the electric field for extraction, the gap electrodes were fixed on a 15 mm thick copper disk with a diameter of 400 mm. The heat originated from power loss of the extracted proton beam in the gap electrodes is transferred to the air side through the copper disk. After

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this modification, the temperature of the copper disk was kept less than 60 degrees Celsius. The geometry of the extraction electrodes is shown in Fig. 1.

The 5 mm diameter hole of the 4 gap electrodes, which were made of stainless steel originally, was damaged by the sputtering of the proton beam and the aperture gradually increased, which resulted in deterioration of the beam emittance. Small fragments chipped by the proton sputtering, attached on the opposite electrode, and caused sparking between the electrodes and instability of the extracted beam. Material of the hole area was changed to tungsten and separately mounted on the stainless steel electrodes.

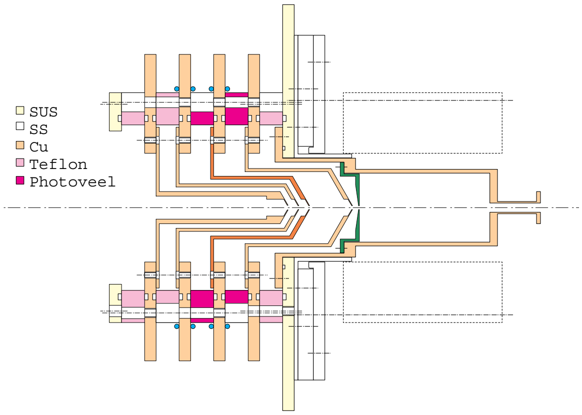

Figure 1: Layout of the extraction electrodes of the 2.45 GHz ECR proton source.

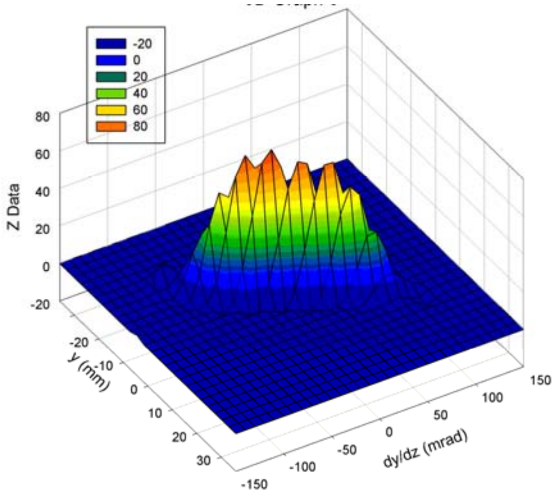

Figure 2: An example of the particle distribution in the vertical phase space for the proton beam extracted from the 2.45 GHz ECR proton source.

EMITTANCE IN THE LEBT SECTION AND BEAM TRANSIMISSION TO THE AVF CYCLOTRON

An emittance monitor was installed in the beam injection line of the AVF cyclotron to evaluate properties of the low energy beam extracted from ion sources. Existing two sets of beam slits were used for defining the beam in horizontal and vertical direction. A beam profile monitor of 3-wire scanning type was placed at the position where the distances from the horizontal and vertical defining slits were 380 mm and 280 mm, respectively. An example of the particle distribution in the vertical phase is shown in Fig. 2. The gap of the slits was set to 3mm and the slits were scanned by 3mm pitch to evaluate the beam emittance roughly. Measured horizontal and vertical emittance showed the range from 50 to 100 π mm-mrad for the beam current of 0.05 to 0.1 mA. The emittance values depends mainly on the operation conditions of the proton source such as the microwave power, voltages supplied to the gap electrodes and vacuum degrees in a plasma chamber.

Beam transmission of the axial injection in the AVF cyclotron, defined by the ratio of the beam current between the inflector and the Faraday cup located in the axial injection beam line, was increased with the aperture of an iris-diaphragm slit, placed upstream of the Faraday cup, went down. The beam transmission was improved from 25 % for a proton beam current of 0.07 mA to more than 90 % for 0.03 mA. More than 90 % transmission was achieved for the iris-diaphragm aperture of less than 8 mm in diameter.

DESIGN OF THE GRADIENT CORRECTOR OF THE AVF CYCLOTRON

The extraction system of the AVF cyclotron consists of an electrostatic deflector, a magnetic channel of passive iron core type. The extracted beam spreads horizontally since the magnetic field of the cyclotron magnet rapidly decreases in this region and there is no focussing element in the extraction region. Some parts of the extracted beam were lost at a vacuum chamber of the AVF cyclotron and a beam duct of the beam line, which caused unwilling activation. We have started the design of the gradient corrector to focus the extracted beam on the object position of the beam transport system. A pair of active coils will be mounted on the iron pole for correction of the beam orbit to match to the beam line axis.

In the design of the gradient corrector, the gap shape of the iron pole and the position of the coils are being optimized to form the field gradient of $(1/B\rho)dB/dx \sim 7\ /m^2$ horizontally for well-matching to the beam object size of the beam transport system. The field gradient should be realized for all main coil excitation levels to apply the focusing force to any accelerated ions and energies.

ANALYSIS OF THE ELECTRIC FIELD DISTRIBUTION FOR THE FLAT-TOP ACCELERATION

A flat-top acceleration system of the AVF cyclotron has been developed to improve the beam intensity and quality. A harmonic frequency range between 50 to 90 MHz is covered by excitation of the flat-top cavity coupled to the main cavity from the opposite side of the main power feeder. Figure 3 and 4 show examples of the absolute electric field distribution on the dee electrode and the inner tube at the fundamental frequency of 10.06 MHz and its 5th harmonic frequency of 50.3 MHz. The electric field of the fundamental frequency has a symmetrical distribution along a 180 degree dee gap since the fundamental voltage is excited using 1/4 λ standing-wave mode in the main cavity. On the other hand, the harmonic voltage distribution is asymmetric due to the difference of a transmission line length from the flat-top cavity to the dee electrode edge. In addition, the flat-top system has a problem of penetration of the power for exciting the harmonic voltage into the main power feeder. More power is required to produce the harmonic voltage on the dee electrode along the acceleration gap. The analysis is now in progress.

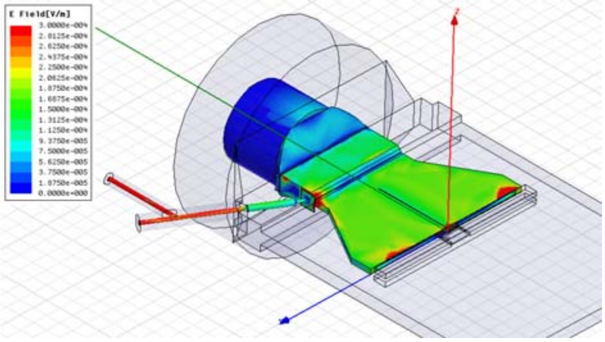

Figure 3: An example of the electric field distribution on the dee electrode and the inner tube of the main cavity at the fundamental frequency of 10.06 MHz.

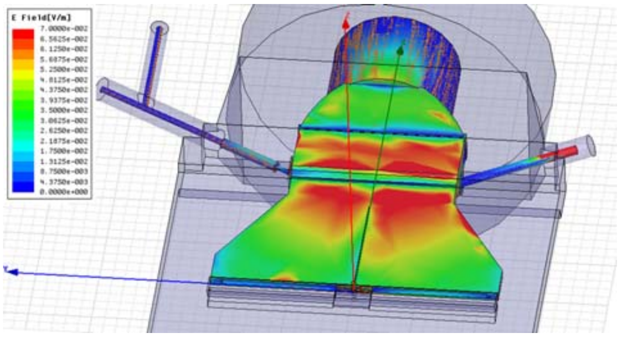

Figure 4: An example of the electric field distribution on the dee electrode and the inner tube of the main cavity at the 5th harmonic frequency of 50.30 MHz. Only the 5th harmonic power is fed through the flat-top cavity coupled from right hand side.

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