MAGNETIC PROCEDURES FOR THE ASSEMBLY OF SUPERCONDUCTING COILS AT THE MILAN CYCLOTRON LABORATORY

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SUMMARY

In a superconducting cyclotron the first harmonic of the magnetic field must be kept at a few Gauss level, thus imposing very tight tolerances for the superconducting coils construction and assembling. This paper presents the calculated levels of the first and second harmonic arising by the coils dissymmetries and deformations and describes a magnetic procedure useful for centering each double pancake and each section of the coils. The results obtained with this procedure during the assembly of the main coils for the Milan Superconducting Cyclotron are presented.

INTRODUCTION

The single turn extraction of the lightest ions ($Z/A = 0.3 - 0.5$) at the maximum energy ($T/A = 60 - 100$ MeV/n) from the Milan Superconducting Cyclotron requires, at the extraction radius, a first harmonic in the magnetic field of suitable amplitude ($C_{1z} = 1 - 5$ Gauss) and suitable phase ($\Phi_{1z} = 240° - 300°$) [1,2].

Therefore the first harmonic arising by dissymmetries in the poles, yoke and coils must be limited to a few Gauss (tipically 5 - 10 G) to assure reasonable operating conditions for the harmonic coils [3,4].

The components of the first harmonic yielded by the magnetic channels and by the yoke holes are counterbalanced respectively by iron bars disposed in the magnet gap [2] and by other two holes in the median plane of the yoke [5].

The first harmonic component produced by the poles dissymmetries and the remaining component derived by the above-mentioned compensations will be corrected, during the magnetic field measurements, by iron shims screwed in the valleys.

The first harmonic given by the superconducting coils is dependent by the current level therefore it cannot be counterbalanced by iron shims but it must be corrected almost fully during the coils assembling.

This paper presents the criteria used during the coils assembling and the results obtained in minimizing the first and second harmonic yielded by lack of cylindrical symmetry in the Milan superconducting coils.

STRUCTURE AND DISSYMMETRIES OF THE SUPERCONDUCTING COILS

The structure of the Milan superconducting coils is described elsewhere [6], here we recall only the features and the parameters indispensable for the understanding of this paper.

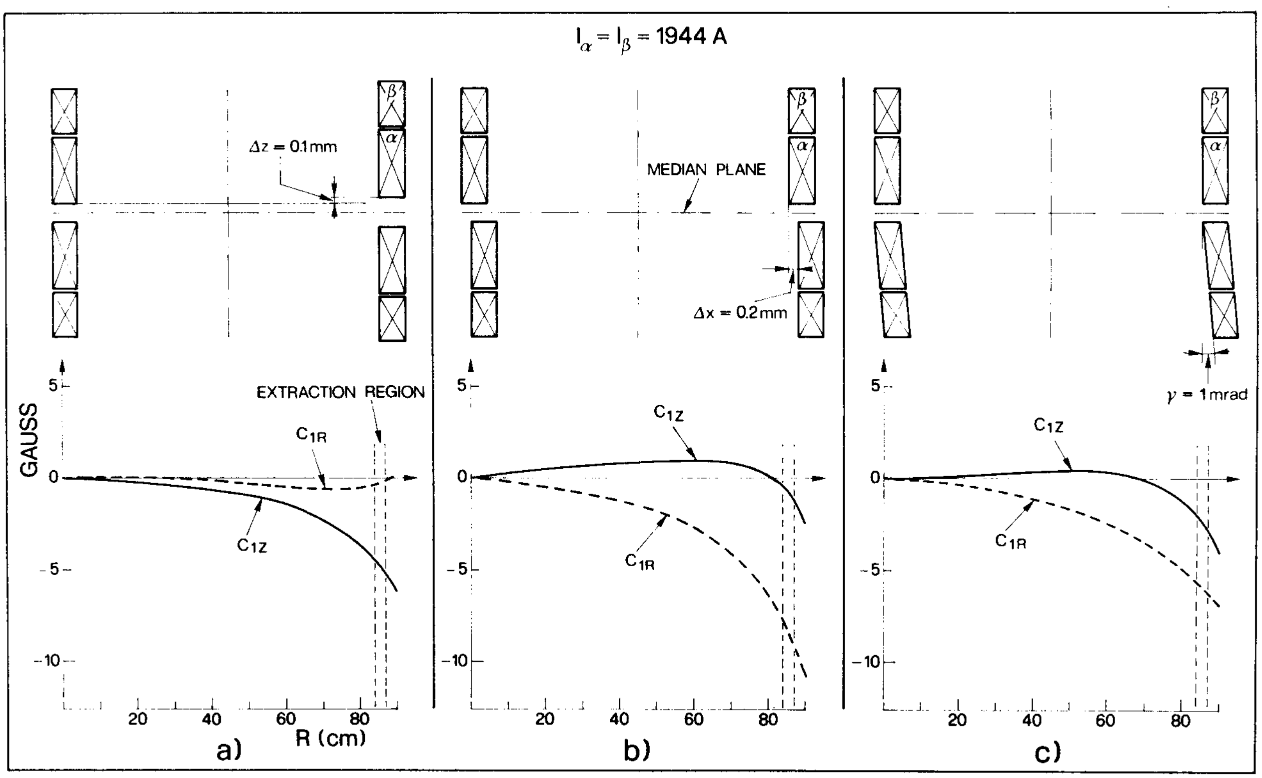

Fig.1 - First harmonic for the axial and radial magnetic field components arising by structure dissymmetries. The negative values of the harmonic means a change of 180° in its phase.

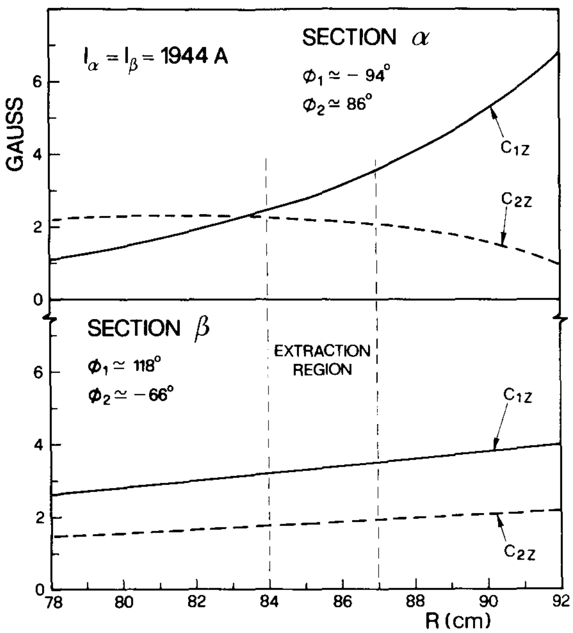

Fig.2 - First and second harmonic arising by intrinsic defects for the α and β sections.

The coils are splitted into two sections (in the following called α and β sections) made respectively by 26 and 18 double pancakes. The operating currents for the α sections are ranging from 800 A to 1944 A, whereas the β section currents cover the range - 830 A - 1944 A. The main parameters of each double pancake are listed in the Table I.

TABLE I

Internal radius (293 °K)	1.000 m
External radius (293 °K)	1.165 m
Turns number	38 x 2
Matrix dimension	13.0 x 3.5 mm^2
Resistance (293 °K)	0.207 Ω
Inductance	17 mH

The lack of cylindrical symmetry follows by inaccuracy in the cryostat machining or double pancakes assembling (structure dissymmetries), by intrinsic defects in the double pancakes (turn to turn jumps, pancake climbs and pancake ends) and by construction defects (deviation from the circularity).

Some important structure dissymmetries in the Milan superconducting coils and the resulting first harmonic for the axial and radial magnetic field components are shown in Fig.1. From these data one draws very stringent tolerances in the azimuthal distribution of the height of the coils gap (Fig.1a) and in the upper-lower coils centering (Fig.1b).

The intrinsic defects in each double pancake are constant and known a priori, for these reason their contributions to the first and second harmonic have been calculated and the results for the α and β sections are reported in Fig.2. The maximum first harmonic in the extraction region (R = 84 - 86.5 cm) is about 3.5 Gauss when the α and β sections are supplied respectively at I_α = 1660 A and I_β = - 830 A (acceleration of the lightest ions at the maximum energy).

The construction defects have been measured with the apparatus shown schematically in Fig.3. Some typical distributions of the deformations measured in the Milan double pancakes are presented in the same figure. The differences between the maximum and minimum radius and the mean radius for the upper and the lower layer

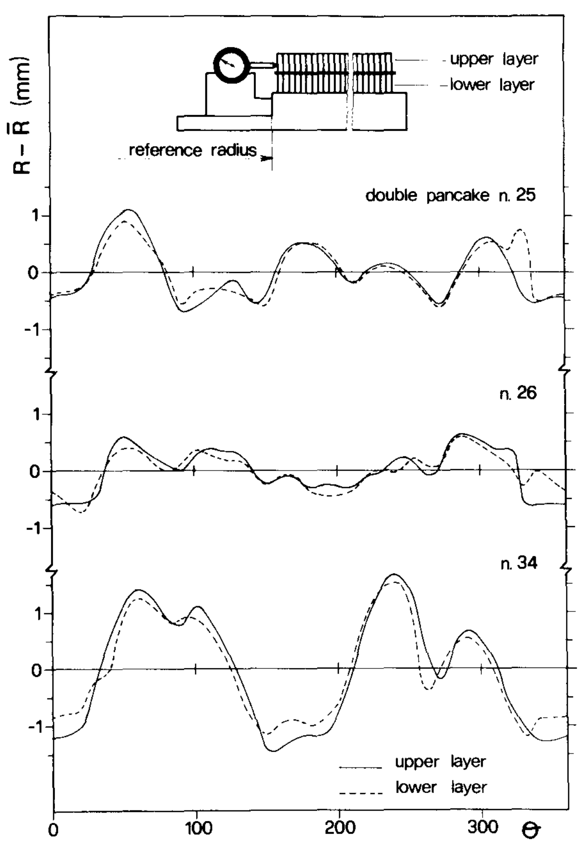

Fig.3 - Sketch of the apparatus measuring the azimuthal deformations of the double pancakes and typical deformation distributions.

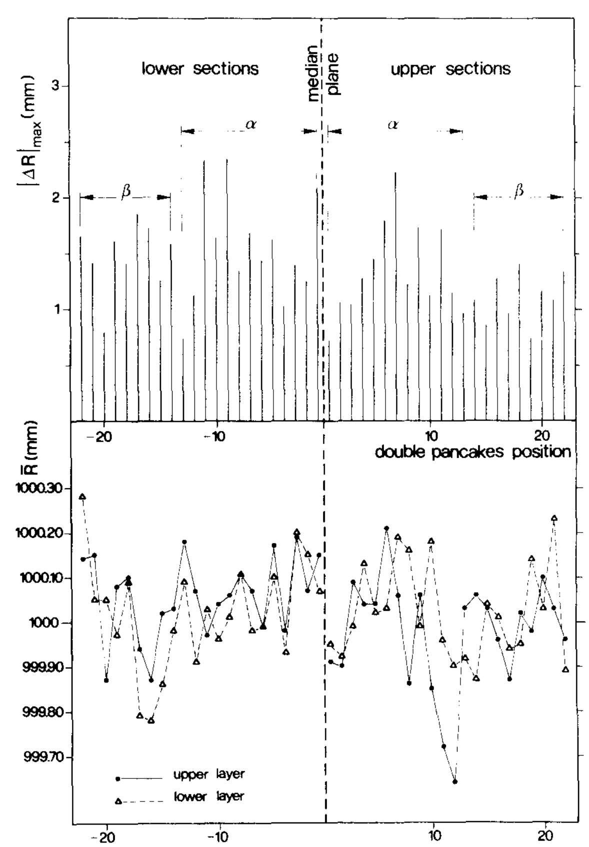

Fig.4 - Differences between the maximum and minimum radius and mean radius for the 44 double pancakes.

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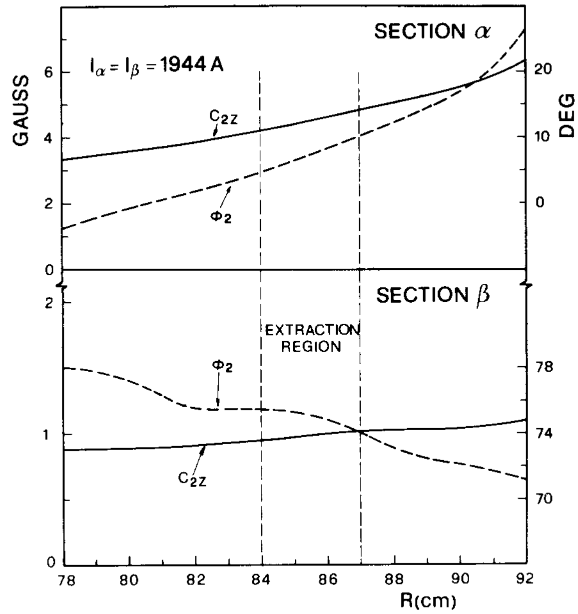

Fig.5 - Second harmonic and its phase arising by the measured deformations in the double pancakes of the α and β sections.

of the 44 double pancakes, as measured just after the winding, are presented in Fig.4, according to the sequence adopted in the coils assembling.

The armonic contribution of these deformations depends by the method used to assemble the double pancakes: in particular if they are centered by annulling the first harmonic, the deformations contribute only to the second harmonic. The Fig.5 shows the second harmonic given by the above-mentioned deformations, supposing a nul-first harmonic centering.

Considering the lack of stiffness of the double pancakes during the transport and assembling operations and the need of a control of the first harmonic resulting by the assembled coils, we have chosen a magnetic method instead of a mechanical one, to realize the nul-first harmonic centering.

MAGNETIC CENTERING OF THE DOUBLE PANCAKES

The method requires the measurement of the magnetic field given by each double pancake in its median plane, the Fourier analysis to determine the first harmonic and its phase and the double pancake displacement necessary to compensate this harmonic.

The apparatus for the magnetic measurements, sketched in Fig.6, consists essentially of a rotating arm, supporting at the radius R = 92 cm a flip coil connected with a linear integrator[7] (sensitivity 16.9 mV/Gauss). The arm can be positioned in the median plane of the double pancake and rotates azimuthally by means of a stepping motor; the flip coil rotation is obtained pneumatically. The axis of the arm is positioned in respect to the cryostat axis with a precision of ± 0.05 mm and its verticality is kept within ± 0.1 mrad.

For the magnetic measurements the double pancake is supplied with a current of 30 A, the mean magnetic field at R = 92 cm is about 39.3 G (comprehensive of the earth magnetic field) and its radial gradient is 0.27 G/mm. The operations for the double pancake centering consist in:

a) a rough mechanical centering (± 1 mm) and blocking of the double pancake with 8 screws at 45°;
b) the magnetic field measurement in the median plane of the double pancake with a 10° or 20° azimuthal steps;

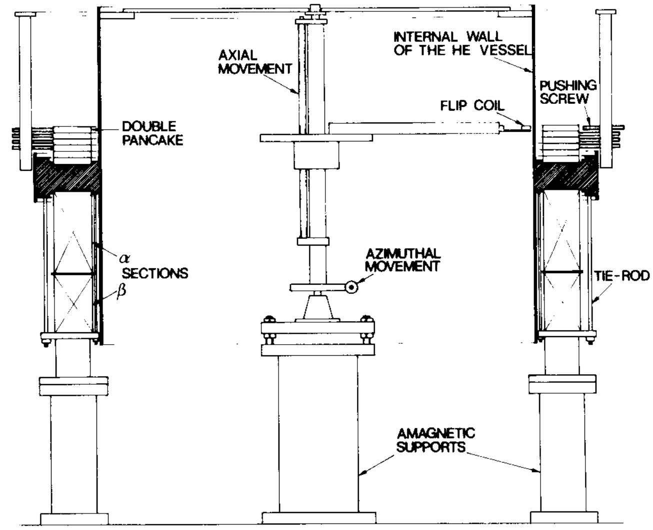

Fig.6 - Sketch of the apparatus for the magnetic centering of the double pancakes.

c) the Fourier analysis with a microcomputer of the magnetic map to determine the displacement and the deformation carrying out on the double pancake to compensate the first and second harmonic;
d) displacement and deformation of the double pancake, unloaded by its weight, using the 8 screw;
e) control of the first and second harmonic and repetition of the operations c), d), e) until the first harmonic in the median plane of the double pancake is lower than 0.027 Gauss (corresponding to a decentering of the magnetic axis of the double pancake in respect to the apparatus axis of 0.1 mm) and the second harmonic is lower than 0.09 Gauss (corresponding to an elliptical deformation with a maximum to minimum radius difference of 0.6 mm).

Typical magnetic field maps, obtained during the centering operations and the resulting first and se-

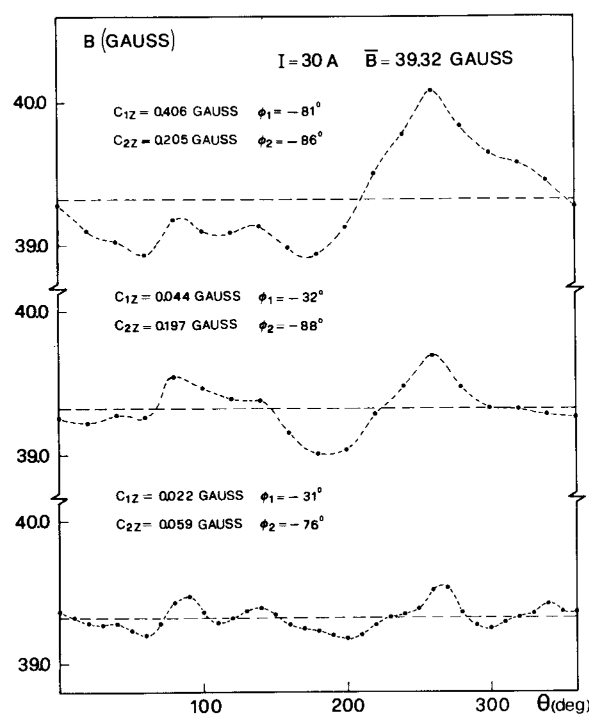

Fig.7 - Typical magnetic maps obtained at different stages of the double pancake centering.

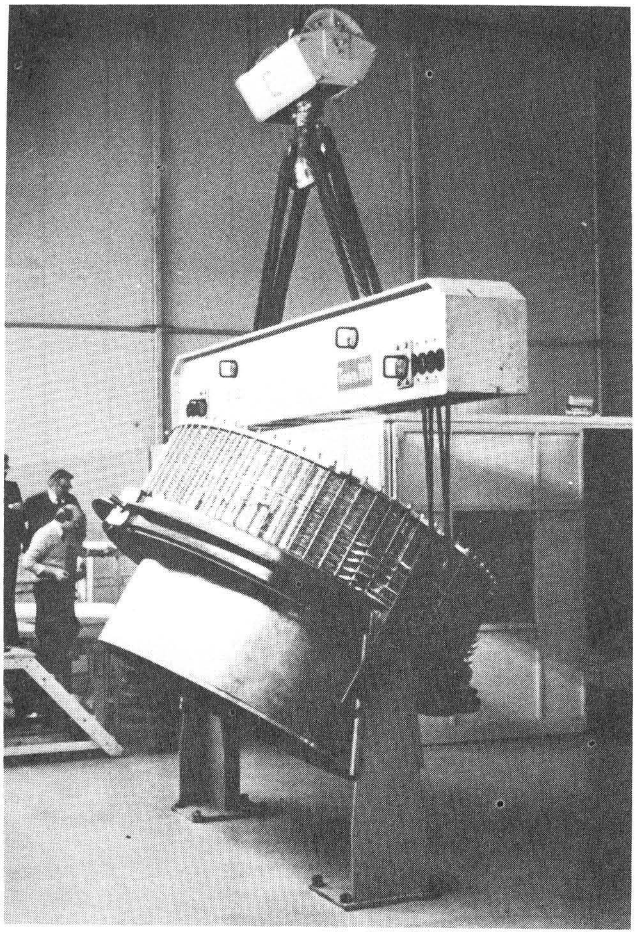

Fig.8 - Cryostat upsetting after the upper coils assembling and prestressing.

cond harmonic are shown in Fig.7. The first map has been measured after the rough mechanical positioning of the double pancake, the second after its displacement (correction of the first harmonic), the last after its suitable deformation (correction of the second harmonic).

Each magnetic field map requires about 10 minutes, the double pancake centering is obtained generally in about an hour and thirty minutes.

COILS ASSEMBLING AND RESULTS

The Milan coils assembling has been carried out in two stages:

i) upper coils centering with the apparatus axis coincident with the cryostat axis, coils prestressing at 700 tons (6) and cryostat upsetting (see Fig.8);

ii) alignment of the apparatus axis with the magnetic axis of the upper coils and centering of the lower coils, coils prestressing at 700 tons.

The coils assembling has required seven months (instead of an estimated period of three months) because they were fully disassembled two times to eliminate some turn to turn short circuits and to change several G11 separators cut during the coils prestressing in consequence of some fiberglass spacers machined outsize and unsettled prestressing of the external and internal tie rods.

The measured first and second harmonic (extrapolated at the maximum current) and their phases for the α and β sections are reported in the Fig.9.

These first harmonic levels are easily corrected by the harmonic coils of the Milan Superconducting Cyclotron, considering also they can further reduced du-

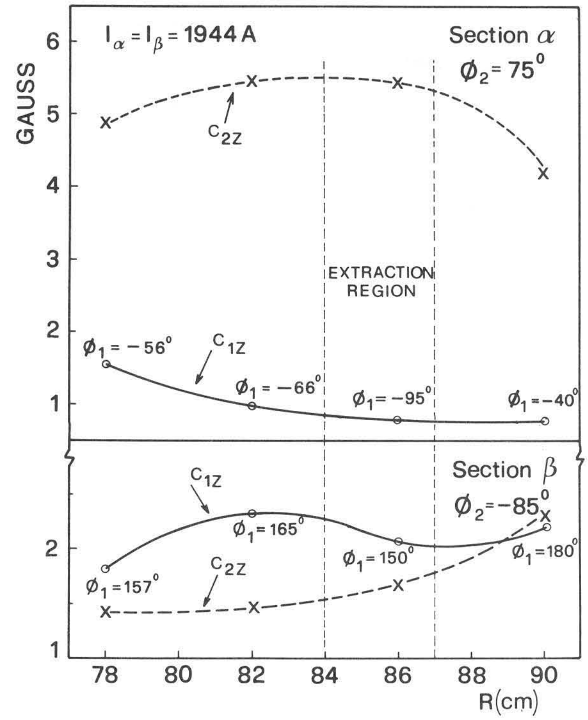

Fig.9. - Extrapolated values ($I_\alpha = I_\beta$ = 1944 A) of the first and second harmonic measured in the coils median plane.

ring the assembling in the magnet; the second harmonic and its radial derivative do not necessitate further corrections (8).

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