MACHINING AND ASSEMBLY OF THE IBA C70 CYCLOTRON MAGNET

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Abstract

Presently IBA designs and produces a 70 MeV cyclotron for radiochemistry and nuclear medicine (C70) [1]. The structure of the magnet reflects the need for isochronous magnetic fields able to accelerate ions with charge to mass ratio q/m=1 (H^-) as well as ½ (D^-,$^4He^{2+}$, H_2^+). The hills are split in 3 parts parallel to the median plane, correction coils being wound around the central parts with very tight tolerances. The whole machining and assembly process is tailored to ensure final gap values, parallelism and flatness to the tolerances required by the magnetic field for both particle types.

INTRODUCTION

The C70 cyclotron geometry reflects the magnetic design described in [2]. The accuracy of the magnetic field in an isochronous cyclotron is of topmost importance, regarding both the need for an as small as possible integrated phase shift and the control of the vertical betatronic frequency. The split structure of the hills required by the location of the correction coils imposes very tight assembly tolerances and the need to design strategies to cope for machining errors or accidents that could happen with that many pieces. The magnetic quality of the steel used is also discussed.

DESCRIPTION OF THE MACHINE

The machine is assembled out of 2 large (1920 mm diameter, 450 mm thickness) disks called *yokes*, 32 pieces with "metric" dimensions i.e. *returns, sectors, poles* and *covers* and about 30 smaller parts, mainly *central plugs* and *pole inserts*. The yokes have 520 mm diameter holes for pumping in 2 valleys and for RF in the 2 others.

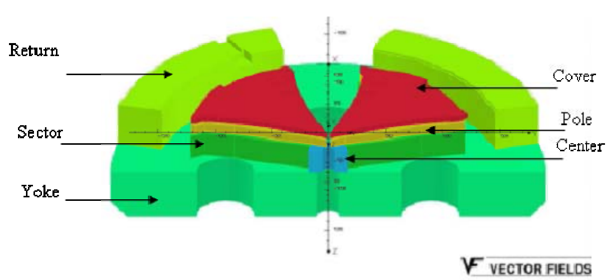

Figure 1: Main parts of C70

The yokes have been cast by Kelin in China and the other parts by Dillinger Huette in Germany. In both cases, the foundry measured the magnetization curves and an independent measurement was made by the certification laboratory of the University of Sunderland in England. Kelin's data are ways too optimistic (almost as good as the top quality C235 steel) compared to Sunderland's while Dillinger compares rather well with the independent measurement. All measured B-H curves are significantly better than standard steel used for IBA PET cyclotrons ("tenten" in Fig 2, C1010 steel). While initial calculations were performed with the standard BH curves ("fish" in Fig 2), measured data were used once available.

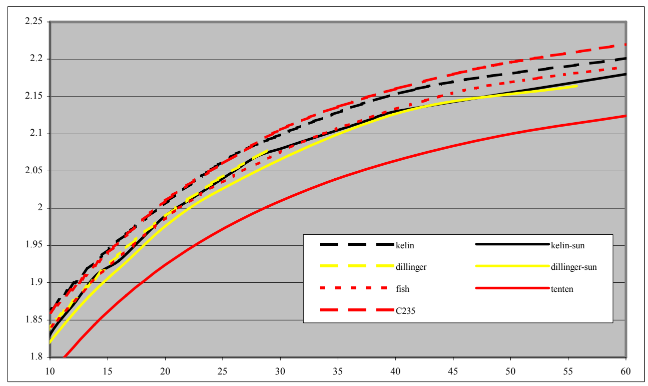

Figure 2: B[T] vs H[kA/m] for different steels. Red are reference steels (not C70), black are yokes (Kelin) and yellow are other parts (Dillinger)

As the most important requirement is the constance of the magnetic gap, everything is made to guarantee it and most parts are machined with a couple of hundreds of mm accuracy. Spacers are used to calibrate the gap between sectors and poles and between poles and covers. They are the last parts to be machined to their final dimension after full assembly and measurements of the different gaps.

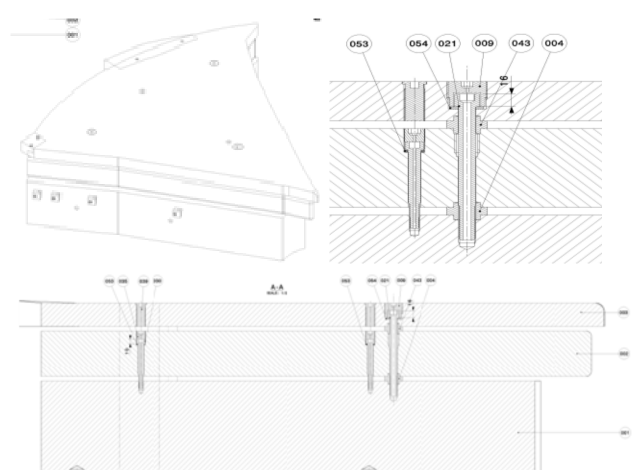

Figure 3: 3D view, lateral cut and detail showing the assembly of sectors, poles and covers with spacers

CORRECTION COILS

Principle

The transition from isochronous magnetic fields for q/m=1 to q/m= ½ is performed by correction coils wrapped around the poles. The machine is made isochronous for protons by design and iron shimming. Coils create a gradient that superimposes to the main field to decrease it at high radii and enhance it at low radii. Reducing the main field finally isochronizes for alphas.

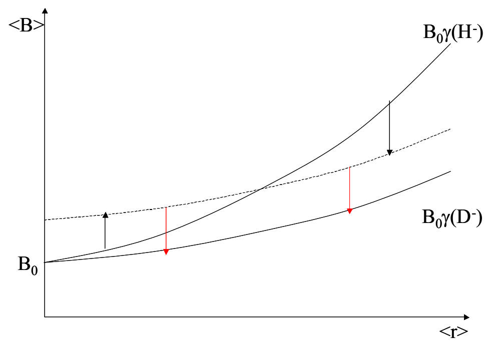

Figure 4: Schematics of the transition from q/m=1 to q/m=1/2 isochronous field.

The coils generate an inwards radial field in the lower pole and an outwards radial field in the upper pole. The magnetic circuit closes through a vertical field in the magnetic gap, which adds up to, or subtract itself from, the main vertical field created by the main coils.

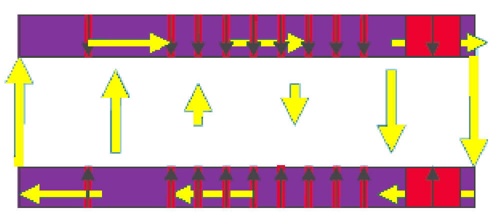

Figure 5: Schematics of the correction coil magnetic circuit. Large radii are towards the right of the drawing. Black arrows indicated the current flow in the coils. Yellow arrows show the magnetic flux from the coils. The main field is not shown.

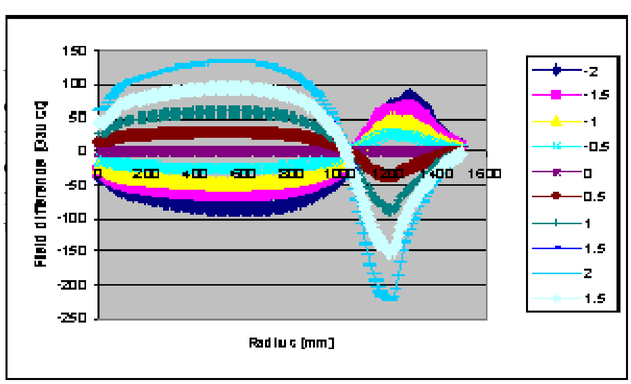

Figure 6: Coil B3 response as a function of radius for different current densities showing non linearities

Construction

The coil is designed and constructed by Sigmaphi in Vannes, France. It is designed to be self-supporting. 2 thin aluminium plates are grooved to hold the conductors in their location. The plates are then assembled to form a rigid hollow body around which the kapton insulated conductors are wrapped. The whole assembly is slid on the pole, in a "sock-like" manner. Due to the small gaps between the pole and sector and the pole and cover, the coil is submitted to very tight construction tolerances.

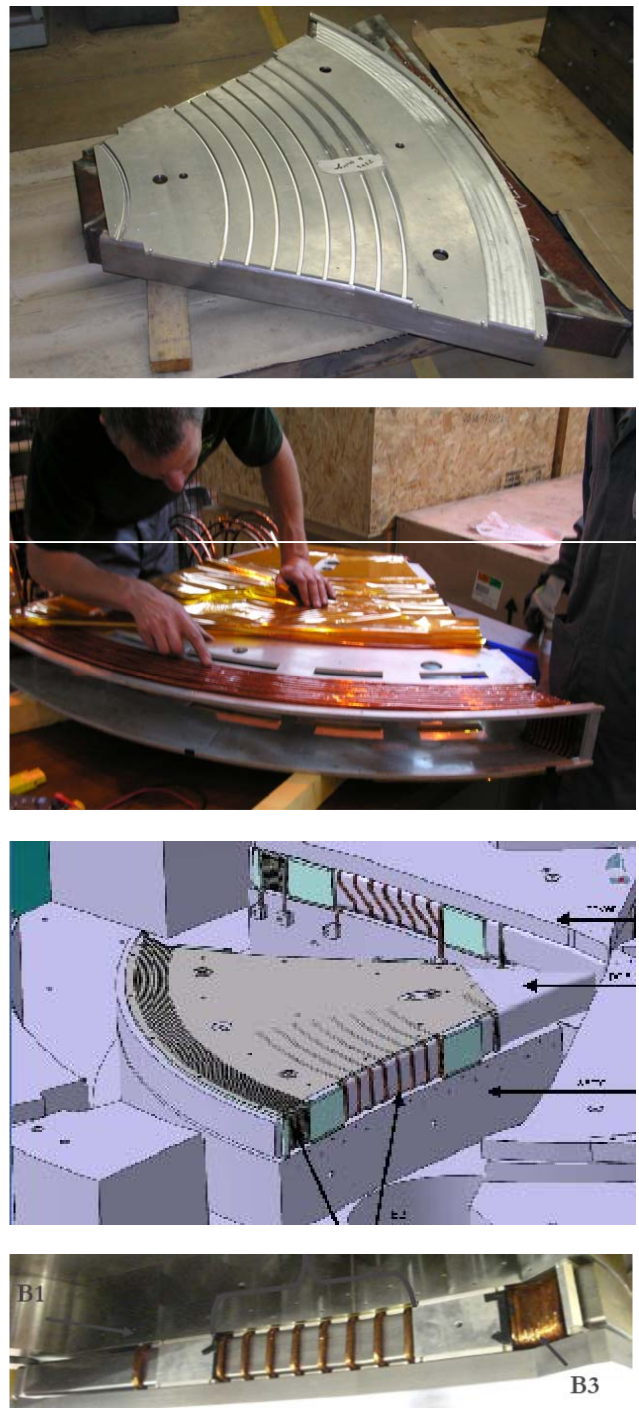

Figure 7: Different steps of construction of the correction coils and their installation in the machine

MACHINE CONSTRUCTION

The machining was done by Pégard in Andenne, Belgium and by CMP in Seraing, Belgium.

Whenever possible, the work was performed in parallel between the 2 subcontractors. Most of the milling was done by Pégard. Lathe machining and assembly was made by CMP. During the whole process, special attention was paid to vertical dimensions in order to ensure the very tight final tolerances on the magnetic gap, resulting in very small differences (< 0.3 mm) in the final dimensions of the spacers.

Figure 8: Cast returns are installed on the yoke to machine all cyclindrical surfaces on a 5m lathe

Figure 9: Indermediate assembly is performed at various stages of machining to ensure final assembly tolerances.

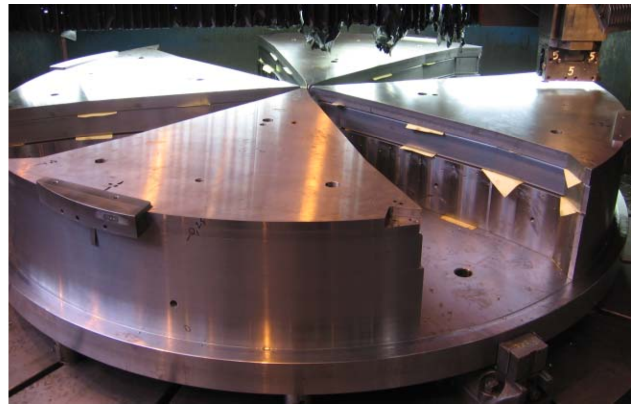

Figure 10: Extraction extensions are assembled for lathe milling

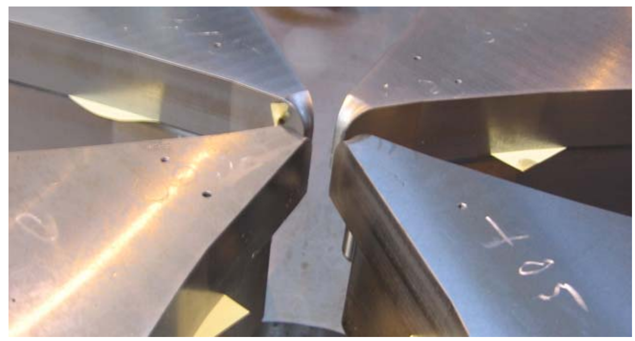

Figure 11: The cover tips at center are very accurately machined to tailor the central field for injection.

REFERENCES

[1] L. Medeiros-Romao et al. "IBA C70 Cyclotron Development", these proceedings

[2] S.Zaremba et al. "Magnetic Field Design and Calculation for the IBA C70 Cyclotron", hhese proceedings