Mapping of the new IBA superconducting synchrocyclotron (S2C2) for proton therapy

J. Van de Walle#, W. Kleeven, C. L'Abbate, Y. Paradis, IBA, Louvain-la-Neuve, Belgium

INTRODUCTION

The newly developed superconducting synchro-cyclotron (S2C2) is the first non-isochronous and superconducting cyclotron build at IBA. It's compact size (2m diameter) is crucial to reduce the footprint and overall cost of existing proton therapy solutions. The compact single room proton therapy system called Proteus® ONE aims at making proton therapy available to more people at a reduced cost and with less impact on building and infrastructure. The S2C2 will be the drive accelerator for the compact proton therapy solution.

MAPPING WHEEL

➢ Magnetic probes

In the center of the S2C2, the homogeneity of the field is good enough to use a NMR probe (Metrolab) to measure the 5.72 T center field with good precision. The probes used to measure the magnetic field as function of azimuth and radius are a Hall probe (Arepoc s.r.o., LHP-NP) and a search coil (MagnetPhysik, FS 2800 W). The search coil is preferred in terms of reduced mapping time and linearity.

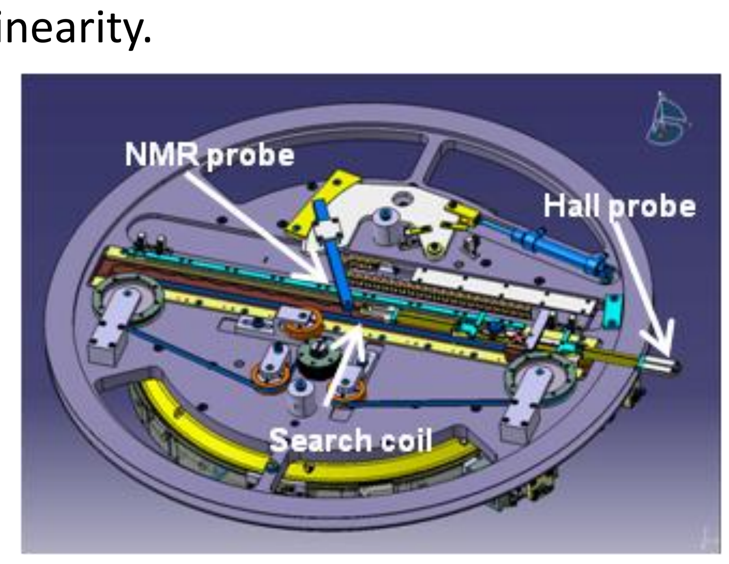

Figure 1: the mapping system

➢ Mechanics

In Figure 1, the mechanical layout of the S2C2 mapping wheel is shown. The three magnetic probes are indicated in the picture. The radial movement of the shuttle holding the Hall probe and the search coil is controlled by a motor and an optical ruler with a radial pitch of 50 mm is used to measure the radial position of the probe.

➢ Integrator

The voltage induced in the search coil is integrated with a Metrolab PDI5025. The integration limits are defined by the optical ruler. The dimensions of the search coil were chosen carefully to minimize the effects from the finite size of the coil, as described in [1]. The magnetic field at any radius r is given by

$$B(r) - B_0 = \int_{t_1}^{t_2} (V - V_{offset})/A_{eff}\,.dt$$

were the offset voltage V_{offset} is measured prior to each radial track. It typically fluctuates about 25 mV during a complete mapping (maximum 24h), which would contribute an artifical 8 Gauss taken into account the effective surface of 0.3 m^2, a speed of 6 cm/s for the search coil and a total track length of about 50 cm.

[1] M.D. Thomason, Cylindrical Point Coils for Magnetic Field Mapping; Los Alamos Informal Report LA-5304-M, 1973

e-mail : jarno.vandewalle@iba-group.com

RESULTS

➢ Average magnetic field

The measured average field inside the S2C2 is shown in Figure 2 with the red line. The dashed black line is the average field as calculated in OPERA3D and the green dotted line represents the pure coil field. The deviation between the measured and the calculated average field is given in the right scale and is below 0.5%. At the extraction radius of about 50 cm, the coil contributes about 80% of the total vertical magnetic field in the median plane.

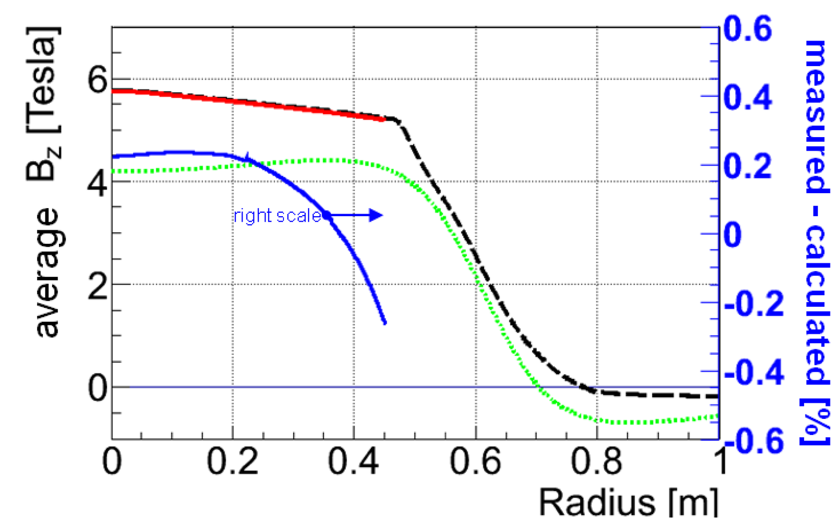

Figure 2: Average field in the S2C2. Red full line= measured, black dashed line= calculated with OPERA3D, green dotted line= calculated pure coil field, blue full line (right scale)= deviation between measured and calculated average field.

➢ First harmonics and tune functions

The first harmonic component is plotted in Figure 3 (top). The full red line is the first harmonic measured with a main coil which was slightly displaced in the horizontal direction. The corresponding tune functions for this configuration are plotted in Figure 3 (bottom, red lines). It can be seen that in this configuration, the Walkinshaw resonance at $Q_H=2Q_V$ is crossed. By shifting the main coil by about 3 mm the first harmonic and tune functions shown in Figure 2 with the full black line were obtained. The first harmonic corresponds better to the calculated first harmonic, which is shown with the dashed line in Figure 3 (top). At the same time the resonance is avoided and the tune functions correspond better to the design tune functions (dashed lines in Figure 3 (bottom)). This illustrates the importance of the main coil position and its influence on beam extraction and dynamics.

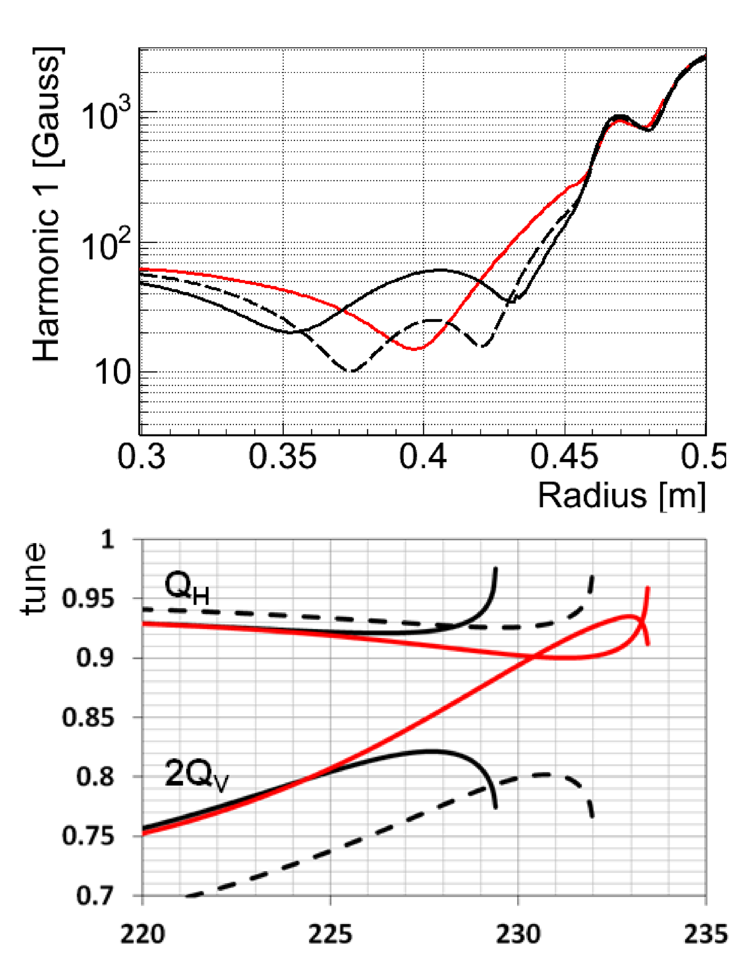

Figure 3: (top) First harmonic component and (bottom) tune functions: red full line= measured with a slightly horizontally displaced main coil, black full line= measured with a horizontally centered main coil, black dashed line= from the calculated OPERA3D field map.

➢ Median plane errors and coil forces

Radial fields in the median plane (median plane errors) are extremely difficult to measure directly. Two major sources for median plane errors were identified in OPERA3D: the iron asymmetries around the machine and the vertical position of the main coil. The former can be corrected for by applying shims on the return yoke of the S2C2. Calculated radial fields are shown in Figure 4 (top) with and without shims on the top yoke. The shims as they have been implemented in OPERA3D and on the S2C2 are shown in Figure 6. In Figure 4 (bottom), the vertical force on the main coil is shown as a function of main coil current for the same configurations (with and without shims). This shows that minimization of the total force at nominal current reduces at the same time the average radial fields in the median plane to less than 1 Gauss.

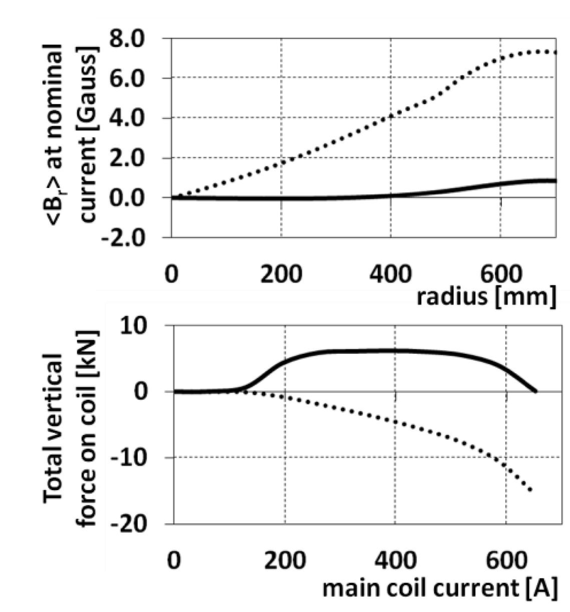

Figure 4: (top) calculated average radial fields in the S2C2 with (full line) and without (dotted line) shims on the top yoke. (bottom) calculated total vertical force on the main coil with and without shims.

Figure 5 shows the evolution of the total vertical force on the main coil as it was measured during commissioning of the machine. The dotted line is the initial vertical force at first ramp-up of the coil. The dashed line is the total force after the coil has been moved by 2 mm and the full line is the total force after full shimming of the S2C2. This shows that the total force has been reduced to almost zero at nominal current by applying shims on the S2C2 and by accurate vertical positioning of the main coil.

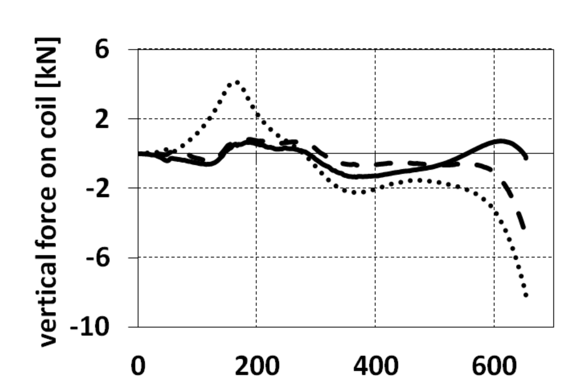

Figure 5: Measured total vertical force on the main coil. Dotted line= during the initial ramp-up, dashed line= after vertical positioning of the main coil and full line= after application of all shims on the top yoke.

Figure 6: (left) shims applied on the S2C2 (may 2013) (right) OPERA3D model of the S2C2 with all shims included on the top yoke.

CONCLUSION

The mapping of the S2C2 has been successfully finalized at IBA. It was found that the positioning of the main coil is a crucial parameter in the fine-tuning of the beam dynamics. Further commissioning of sub-systems and beam tests are scheduled for the coming months.