Developments on the S2C2 mapping system

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INTRODUCTION

The new IBA Proteus One will be equipped with the newly developed Super Conducting Synchro-Cyclotron. Contrary to other IBA accelerators, this accelerator utilizes a superconducting coil and is the first non-isochronous cyclotron. The much higher magnetic field (5.8 T) in the S2C2 should be measured at a relative precision of 10^{-3}-10^{-4}. A search coil has been foreseen as magnetic probe. Preliminary tests with this search coil have been performed both in a calibration magnet and in the S2C2, equipped with resistive coils.

MAPPING WHEEL

Mechanics

In Figure 1, the mechanical layout of the S2C2 mapping wheel is shown. The three magnetic probes are indicated in the picture.

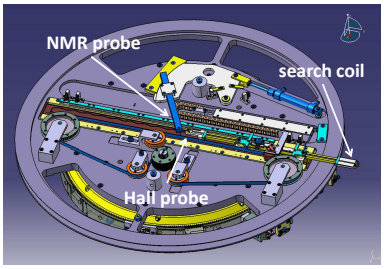

Fig. 1 : Layout of the S2C2 mapping wheel.

The radial movement of the shuttle holding the Hall probe and the search coil is controlled by a motor and the angular movement of the wheel is performed with a pneumatic system.

Magnetic probes

In the center of the S2C2, the homogeneity of the field is suitable to use a NMR probe. The accurate field value in the center will be used as reference for the integrated voltage from the search coil.

Integrator

The search coil is connected to an integrator (PDI5025, Metrolab) which integrates the induced voltage in the moving search coil between two positions, determined by a linear optical encoder. The integration points are 0.05 mm apart. The magnetic field is obtained from

$$\Delta B.A_{eff} = \int_{t_1}^{t_2} V.dt \qquad (1)$$

where t_1 and t_2 are determined by the optical encoder.

SEARCH COIL CALIBRATION

The effective surface of the search coil was calibrated by rotating the search coil in static homogeneous magnetic fields in the range 1 to 2 T. The effective surface was determined at several temperatures (also taking into account the changing coil resistance). The temperature coefficient is 13 ppm/°C. The effective surface at 20°C was determined to be 0.30433(3) m^2 (error = 94 ppm).

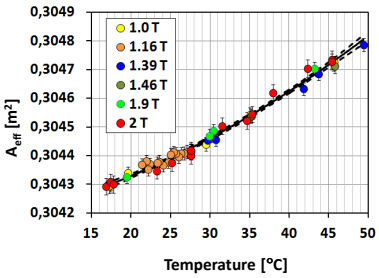

Fig. 2 : Measured effective surface of the search coil as a function of temperature.

Sources of error

Finite size effects

The search coil has an outer radius of 4.95 mm, an inner radius of 1.35 mm and a height of 7.5 mm. Due to these dimensions, the magnetic field in the center of the search coil is not simply linked to the integrated induced voltage according to Eq. (1), but additional correction terms are needed. The dominant correction term incorporates the dimensions of the search coil and the second derivative of the magnetic field in the median plane. This correction term can be derived by a series expansion of the magnetic field around the center of the coil and is described in Reference [1]. Formally this is expressed as :

$$\Delta\phi_i = A_{eff}.\Delta B + A_{eff}.\alpha.\left(B^{(2)}_{x,i}\Big|_c + B^{(2)}_{y,i}\Big|_c\right) \qquad (2)$$

where $\Delta\phi_i$ is the total integrated flux difference between the center of the S2C2 and point "i", A_{eff} is the effective surface, ΔB is the magnetic field difference between the center of the S2C2 and point "i", α is a geometric factor which is determined theoretically and $B^{(2)}$ are the second derivatives to R and Rdθ of the measured magnetic field, evaluated in the center of the coil.

Integrator offset drift

The voltage offset on the integrator input can be minimized manually at the start of the mapping procedure. Temperature fluctuations cause the voltage to fluctuate around 100 µV over a period of 24h. Accumulated over 1000 integration intervals of 1 ms (1 radial track) this might contribute an "artificial" 3 Gauss to the magnetic field at the end of a 24h mapping period.

Search coil centering in the median plane

The error due to a potential misalignment of the search coil with respect to the median plane (center of the coil below or above) was calculated to be around 1 Gauss/mm.

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

MEASUREMENT SEQUENCE

- ✓ NMR measurement in the center of the S2C2 (10")
- ✓ Offset measurement (10") - stationary coil
- ✓ Data transfer (25")
- ✓ Radial track (trigger interval = 500 µm - max. 50 cm/s) from the center to the outer radius (5")
- ✓ Data transfer (25")
- ✓ Radial track from the outer radius to the center (5")
- ✓ Data transfer (25")
- ✓ Azimuthal rotation

Mapping time (360 degrees) ≈ 11 hours

MEASUREMENTS IN THE S2C2

A first measurement was made in the S2C2 which was equipped with resistive coils, yielding a central field of 0.82 T and a maximum field of 1.12 T. Radial tracks were measured with a Hall probe and the search coil. The measured profiles and their difference is shown in Figure 3 and 4 below. In Figure 3 also the calculated field profile, obtained with OPERA2D is shown.

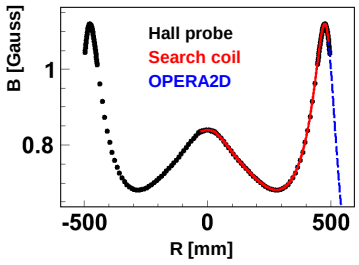

Fig. 3 : Measured magnetic field profile at fixed azimuth in the S2C2, equiped with resistive coils (0.5 A.turns). (Black) Hall probe (Red) Search Coil (Blue) OPERA2D calculation.

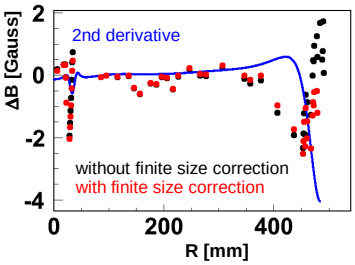

Fig. 4 : Difference between field values measured with the Hall probe and the search coil. Without (Black dots) and with (Red dots) "finite size" corrections (i.e. involving the second derivative - shown in Blue).

CONCLUSION

Theoretical and experimental investigations have been performed at IBA to allow a reliable and accurate usage of a search coil during the magnetic mapping of the S2C2 in the coarse of 2012.