PROGRESS ON THE DESIGN STUDIES OF THE 300 AMeV SUPERCONDUCTING CYCLOTRON

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Abstract

The design study of a compact superconducting cyclotron for hadrontherapy being carried out at Laboratori Nazionali del Sud (LNS), Catania. This machine accelerates Carbon ions with a charge to mass ratio of 0.5 (Q = 6+) to a maximum energy of 300 AMeV. These ions will be extracted by means of two electrostatic deflectors. The cyclotron subject of this study, is able to accelerate also the ionised hydrogen molecule H_2^+ to 260 AMeV of energy, which is extracted by stripping, giving a proton beam at the same energy. The main parameters of the cyclotron and the main beam dynamics features will be presented.

INTRODUCTION

At the end of 2005 the SCENT project [1] has been completed. The preliminary studies of a superconducting cyclotron accelerating ions with mass to charge ratio of 0.5 to the energy of 250 AMeV were carried out by the R&D group of LNS. In March 2006, the group investigated the possibility to achieve the extraction energy of 300 AMeV, for Carbon ions, increasing the average magnetic field, but keeping unchanged the main parameters of the machine as the dimensions and the pole radius too. Moreover, we tried to extract the protons by the stripping process at the energy of 250 AMeV.

The choice to get the energy of 300 AMeV is due to the higher number of tumours reachable inside the human body using the carbon beams, as shown in the following plot.

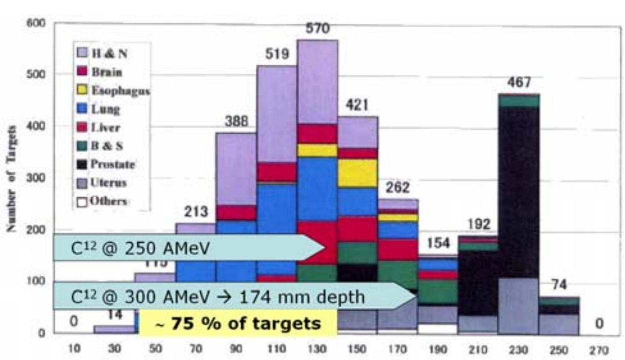

Fig.1 : the plot shows the number of targets (for different tumours highlighted on the left square) as function of the depth inside the human body. The arrows indicate the depth limits of the carbon beams at two different energy. These data are provided by HIMAC (Japan) concerning the treated patients from 1995 to 2001 [2].

On the other hand the extraction energy of protons of 250 AMeV, guarantees to treat the whole targets.

Combining the compactness of a superconducting cyclotron, with the advantage of the cyclotron as its continuous beam and its very good current control, the accelerator R&D group of LNS, by its ten-year of experience with this kind of machine, has developed a concept for a multiparticle therapy cyclotron which is described in the following report.

MAIN PARAMETERS

The cyclotron under study is based on the SCENT design. It is a four sector compact machine with a diameter of 5 m, height of 3 m and a weight of 350 tons. The magnet is energized by a pair of superconducting coils symmetrically placed above and below the median plane. These coils operate with a current density of 45 amp/mm^2. The machine, whose K bending value is fixed at 1200 MeV, achieves the maximum average magnetic field of 4.2 tesla. Four RF cavities operating in 4th harmonic at the fixed frequency of 98 MHz, accelerate the ions with a maximum average voltage of 120 KV. Table 1 summarizes the parameters of the cyclotron.

Table 1: Main Specifications

Parameters	Values
Particles	H_2^+, $^{12}C^{6+}$
Injection energy	25 AKeV
Extraction Energy	$^{12}C^{6+}$ @ 300 AMeV protons @ 260 AMeV
K bending	1200 MeV
Number of sectors	4
Magnetic Field in the center	3.2 tesla
Extraction radius	130 cm
Hill gap	5 cm
Main size	5 m x 3 m
Weight	350 tons
Coils	2 SC
Nominal current	950 amp
Current density	45 amp/mm^2
Number of cavities	4
Operating frequency	98 MHz, 4th harmonic
RF power	50 kW per cavity
Extraction Systems	Electrostatic deflectors Stripping process

MAGNETIC FIELD DESIGN

The magnetic circuit of the cyclotron has been designed using the dedicated FEM code TOSCA by Vector Fields. The poles are shaped with four spiral sectors in order to ensure an adequate axial beam stability. The maximum angle of the magnetic spiral reaches 80 deg. The average magnetic field varies from 3.2 tesla at the center of the machine, up to 4.2 tesla at the extraction radius. This radius is fixed at 1.3 m to extract the light ion beam at the final energy of 300 AMeV.

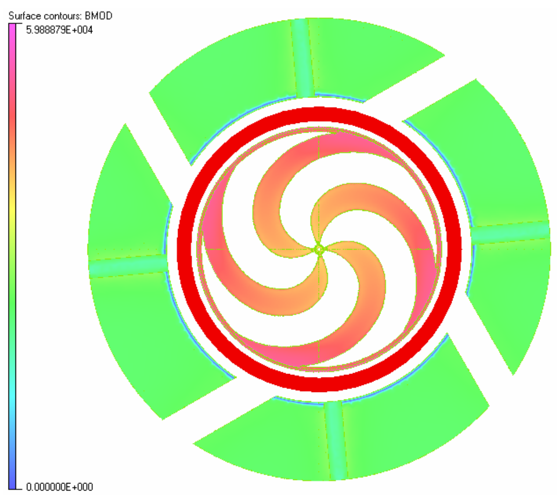

Fig.2: Top view of the magnetic field in the hills and the yoke.

Since the cyclotron operates in 4^{th} harmonic, it need to refine accurately the magnetic field in order to keep within few degrees the phase history of the accelerated beam as shown in the plot.

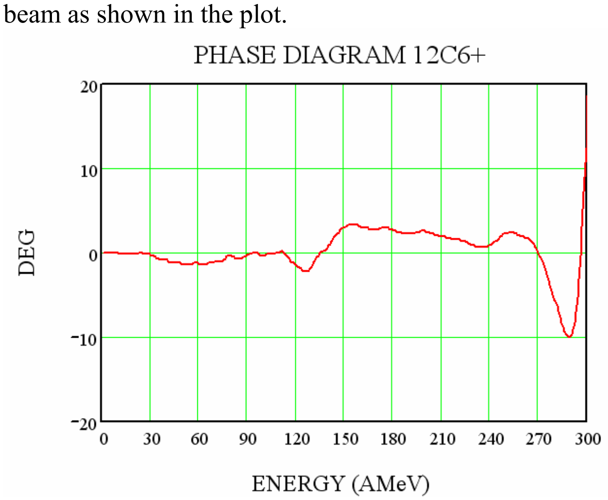

Fig.3: Phase history of carbon ion as a function of the energy. Due to the 4^{th} harmonic operation of RF system, the phase excursion of the beam has to be kept within few degrees to get an acceptable acceleration.

Despite the beam dynamic due to the preliminary magnetic model [3] did not show any crossing of dangerous resonances, the need to get a very accurate isochronism caused the crossing of resonances. Since the resonances cannot be avoided, the goal was to cross those within few turns, adjusting locally the magnetic field as suggested from IBA-JINR calculations [4].

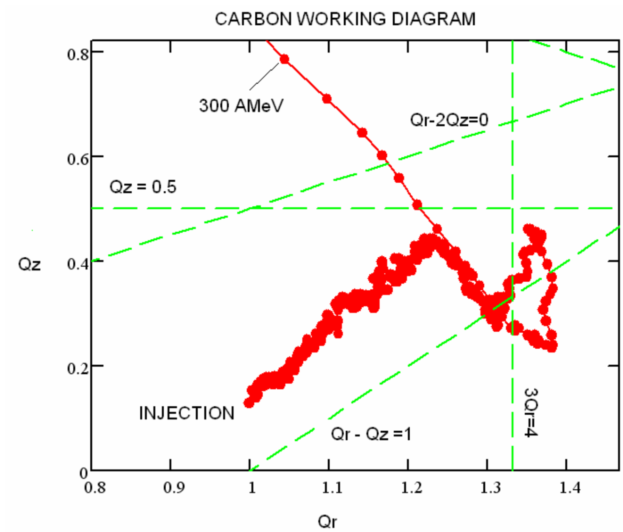

Fig.4: Working diagram of the cyclotron. The main dangerous resonance are shown as dashed green line.

CARBON TO H_2^+ SWITCHING

Despite the charge to mass ratio of both ion species accelerated ($^{12}C^{6+}$ and H_2^+) is similar Q/A~0,5, the isochronous magnetic field has to be changed of ~0.35% to guarantee an acceptable phase varying during the acceleration.

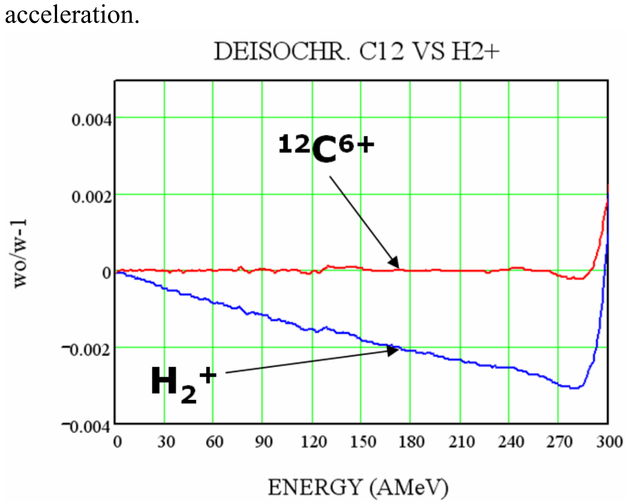

Fig. 5: The plot shows the isochronism as a function of the energy of both beams without tuning of the magnetic field. To accelerate the H_2^+ in the proper way, it requires that isochronism value (ω_o/ω -1) be less than 0.0005 as the red line shows for the carbon ions.

The fine tuning of the magnetic field was done, preliminary, by means of a number of movable trim rods positioned inside the hills. In order to avoid, or to reduce at least, the use of these pistons, we are considering to insert an additional coil of small size, operating at room temperature and placed outside the iron yoke, which compensates the main difference in terms of magnetic field needed to accelerated the two beams.

RF SYSTEM DESCRIPTION

The RF system, working in the fourth harmonic, is based on four cavities operating at 97 MHz. These cavities, copper made and water cooled, are entirely installed inside the free valley regions. The multistem cavity configuration [5] needed to reach the high resonant frequency, found out by means of 3D electromagnetic codes. The aim is to obtain a cavity with a voltage distribution going from 70 kV in the injection region to a peak value of 120 kV in the extraction region, and a low power consumption (60-70 kW per cavity). The cavities operate at the phase, and the power is fed by an inductive coupler for each cavity. A trimmer capacitor per cavity will be used for the fine tuning of the resonant frequency. The RF system is powered by four amplifiers.

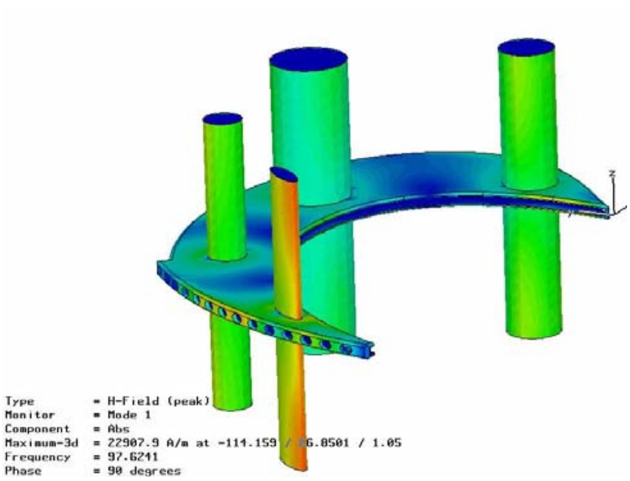

Fig.6: Current distribution on the complex DEE-stems of one cavity. As shown, four stems are expected to get the resonant frequency of 97 MHz. Due to the high value of voltage (120 KV) at the extraction region, the power dissipation on the outer stem becomes higher.

EXTRACTION STUDIES

The extraction of a fully stripped ion $^{12}C^{6+}$ requires the use of electrostatic deflectors (ED). The choice to install the 4 RF cavities inside the valleys implies to put two electrostatic deflectors in two hills, where the gap is deep enough (5 cm). However a system with the ED placed into the cavities, between the accelerating DEE, was studied. This choice makes the extraction process easier, but it increases the power consumption of the RF cavities.

The protons are extracted by stripping of the H_2^+. The carbon foil is positioned at the internal radius of 120-122 cm, in order to intercept the accelerated beam at the energy of 260 AMeV as shown in fig. 6.

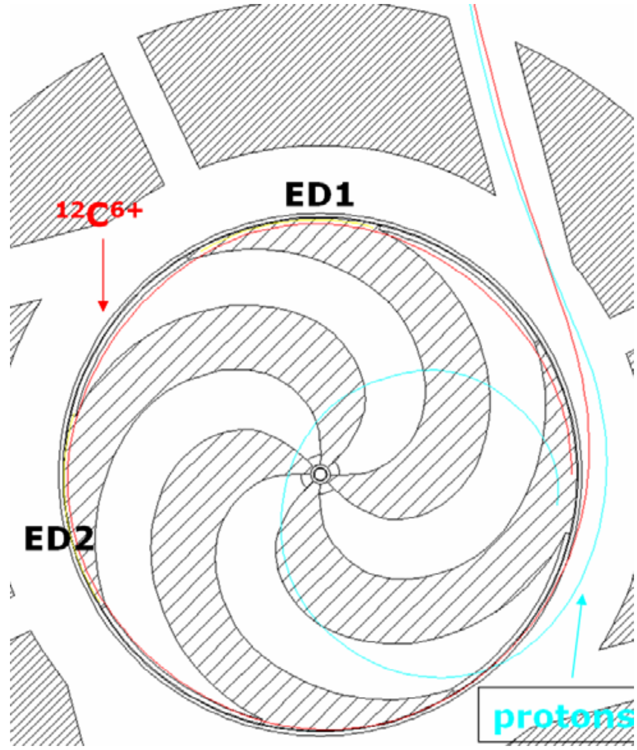

Fig. 7: Two different extraction processes.

CONCLUSIONS

While the use of both superconducting (K250 SC by ACCEL Gmbh) and conventional cyclotrons (C235 RT by IBA) in protontherapy centers is consolidated. The cyclotron subject of this study is an interesting option for the facilities dedicated to the treatments of tumours with ions and protons too. The preliminary design of this machine was carried out. The INFN has signed a technology-transfer deal that will fast-track the commercialization of its know-how in superconducting cyclotrons for hadron-beam cancer therapy.

REFERENCES

[1] L. Calabretta et al., "A NOVEL SUPERCONDUCTING CYCLOTRON FOR HADRONTHERAPY AND RADIOISOTOPES PRODUCTION", NIM A, 2006, 557, pp. 414-420.

[2] Y. Hirao , "Results from HIMAC and other therapy facilities in Japan", Cyclotrons 2001, East Lansing, USA, May 2001, p. 8.

[3] M. Maggiore et al. "Design Studies of the 300 AMeV Superconducting Cyclotron for Hadrontherapy " PAC'07, Albuquerque NM, USA, June 2007.

[4] Y. Jongen et al., "Simulation of Ions Acceleration and Extraction in Cyclotron C400", EPAC 2006, Edinburgh, Scotland. June 2006.

[5] M. Maggiore et al., "Conceptual design of the RF accelerating cavities for a superconducting cyclotron", Nuclear Instruments and Methods A 557 (2006) p 441-420.