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A NEW ACCELERATOR SUPERCONDUCTING DIPOLE SUITABLE FOR HIGH PRECISION FIELD.

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Abstract

Work on superconducting dipoles for accelerators started about twelve years ago in several High Energy Physics laboratories. At present, many problems have been solved and three big superconducting synchrotrons or storage rings are under construction : the "Doubler" and "Isabelle" in the USA and "UNK" in the USSR. In Europe, the DESY Laboratory in Hamburg is studying the "HERA" project (not yet approved).

All these projects use dipole fields in the range of 4 to 5 teslas in coil bores of 75 to 130 mm in diameter. However, these magnets still raise difficulties and their required field quality remains hard to achieve due to the high level of accuracy needed in conductor placement. In this paper a new design is proposed to improve this accuracy. Models along this design are being developped at Saclay, requiring a quite novel technology, whose advantages and possible difficulties are reviewed.

Introduction

The Saclay Laboratory has been involved for more than ten years in superconducting dipole technology. Many coil configurations and designs have been investigated. Some of these coil configurations are shown on Fig.1.

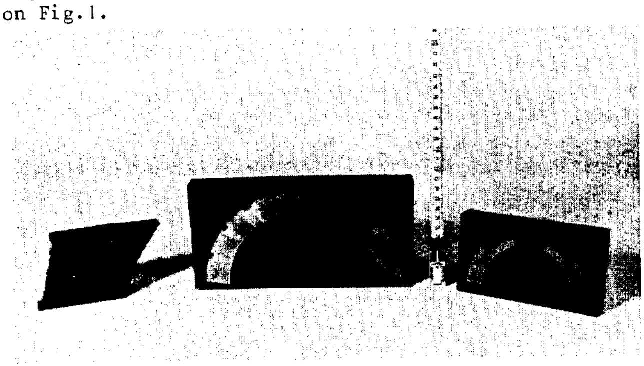

Fig.1 - Different coil shapes investigated at Saclay.

Starting from the left these coils are those of dipoles ALEC[1], CESAR[2], and UNK[3].

The CESAR magnets (two of them were constructed) have been installed on a beam line at CERN for two years.

They were built and tested in collaboration with CERN and are still among the most accurate superconducting magnets ever made. Their field integrals are constant within $\pm 2.10^{-4}$ over 50% of the coil bore (∅ 150 mm). The central field is 4.5 T and the magnetic length 2 meters. They reached their nominal field without training (80% of short sample). However, when in 1977 we started a new collaboration with the IHEP of Serpukhov to develop magnet models for the UNK project, the CESAR solution was not retained because the design was not adequate for mass production. Instead we adopted, in agreement with Serpukhov, a design very similar to the Fermilab "Doubler" dipole with a larger coil aperture (∅ 90 mm instead of 75 mm). Three short models (0.7 m) were built and tested at Saclay in 1979. Overall performances were satisfactory such as :

- Small training, 4 to 7 quenches to reach critical field (4.9 T) ;
- No ramp rate dependance up to dB/dT = 1 T/s ;
- Low electrical losses, less than 100 Joule/cycle/meter for the nominal cycle.

The only point which did not fully meet the specification was the field homogeneity which was initially required to be $\Delta B/B < \pm 2.10^{-4}$ over half the coil aperture and which was found to be randomly from magnet to magnet in the range of four to five times this value. This result must be related to the placement of conductors whose position cannot be perfectly controlled with this type of design.

Problem to be solved

The misplacement of conductors in the UNK dipole comes from the coil configuration. In this configuration (Fig.2) the accuracy of the two angles and the even distribution of conductors are both essential for good field homogeneity. In the fabrication process the two angles can be controlled very accuratly, first by curing the coil in an accurate mold, and second by clamping the coil into the laminated collars whose profile can be punched also very accuratly. Unfortunately, even if the two actual angles can be kept very close to their theoretical values there are too many conductors stacked between the boundaries of these angles to insure a uniform angular distribution of these conductors.

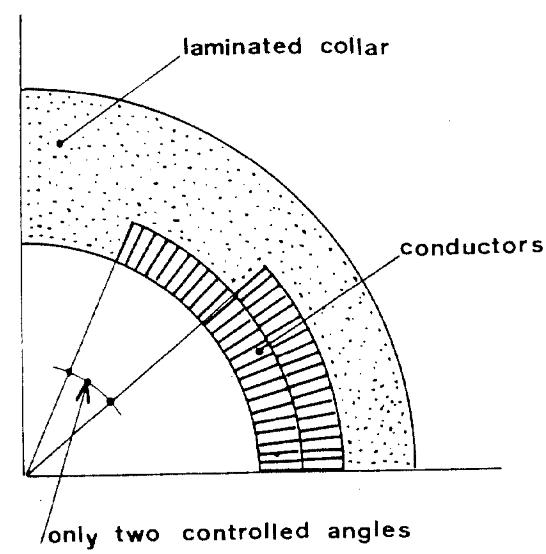

Fig.2 - Two shell configuration.

An obvious remedy consists in building up more accurately controlled angles through the stack of conductors as indicated on Fig.3 which results in a current block configuration. Such a block structure would not be successfully achieved by simply inserting wedges during winding but by punching slots in the collar laminations in order to insure accurate positionning angles with no cumulative errors. This structure is the basis for the new proposed models.

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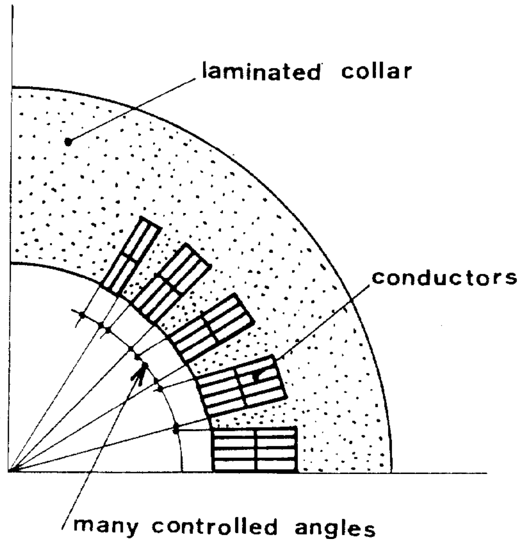

Fig.3 - Slot configuration.

Consequences of the new design

This new feature leads to several important differences from the shell structure of the "UNK" model. These differences are the following :

Field homogeneity

As explained above the slot dipole should improve the field homogeneity and reproducibility by getting a much better conductor placement and this is the main goal of this new design.

On the other hand the theoretical field homogeneity can be achieved as well with the blockconfiguration as with the shell configuration provided enough blocks are used. Four blocks are found sufficient to get zero sextupole and decapole terms.

Efficiency of ampere-turns

The block configuration is not as effective as the shell configuration due to the voids of current between the blocks. If we compare both solutions for a 100 mm coil bore, a 4.5 teslas central field and a warm iron solution, the block configuration costs in superconductor about 9% more than the shell solution.

Coil winding and molding

Usually a coil is wound on a mandrel and cured afterwards in an accurate mold. In the present configuration the turns are laid into the slots during the winding and this from the inside of the bore instead of from the outside in previous windings. The coil ends need special spacers whilst no spacers at all are required for the shell solution. The winding time will therefore be longer. However once the coil is cured neither unmolding process nor collaring are necessary for the coil, and this saves time and tooling.

Mechanics

From the mechanical point of view and compared to the shell structure some aspects of the new design are advantageous and some are less convenient. One negative aspect is that, the turns being wound into the slots, there is no simple way of presstressing the conductors as it is done with the collars of the shell configuration.

However, as a positive aspect, the new structure results in relatively small electromagnetical stresses within each block. In fact the forces acting on each block are taken directly by the steel structure and are not transmitted to the other blocks so that there is no cumulative stresses as in the shell structure.

On the one hand the lack of presstress might lead to training or degradation, but in the other hand the decrease of stress due to non cumulative forces may compensate, for this effect, the appearance of training depending strongly on the stress level. One definite advantage of the block structure is that, under magnetic forces, conductor motions are kept below a very small amplitude and will not disturb the field quality.

Cost

The cost of such a magnet should be very competitive with to-day techniques. The cost of accurately punched laminations is low. These laminations serve both as a very accurate mold and as a rigid collar for the electromagnetic forces.

Therefore large savings are expected in fabrication toolings as there is no more need for winding mandrel, accurate curing mold and big and powerful press. Also only one curing operation is needed instead of two in the shell design.

Program of development

A program of development for such new dipole was started at Saclay in 1980. This program is partly supported by the DESY Laboratory which is interested in looking at eventual alternative solutions to the dipole design adopted in the first proposal of the HERA machine[4].

This program includes the construction of several short model dipoles (0.7 m long) with two different slot and winding arrangements. The designed central field is currently 4.72 T at 4.6 K in a coil bore of 100 mm in diameter.

- The first arrangement consists of slots of identical radial depths and of variable widths in the azimuthal direction with two layers of conductors in the slots as shown in Fig. 3. The wide face of the flat cable conductor is parallel to the radial direction.

- For the second arrangement the slots have identical widths and variable depths and the conductor is positioned with its wide face perpendicular to the radial direction.

The two configurations have respective advantages and disadvantages which will be experimentally investigated.

Already copper dummy models have been constructed to make sure that the process was feasible and to design the tooling needed for winding the actual superconducting models. Figure 4 shows one of these dummy coil (wide face of conductor perpendicular to the radial direction).

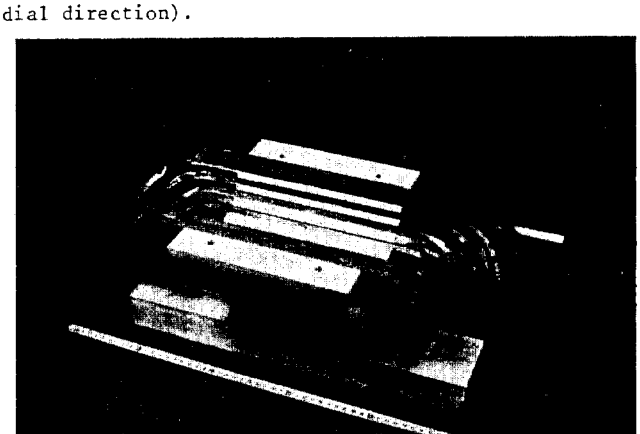

Fig.4 - Dummy coil made with the slot design.

Figure 5 shows the punched laminations for both slot arrangements compared with the collar of the "UNK" model.

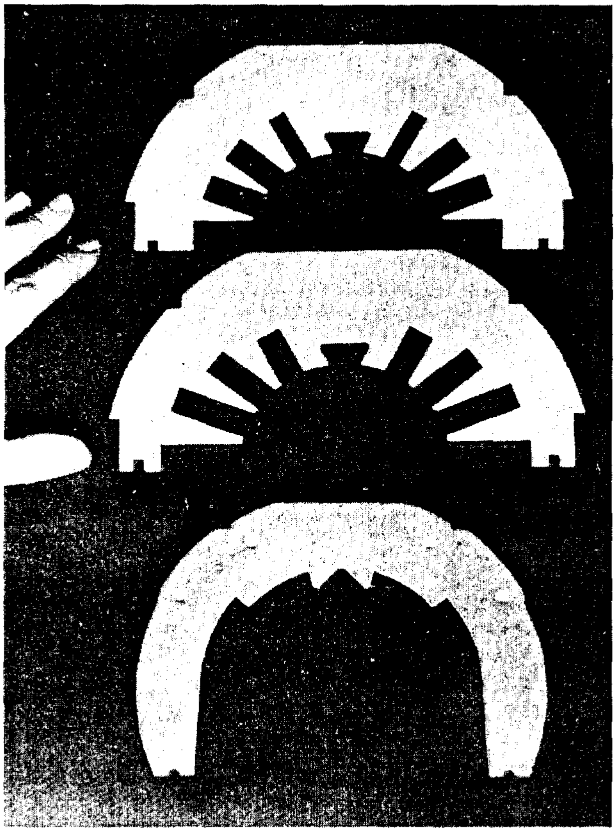

Fig.5 - The two slot configurations investigated compared to the shell collar.

Figure 6 shows an assembled block of lamination ready for winding.

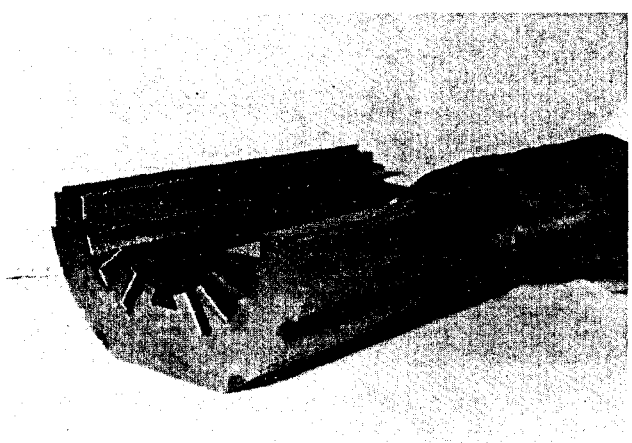

Fig.6 - Assembled laminations ready for winding.

The construction of the superconducting models is in progress and tests of the first one should take place in May 1981.

Conclusions

In spite of uncertainties concerning the training behavior, this new dipole design should solve the difficult problem of field homogeneity and reproducibility. The construction cost should be competitive with present designs. By the end of 1981 several short models will have been tested and conclusions will be drawn.

As a final remark it seems that such design, with current blocks separated by solid stainless steel fins splitting the electromagnetic forces within the whole structure, should be well adapted to high field magnets, using eventually several rings of blocks.

In particular for Nb_3Sn magnets reacted after winding the heat treatment can be made directly in the final assembly, the magnet being impregnated and cured afterwards.

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