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ELECTROMAGNETIC STUDY AND MEASUREMENTS OF THE iRCMS CELL*

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Abstract

The ion Rapid Cycle Medical Synchrotron (iRCMS) [1,2] will provide proton and Carbon ion bunches with maximum energy 200 MeV and 400 MeV/u respectively at a frequency of 15 Hz for treating cancerous tumors. One of the six cells of the iRCMS has been designed, built and magnetic field measurements are being performed. We will present results from the static and AC electromagnetic study of the iRCMS cell and compare the measured magnetic fields with those calculated using the OPERA computer code [3]. In addition the beam optics of the cell will be calculated based on 3D field maps, provided by the OPERA computer code, using the zgoubi computer code [4] and compared with the designed beam optics.

INTRODUCTION

The iRCMS is a medical synchrotron designed to provide proton and $^{12}C^{+6}$ single ion bunches with maximum energy 270 MeV and 400 MeV/u respectively at a frequency of 15 Hz for treating cancerous tumors. The synchrotron is a racetrack type with two 10.5 m long straight sections and two arcs of 5 m in radius. Figure 1 is a perspective view of the iRCMS. Each straight section has five quadrupoles and

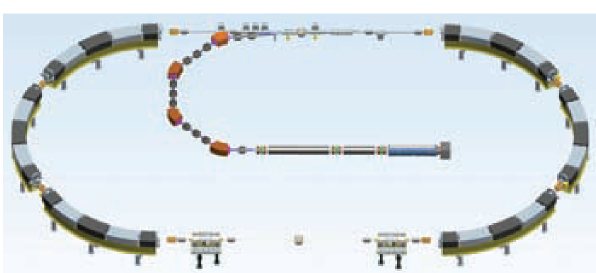

Figure 1: The layout of the iRCMS. The racetrack design consists of two 10.5 m long straight sections and two 180 degrees arcs of radius 5 m.

one of the straight sections is devoted to the RF devices and the other to the injection and extraction devices. Each cell is made of five combined function magnets and the three consecutive cells of each arc form an achromatic system. Table 1 lists some of the iRCMS design and beam optics parameters. and Table 2 lists the injection and extraction energies of the proton and Carbon ions.

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Table 1: Some Geometric and Optical Specifications of the iRCMS

Circumference [m]	64
Number of cells in the arcs	6
Combined function magnets per cell	5
Quadrupole magnets per Straight Section	5
Horizontal/Vertical tunes	4.84/4.41
Max Hor./Vert. beta functions [m]	12.16/9.44
Max Hor. dispersion function [m]	1.55
Hor./Vert. chromaticity $\xi_{x,y}$	-5.3/-5.12
Transition γ_t	4.2
Repetition rate [Hz]	15

Table 2: Some Specifications of the Beam Bunches of the iRCMS

Species	proton	Carbon
Injection Energy [MeV/u]	8	8
Extraction Energy [MeV/u]	8 to 100	8 to 400
Normalized $\epsilon_{x,y}$ [μm]	0.5	0.5

THE iRCMS CELL

Each of the two arcs of the iRCMS consists of 3 cells each focuses and bends the circulating bunches by 60^o. Figure 2 is a perspective view of the iRCMS cell showing all five magnets of the cell and the coil. For positive ions the focusing properties of the five magnets starting from the outside magnet are D,F,D,F,D. The focusing and defocusing property

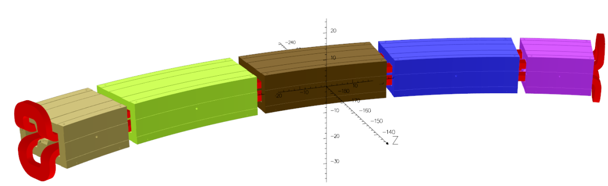

Figure 2: Perspective view of the iRCMS cell showing all five magnets of the cell and the coil.

of the magnets is generated by the slanted pole faces of the magnets as shown in Fig. 3 which is a perspective view of

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two of the five magnets of the iRCMS cell with the top half of the magnets and coil above the median plane removed. Note that the pole faces of the magnets have a slope which defines the quadrupole strength.

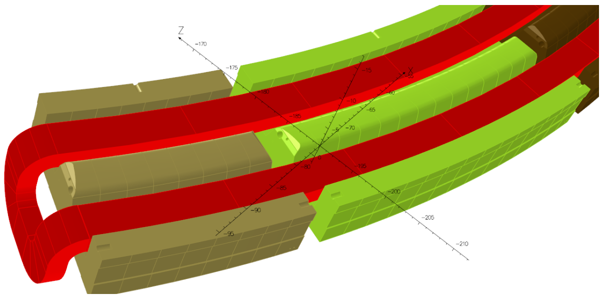

Figure 3: Perspective view of the two of the magnets of the iRCMS cell with the top half of the magnets and coil above the median plane removed. The quadrupole strength of the magnets is defined by the slope of the pole faces.

A cross section of the upper half of a focusing combined function magnet is shown in Fig. 4.

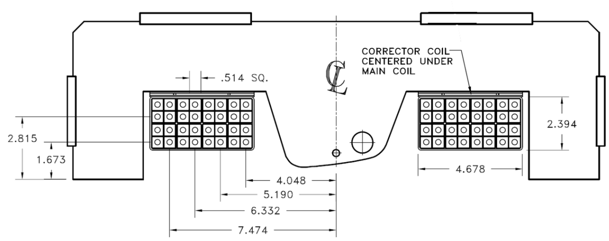

Figure 4: The cross-section of the upper half of a focusing magnet.

THE OPTICS OF THE iRCMS CELL

Figure 5 is a plot of the $\beta_{x,y}$ and $\eta_{x,y}$ functions of the iRCMS ring. The yellow highlighted areas are the 180^o arcs of the iRCMS and the green highlighted area is the middle cell of one of the 180^o arcs. The $\beta_{x,y}$ and $\eta_{x,y}$ functions of the iRCMS ring were optimized by the computer code MADX [5]. The optical function of the iRCMS shown in Fig. 5 show that there are two periods in the iRCMS.

MAGNETIC MEASUREMENTS OF THE iRCMS CELL

An AC power supply will provide the excitation current of the iRCMS magnets which will be part of the RLC circuit with AC Voltage of 15 Hz. The excitation current of the arc magnets is of the form I=I$_{inj}$+I$_0$sin(2π15t). The beam will be injected at the lowest excitation current I$_{inj}$ and will be extracted at any point along the sinusoidal current pulse depending on the extraction energy required.

The magnetic field measurements of the iRCMS under AC operation, will reveal the magnetic properties of the iRCMS and the effect of the eddy currents of the vacuum pipe on the magnetic field at the region of the circulating

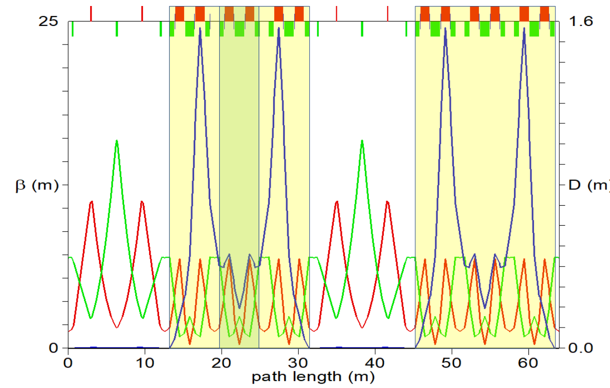

Figure 5: Plot of the $\beta_{x,y}$ and $\eta_{x,y}$ functions of the iRCMS ring. The yellow highlighted areas are the 180^o arcs of the iRCMS and the green highlighted area is the middle cell of one of the 180^o arcs.

beam. To confirm the correctness of the mechanical design of the magnet, static magnetic field measurements are also under way. This paper reports on the static magnetic field measurements that have been performed till now.

The Hall probe system Figure 6 is a picture of the three hall probes which are embedded at the tip of a long horizontal fiber glass tube mounted on a X-Y table controlled by stepper motors. X axis is 1500 mm long and Y axis is 100 mm. The hall probes are made by Group 3, model MPT-141 along with the readout meters model DTM-151. The position control and data logging software was programmed using LabView and National Instrument PXIe hardware. The hall probe measurement system was positioned on a granite block in front of the first magnet. FEROARM 3D measurement system was used to precisely align the mechanical center of the magnet airgap with the center of hall element.

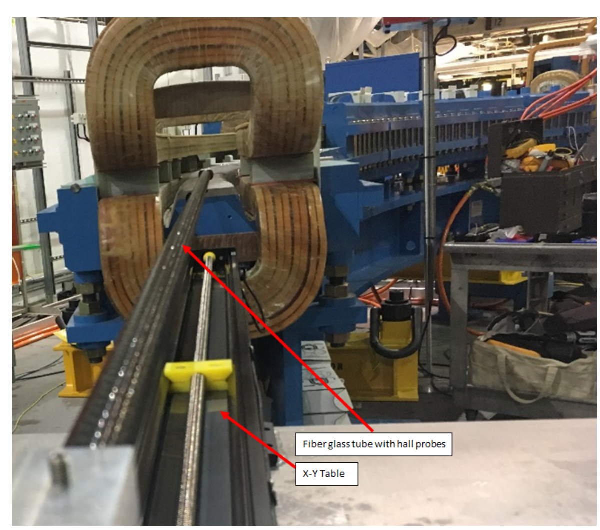

Figure 6: The AC current of the iRCMS magnets. The beam will be injected at the lowest current and will be extracted at any point along the sinusoidal current pulse depending on the energy required.

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Some results from the measurements At the present time static magnetic field measurements have been performed on an area over the median plane of the magnet, covering the first magnet and part of the entrance of the second magnet. The narrow ribon-like area shown in Fig. 7 is the area on the median plane of the iRCMS cell over which the measurements were carried out on grid points located along eleven circular arcs. The grid points along each arc are separated by 0.003 radians. The circular arcs are separated radially by ΔR=5 mm and have the same center. The central circular arc has a radius R=508.022 cm. One of the arcs is shown by the yellow trace in Fig. 7 The top half of the magnet has been removed from the figure to make the yellow arc visible. Figure 8 shows the measured B_y component of the field (black dots) along the arc R=508.022 cm at the median plane y=0.

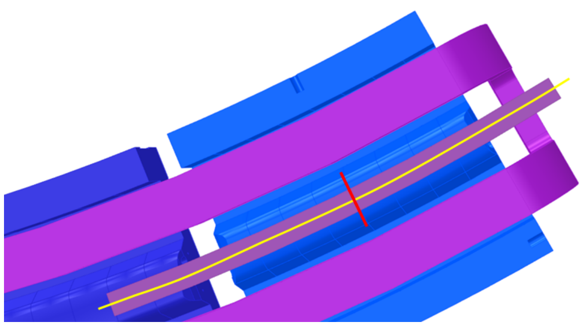

Figure 7: A perspective view of the iRCMS cell with the top half of the magnets removed to make visible the ribbon-like area over the median plane of the magnets where the measurements were performed. This area covers the first magnet and part of the second magnet. One of the arcs along which the measurements took place is shown as a yellow trace.

The red curve is the B_y component of the magnetic field as calculated by the OPERA [3] computer code.

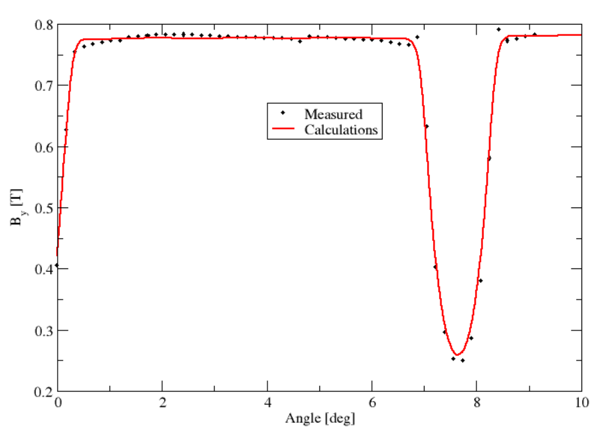

Figure 8: Measured B_y component of the field (black dots) along the arc R=508.022 cm at the median plane y=0. The red curve is the B_y component of the magnetic field as calculated by the OPERA computer code.

The comparison between the experimental and calculated values of the B_y component of the field as shown in Fig. 8 is under investigation and a new round of similar measurements will be performed. A set of measurements were also performed of the B_y component on the radial direction as shown by the red line in Fig. 7. The black dots on the plot in Fig. 9 are the measured B_y component along the radius at the median plane y=0 shown by red line in Fig. 7. The red curve on the plot is the calculated B_y component of the magnetic field as calculated by the OPERA computer code. The green line is a straight line fit to the measured values. The slope of the B_y component on Fig. 9 is the gradient of the combined function magnet and is in excellent agreement with the calculated value from the OPERA code.

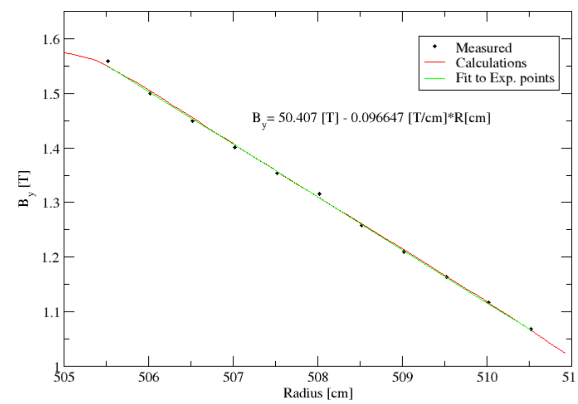

Figure 9: Measured B_y component (black dots) along the radius at the median plane y=0 (red line in Fig. 7). The red curve on the plot is the calculated B_y component of the magnetic field as calculated by the OPERA computer code. The green line is a straight line fit to the measured values.

CONCLUSION

The static magnetic field measurements performed the iRCMS cell indicated that magnets were built according to the design. Additional static field measurements are being planed to allow the computation of the integral dipole and quadrupole components for each magnet of the cell. Preparations for the AC measurements at the frequency of 15 Hz are under way.

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