THE MAGNETIC FIELD MAPPING SYSTEM FOR THE IBA C70 CYCLOTRON

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Abstract

In IBA's C70 cyclotron, the number of turns to full energy in the h=2 mode of acceleration is around 600. This shows the need for a field mapping system with a typical accuracy in the 10^{-4} range. This figure is very comparable to the case of the IBA protontherapy machine C230. Therefore we adopted for the C70 cyclotron the same measurement philosophy as for the C230: a Hall probe connected to home-made electronics, azimuthal accuracy obtained by mechanical indexation, a high resolution radial movement and position measurement, precision temperature compensation. A typical field map consists of 180 radial tracks of around 200 points each, and will last for some 36 hours. Each field map point results from a running average in order to ensure the stability of the measurements. The layout of the mapping system is described and first field measurements is commented.

MECHANICAL CONSTRAINTS AND MEASURING REQUIREMENTS

The following list presents the main specifications of the C70 mapping system.

For the mechanical part:

- the available gap is equal to 30 mm for all the radii except at extraction which it reduces to 20 mm
- the main coil gap is equal to 240 mm
- the pole radius is equal to 1240 mm
- the Hall probe movement should coincide with the mechanical median plane ± 0.5 mm

Concerning the field measurements:

- magnetic field range from 0.1 T to 1.6 T
- magnetic field accuracy goal 10^{-4}
- radial position accuracy 0.2 mm
- minimal radial step 1 mm
- azimuthal resolution 0.5 degree
- one full map (0 to 390 degrees) in less than 36 hours

Concerning the control system:

- remote access and control
- maximum fault recovery

MAPPING SYSTEM IMPLEMENTATION

Mechanical part

We took as a starting point the mapping system previously designed for the C230 IBA cyclotron for the following reasons:

- it fully fits the C70 measurement requirements
- it is a robust and reliable system
- we can reuse the existing schematics for the control system and for the operational scheme

The design phase of the mapping system coincided with the C70 magnetic field computation, so we could not base our system on a well defined pole shape. Moreover, the gap is smaller than for the C230, so even if the C230 "philosophy" matches almost all our requirements, we had to redesign most mechanical parts. This gave us the opportunity to improve the radial movement: the synthetic belt to move the C230 shuttle was felt inadequate, because of the backlash and the possibility of slipping.

The design department came up with the idea of a large table sustained in its centre and sliding on a ring pinched by the return yoke. This ring carries some cogged segments: one cog every 0.5 degree. For the azimuthal movement three air jacks are used: one for the grip into a cog, the other to lock and the third to make the movement itself. This indexation mechanism is shown in Figure 1.

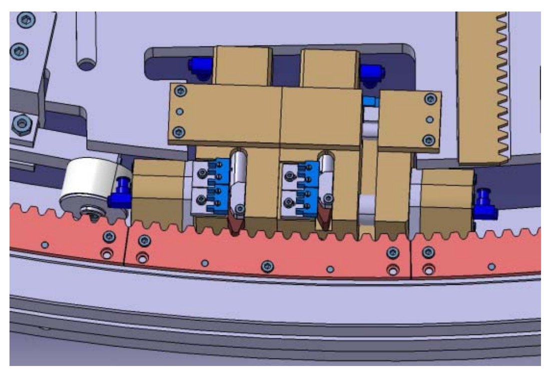

Figure 1: Azimuthal indexation mechanism

For the radial movement, we adopted a rack rail moved by a gear wheel and a stepping motor. The shuttle carrying the Hall probe is fixed to this rail. Figure 2 presents the rack rail and the shuttle

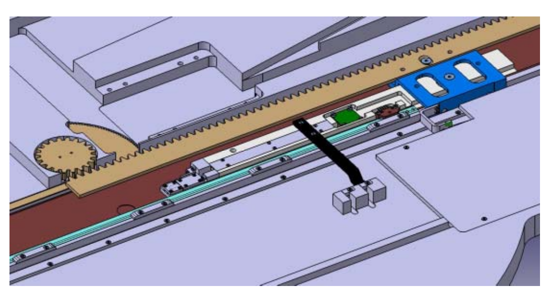

Figure 2: The rack rail and the shuttle

Control

For controlling the system we use an industrial PC connected to a PLC and a digital multimeter through a TCP/IP link. The operating system is Linux, so we can take advantage of all the native remote access procedures. We use a self-made C++ program to operate the mapping.

Measuring chain

The measuring chain consists of:

- a BHT-910 Hall probe [1]
- a PT100 temperature sensor
- a self designed multichannel pre-amplifier board with an embedded multiplexer of the output signal
- a Keithley 2700 dvm with TCP/IP link [2]
- PLC analogical inputs for low accuracy measurements like the yoke temperature [3]

Mapping scheme

We use the same mapping scheme as for the C230 cyclotron. A radial track starts some centimetre ahead of the cyclotron centre. The central region is scanned with high radial resolution. After the central region is passed, the radial step is increased in the region where the radial field derivative is small. Close to the radial pole edge the step is reduced again in order to precisely determine the extraction region. Then the table is moved by an angle of typically 2 degrees and the previously described radial track is repeated.

A higher angle resolution may be required in regions of strong field variation.

A full map consists of 390 degree, so the 30 overlapping degrees can be used to check the consistency of the measurements.

HALL PROBE CALIBRATION

The main issue in the Hall probe calibration process is to be able to de-correlate the Hall probe field response and the Hall probe temperature dependency.

Therefore a Hall probe calibration campaign starts by installing a field regulation loop on the calibration magnet. This loop consists of a NMR probe and a PC based regulation of the coil current. With such a regulation loop we can achieve a constant 2 T field to better than 0.2 G, independent of the magnet temperature. In order to obtain the Hall probe temperature coefficient we then heat the shuttle head to about 50°C and record the Hall voltage during the cooling down.

The following equations show how to convert Hall probe voltage to magnetic field taking into account the Hall probe temperature coefficient.

$$B = C_n \cdot V_h(T)^n + \cdots + C_1 \cdot V_h(T)^1 + C_0 \qquad (1)$$

$$V_h(T) = V_{h-meas} \cdot [1 - \alpha \cdot (T - T_0)] \qquad (2)$$

with $\frac{dB}{dT} = 0$, α becomes :

$$\alpha = \frac{-\frac{\partial V_h(T)}{\partial T}}{V_h(T) + (T - T_0) \cdot \frac{\partial V_h(T)}{\partial T}} \qquad (3)$$

The temperature coefficient of the C70 Hall probe is found to be -2.3 10^{-5} V/°C, which happens to be a particularly small value. The temperature variation during a full map is not more than a few degrees, so voltage corrections due to temperature variations are small.

FIRST MAP RESULT

The first C70 mapping results is displayed in figure 3.

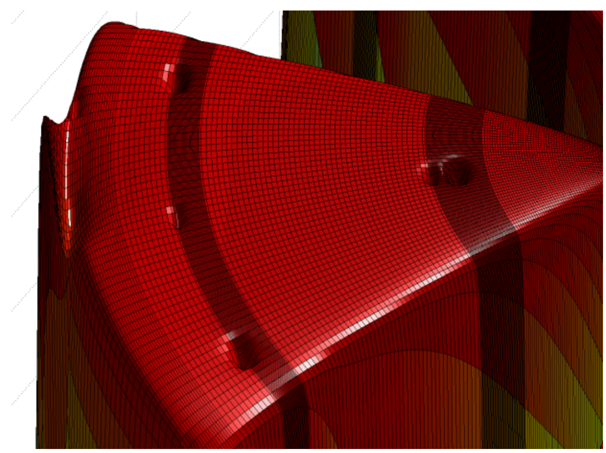

Figure 3: First field map in the C70 cyclotron

Besides the obvious numerical field results this map clearly pointed to defects of the machine located at each cover fixation screw of the so called cover [4]. This can be directly seen on figure 3. The resolution of this problem is on the way.

To explore the symmetry errors in the machine, it is common to compute the difference map between the measured field and the average field. As an example figure 4 shows such map in the case of an evident error on the pole in the first quadrant. This is due to a local mechanical error in the gap height of the order a few tenths of a millimetre. It is cured by individually adjusting the spacers between the cover and the sector [5].

CONCLUSION

The mapping system is found to behave fully adequately for the isochronisation of the C70 cyclotron. Its mechanical reliability is now brought to a satisfactory level, and the reproducibility of the measurements is remarkable.

At the date of writing the first pass of the pole edge cutting is completed and the results compare very favourably with the model calculations [4]. This will allow us to complete the full isochronisation within a few iterations more.

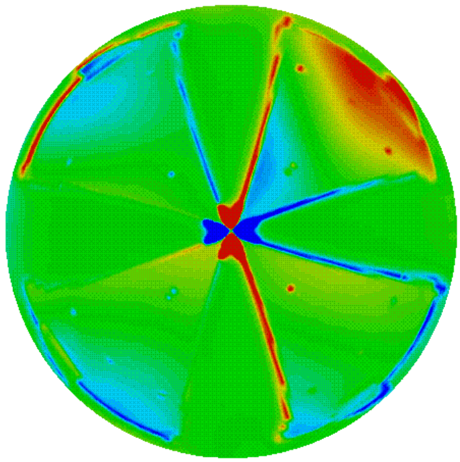

Figure 4: Difference map between the measured field and the average field

REFERENCES

[1] Sypris, http://www.sypris.com

[2] Keithley, http://www.keithley.com/

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[4] S. Zaremba et al., "Magnetic Field Design and Calculation for the IBA C70 Cyclotron", these Proceedings.

[5] W. Beeckman et al., "Machining and Assembly of the IBA C70 Cyclotron Magnet", these Proceedings.