MCC-30/15 CYCLOTRON – PARAMETERS, ADJUSTING WORKS AND THEIR RESULTS

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Abstract

The Medical Compact Cyclotron MCC-30/15 is intended for acceleration of hydrogen and deuterium negative ions in the energy control range. The Cyclotron was designed in the frame of the Contract for the delivery of the MCC-30/15 cyclotron equipment to the Accelerator Laboratory of the Jyvaskyla University, Finland.

The Cyclotron is built up on the basis of a shielded-type electromagnet with a pole diameter of 140 cm. The Cyclotron is equipped with the external injection system of negative hydrogen and deuterium ions.

Particles are accelerated at a fixed frequency (the 2nd and 4th harmonics). The beam current of 30-18 MeV protons and 15-9 MeV deuterons extracted into two beam lines is more than 100 μA and 50 μA, respectively.

The Cyclotron equipment has been delivered to the Buyer; the commissioning works were finished on April 30, 2010.

THE MAIN DESIGN FEATURES OF THE CYCLOTRON

The designing of the MCC-30/15 cyclotron was started in 2007 after signing the Contract for the cyclotron delivery to the Jyvaskyla University, Finland. The main cyclotron characteristics were agreed upon with the Customer: the cyclotron must be equipped with an external ion injection system, the negative ions of hydrogen and deuterium must be accelerated up to an energy of 30/15 MeV with an energy control range of 60-100% of the ions maximum energy, the cyclotron beam are to be extracted by negative ion stripping on thin carbon foils to two beam lines with a possibility to irradiate two targets simultaneously. The maximum beam current was defined to be 100 microamperes for protons and 50 microamperes for deuterons.

When designing the cyclotron, the positive experience gained when designing and commissioning the CC-18/9 cyclotron at the Abo Academy PET Center (Turku, Finland) in 2006 was used. A series of basic engineering solutions were applied, in particular, the external multicasp source of negative hydrogen and deuterium ions, the RF field frequency similar for both types of ions, the vertical location of the beam acceleration and extraction plane, which gives an operator an easy access to in-chamber units and injection system for maintenance/repair in the process of exploitation. A software package previously applied on the CC-18/9 cyclotron was used for 3D calculations of the cyclotron magnetic and accelerating RF systems.

While elaborating the Technical Project, a Planning Information document for the layout of the cyclotron equipment was worked out. On the basis of this document, the works on elaboration of construction documentation and on building the rooms to house the cyclotron equipment have been finished by the Finnish side for two years.

THE CYCLOTRON MAGNETIC FIELD

3-D calculations of the cyclotron magnetic field were performed to provide isochronous magnetic fields required for the acceleration of two particles, hydrogen and deuterium ions. The calculations were carried out by the method of successive iterations. The magnet pole geometry and corresponding magnetic field in the acceleration area were defined from the beam dynamics calculations [1].

Two magnetic fields needed for isochronous acceleration of hydrogen and deuteron ions were formed in the following way. The rotating shims placed into two cyclotron valleys free of dees were used when changing from one accelerating mode to another. In the acceleration mode of deuteron ions, these shims were placed completely inside the magnet pole. The pole sector sides were provided with plates of small azimuth length, which shape was chosen when forming the isochronous field for the deuteron ion acceleration. If hydrogen ions are accelerated, the magnetic shims are rotated so that the magnetic masses enter the magnet gap thus providing the magnetic field increase along the radius. The required isochronous radial dependence was provided by adjusting the shim generatrix.

Use of the shims located in two cyclotron valleys free of dees results in the appearance of the 2nd harmonic of the magnetic field. To decrease its value, two fixed shims were additionally placed into two other valleys. In the deuteron ion acceleration mode with these fixed shims, the 2nd harmonic of the magnetic field appeared and the 2nd harmonic in the hydrogen ion acceleration mode decreased respectively.

The carried out calculations of the beam dynamics have shown that the 2nd harmonic of the magnetic field of the 500 Gs amplitude does not affect the accelerated beam stability and does not increase the radial emmitance of the beam.

Radial distributions of the measured average magnetic field are shown in figs. 1-2.

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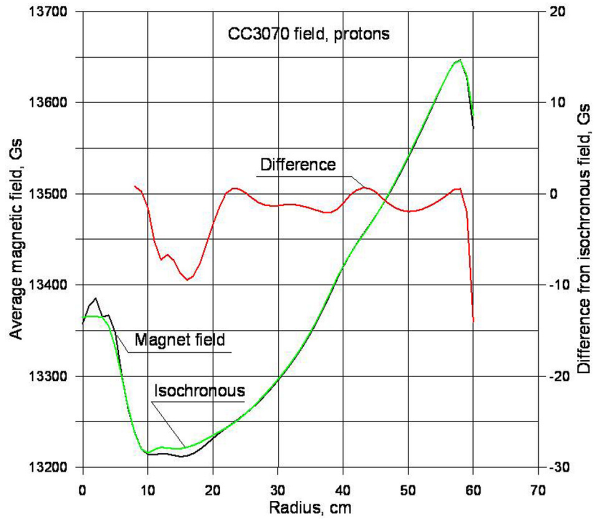

Figure 1: Isochronous field for the deuterium ion acceleration.

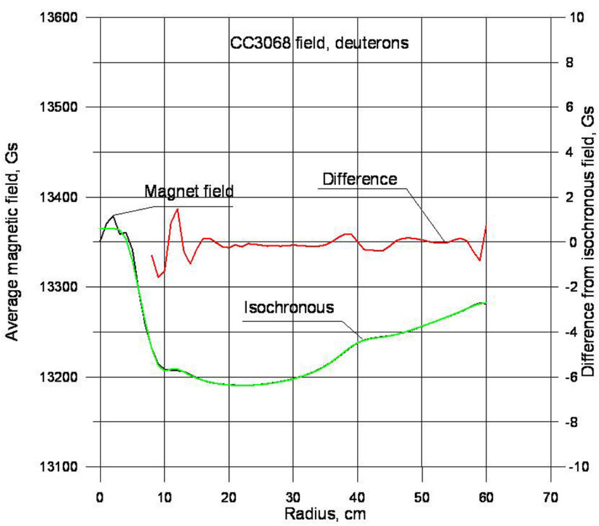

Figure 2: Isochronous field for the hydrogen ion acceleration.

THE CYCLOTRON ELECTROMAGNETIC FIELD

The MCC-30/15 cyclotron operates at a fixed frequency of 40.68 MHz. The hydrogen and deuteron ions are accelerated by the 2nd and 4th harmonics, respectively. The similarity of the ion orbits is not applicable in this case; therefore when calculating the beam dynamics, much attention was given to the beam centering in order to achieve optimum conditions for two-particle acceleration.

An electric field map obtained as a result of 3-D calculations [2] was used in the beam dynamics calculations. The map of the cyclotron central region was 16×16 cm in size in the acceleration plane and ±8 mm in the axial direction with a step of 0.5 mm for each of three coordinates. The resultant electric field map was obtained after several iterations. The electric field corrections were made from the results of the beam dynamics calculations.

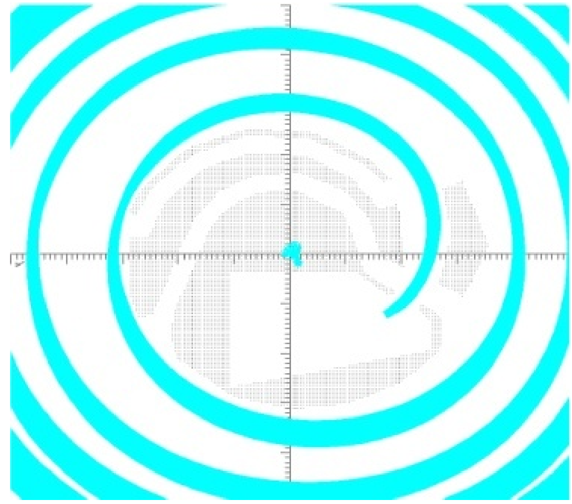

Figure 3: Centering of accelerated hydrogen ions. Phase range is ±0.25 rad. Accelerating voltage is 37.5 kV.

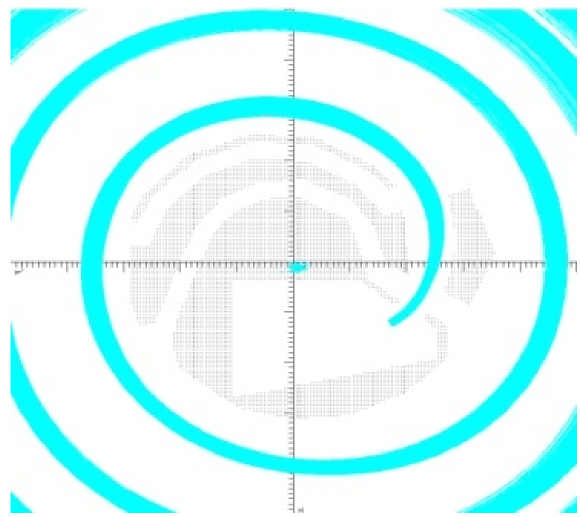

Figure 4: Centering of accelerated deuterium ions. Phase range is ±0.25 rad. Accelerating voltage is 25.5 kV.

When calculating the beam centering, the beam characteristics at the inflector output were taken as the key parameters of the cyclotron central region. These characteristics were corrected when calculating the beam dynamics to obtain the maximum acceptance in two perpendicular planes: the acceleration plane (the maximum phase range for the minimum orbit center zone) and the axial plane (the dee aperture restricted at the maximum axial emittance).

From the calculations, the following output parameters of the helical inflector were defined: hydrogen ion injection energy of 19 keV (for deuterium ions it was 9.5 keV), initial radius of 20.5 mm, central trajectory output angle of 23 degrees, tilt parameter of 0.28, radial emittance of 50 π mm. mrad and axial emittance of 50 π mm. mrad [2].

EXTERNAL BEAM ENERGY RANGE

In the MCC-30/15 cyclotron, the beam is extracted by carbon foil stripping of negative ions with control of the extracted beam energy. Strippers are placed symmetrically relative to the cyclotron dees, which allow external beams in two beam lines to be vertically shifted relative to each other and located 1350 and 1582 above the ground. The extracted beam energy range is provided by changing the stripper radial position by 120-130 mm and its azimuth position by 2-3 degrees.

The matching magnets installed at the cyclotron outputs allow the difference in the output beam angles of different particles with different energies to be compensated up to approximately 11º. The diagram of the beam extraction is shown in Fig 5. Fig. 6 shows the results of numerically simulated beam acceleration and extraction. The initial particle (500 pcs.) parameters were chosen randomly from the phase range of ±0.25 rad and amplitudes of radial and axial betatron oscillations (the radial emittance of 50 π mm.mrad and the axial emittance of 50 π mm. mrad).

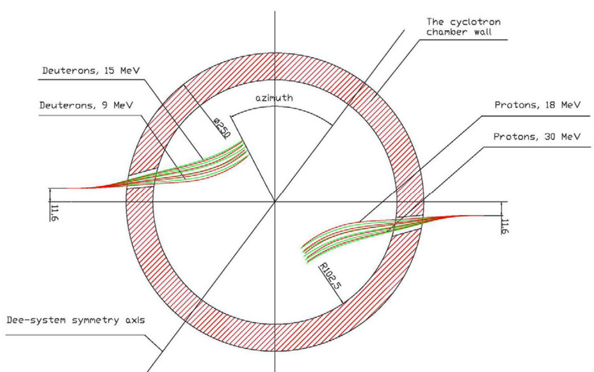

Figure 5: The cyclotron beam extraction.

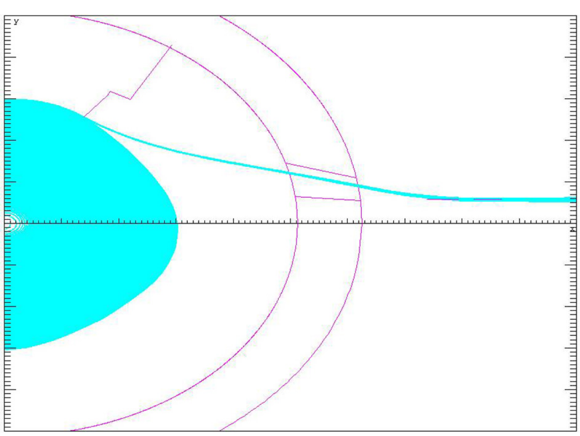

Figure 6: The results of numerically simulated acceleration and extraction of the beam. A small division value is 2 cm.

STARTUP AND COMMISSIONING OF THE CYCLOTRON

In August 2009, the MCC-30/15 cyclotron equipment was shipped to Finland and installed at the Accelerator Laboratory of the Jyvaskyla University. Works on the installation and adjustment of separate cyclotron systems: power supplies, water cooling, pneumatic, vacuum, ion source, injector, RF power supply and control systems were carried out during September-October. In October-December 2009, the adjusting of the cyclotron as a whole system and preliminary cyclotron tests were carried out, in the process of which the design cyclotron parameters were obtained. External proton beam with the maximum energy and current of more than 200 µamps per pulse and deuteron beams with the maximum energy and current of more than 60 micro µamps per pulse were obtained. From the results of the cyclotron preliminary tests, definite measures were planned to be taken to improve the RF power supply in-feeding unit and power filter. Final acceptance tests were planned for spring 2010.

Prior to the commissioning works, the isochronism of the particle acceleration was checked once more when the cyclotron RF system operated in the dee voltage stabilization mode. Measured resonance curves for the deuterium ion acceleration mode (see Fig. 7) show a negligible phase drift and no phase losses when passing the main acceleration area.

A list of the cyclotron operating modes (10 modes) to undergo the acceptance tests was agreed upon with specialists of the Accelerator Laboratory of the Jyvaskyla University. At the end of April 2010, during one week all the agreed upon modes were demonstrated, and on May 1, 2010 the MCC-30/15 cyclotron was put into operation.

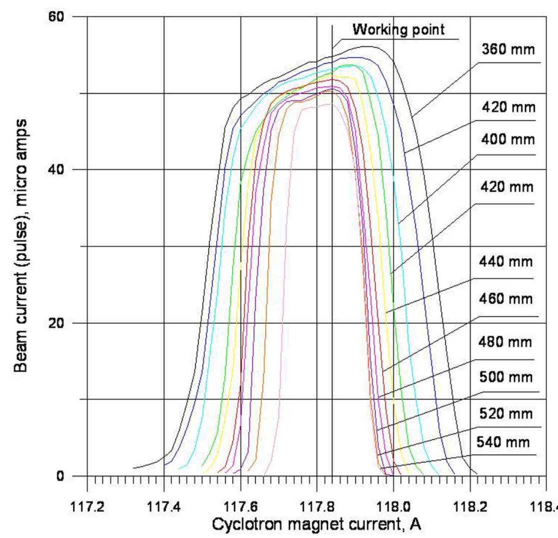

Figure 7: Resonance curves for deuterium ion acceleration modes.

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[2] A. Galchuk, S. Grigorenko, Yu Zuev, S. Silaev, A. Strokach. "Simulation of Electromagnetic Fields and Computations of the Beam Dynamics in Compact Cyclotrons", The paper of the current Conference.