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A PANOFSKY-TYPE SUPERCONDUCTING QUADRUPOLE WITH A VERY HIGH GRADIENT HOMOGENEITY

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Abstract

A Panofsky type superconducting quadrupole has been designed and built to be used on a spectrometer beam line at the synchrotron Saturne II. Its main characteristics are a large rectangular aperture (39.4 x 16.4 cm^2 useful aperture), a gradient of 10 T/m on a magnetic length of 85 cm and a very high gradient homogeneity ($\int \Delta G/G \leq 3.10^{-3}$ requested in the largest part of the useful aperture), for which several improvements from the standard configuration have been necessary: coil end shape, iron shimming and possibility of overpowering some coils in the winding.

The design, the construction, the electrical tests and magnetic measurement results obtained with this quadrupole are described in this paper.

Introduction

Among several configurations which can be considered for large rectangular aperture quadrupole, the one originally described by L.N. Hand and W.K. Panofsky seems very attractive [1] . However, the importance of very accurate positioning of the conductor was shown by early models using a copper conductor: the measured gradient homogeneity was not as good as expected, due to the large size of the conductor.

This defect should be strongly reduced when using a superconducting conductor, as mentioned by H. Desportes et al. [2] · The results obtained with two magnets built at KEK have confirmed that point [3, 4] .

In our case, where the quadrupole is an element of a spectrometer beam line with a very high resolution an integral gradient homogeneity of the order of 3.10^{-3} is requested in the largest part of the aperture, over a wide current range. The following points were studied to try to get this value :

- Very accurate calculation of the 2D configuration , taking into account the exact coil distribution and not a continuous current sheet.
- End shape of the coils so as to minimize their effect on the integral gradient homogeneity.
- Shimming of the iron ends.
- Possibility of dynamic correction by adding a small current in one coil of each pole if necessary.

The magnet was tested twice at helium temperature. During the first test, a series of magnetic measurements was done, showing that some improvements were needed to fulfill the gradient homogeneity requirements. The description given here is the final one.

Magnet description

Main characteristics

The main characteristics of the quadrupole are given in Table A :

Nominal gradient	10 T/m
Nominal current	830 A
Stored energy	110 kJ
Magnetic length	85 cm
Useful aperture	39.4 x 16.4 cm^2
Coil aperture	45.2 x 22.6 cm^2
Maximum field on the conductor	2.8 T
Iron length	70 cm
Iron thickness (on each side)	13 cm
Cryostat total length	1.6 m

Table A : Magnet main characteristics

Coils

Because of the rectangular aperture and in order to get short coil ends, each pole winding has been divided into four coils the position of which has been accuratly determined. (Fig.1).

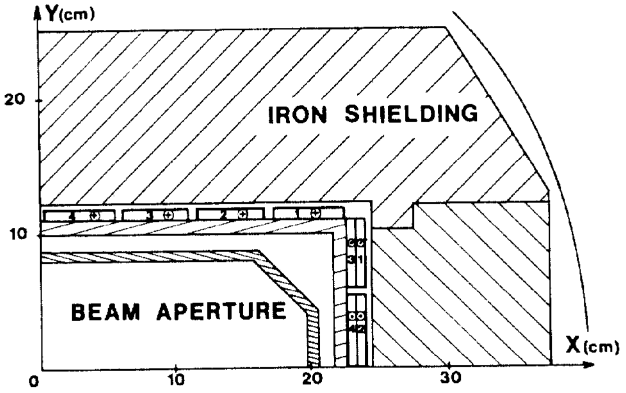

Fig.1 - Magnet cross section (1 pole).

Each coil is wound as a double pancake, with 33 turns per layer, the conductor being wound on its small edge in the body part. The main characteristics of the conductor, supplied by MCA are given in Table B :

Dimensions	2.20 x 1.31 mm^2 (bare) 2.43 x 1.54 mm^2 (insulated)
Copper to SC ratio	1.9/1
Filament	1380 x 30μ

Table B : Conductor characteristics

In the ends, the conductor is bent on a radius as small as possible to limit the fringing field. The coils are epoxy impregnated during the winding, then cured at 150°C for several hours.

Assembly

The assembly of the 16 coils is made on the inner helium wall, as accuratly as possible. Theoretical calculations show that a shift of 0.1 mm of one coil from its theoretical position gives an extra gradient inhomogeneity of 10^{-3} at the limit of the useful aperture. An epoxy impregnated fiberglass tape is then wound from place to place around the coils (Fig.2). The whole assem assembly is then cured once again then accuratly machined to fit in the iron yoke.

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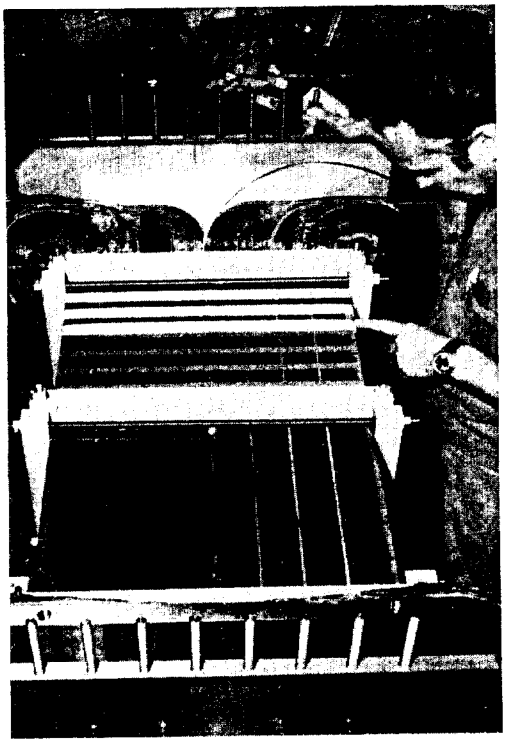

Fig.2 - Coil assembly.

Iron yoke

The cold iron yoke is made of four parts, machined from compact blocks and assembled so as to prevent gaps between the pieces. In the ends, shims have been added onto the vertical faces of the iron; for one pole, each shim consists of a wedge-shaped part and a flat plate of constant thickness (19 mm).

Connections

The connections are done in such a way as to have the possibility of supplying one coil in each pole with an extra current. (Each coil # 4). (Fig.3).

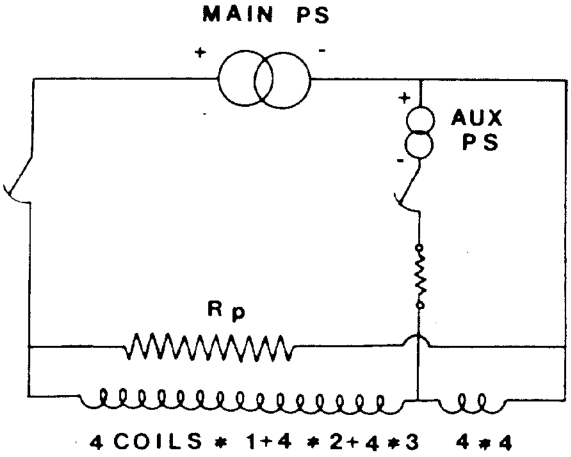

Fig.3 - The electrical circuit.

Cryostat

The cryostat is quite conventional; it uses a double wall stainless steel tank with two copper end plates as a nitrogen screen. The magnet and its shielding are supported by three fiberglass tie rods. It is equipped with two main current leads (1000 A) plus an auxiliary one (30 A) to oversupply the four coils # 4.

Tests of the magnet

Cryogenics

It takes about 1200 l LN_2 plus 500 l LHe to cool-down the magnet from 300 K to 4 K.

At the nominal current, the consumptions are 4.2 l/h LHe and 1 l/h LN_2.

Thanks to the cryopumping, the static vacuum is better than 1.10^{-7} mbar at low temperature.

Training

During the first test, the magnet reached its nominal current in four quenches; after a few other quenches, the current reached 920 A, not a maximum but a safety limit.

During the second test, the magnet showed a small retraining due to the reassembly of the coils inside the iron shielding and end wedges.

Magnetic measurements

First test magnetic measurements [5] : they were done with an assembly of sixteen Hall probes.

Two effects were noticed on the gradient homogeneity (Fig.4) :

- At medium field : a too large gradient inhomogeneity.

- At high field : a saturation-like effect.

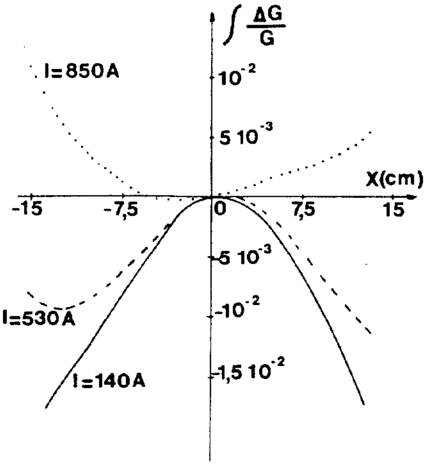

Fig.4 - Integral gradient homogeneity (first test).

Though the results would be acceptable for a standard beam line quadrupole, they were almost an order of magnitude larger than requested for our spectrometer use. So it was decided to try to improve the homogeneity of the quadrupole.

From calculations, it appeared that the saturation effects were mainly due to air gaps left by the iron yoke design for assembly. The yoke assembly technology was modified to eliminate these air gaps, which requested a cryostat disassembly. At the same time, the opportunity was taken to increase the iron yoke thickness, to optimize iron shims at the ends of the yoke, and to rearrange the electrical connections, as previously mentioned.

Room temperature measurements

The aim of these measurements was to verify the effect of the end shims, determined to give a good gradient homogeneity in the horizontal plane, at low field. These measurements were done with a set of two coils, 1.4 m long and a current of 8 A in the warm magnet.

Second test magnetic measurements

The results have shown a good improvement (Fig.5):

- Without correction, the integral gradient homogeneity is in the range ± 2.10^{-3} for a current between 150 A and 400 A. Above, a small saturation effect appears, giving a maximum gradient inhomogeneity of about 6.10^{-3} around 700 A. This effect then lightly decreases for higher currents.

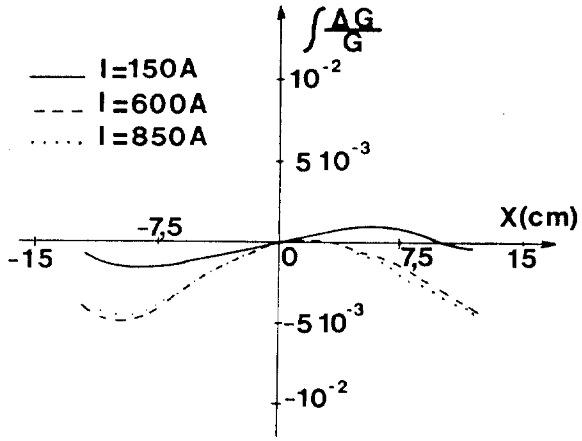

Fig.5 - Integral gradient homogeneity (second test).

- With correction : the range ± 1.10^{-3} is reached with a small adjusting current, as it can be seen on the typical curve of Fig.6.

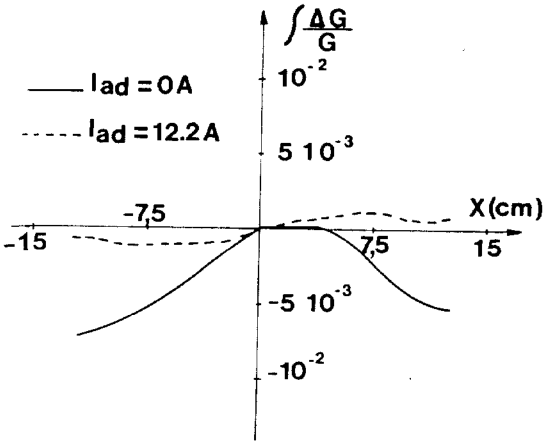

Fig.6 - Typical effect of the current modulation. (I_{main} = 725 A; I_{adj} = 12.2 A).

These measurements have shown that the initial challenge can be met without any adjustment in a large current range.

The tests are now over and the magnet will be installed on Saturne II experimental areas (spectrometer # 3) in April 1981.

Conclusions

A superconducting Panofsky quadrupole can be built with a high accuracy, typically less than few 10^{-3} on the integral gradient homogeneity, when taking care of the following points :

- Accurate calculation of the 2D design, taking into account the real coil structure.
- Choice of end shapes to minimize their effect.
- Very accurate assembly of the coils.
- Shimmed iron yoke : it has been shown that magnetic measurements made at room temperature are sufficient to determine the shims.

If a still better homogeneity is needed, the possibility of correction without any supplementary coils has been demonstrated.

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