THE USE OF CORRECTING COILS IN END MAGNETS OF ACCELERATORS

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Abstract

The end magnets of the race-track microtron booster [1], which is the second stage of the 30.0 MeV cw electron accelerator under construction at IFUSP, play a fundamental role in terms of the beam quality. The use of correcting coils, based on the inhomogeneities of the magnetic field and attached to the pole faces, assured uniformity of 10^{-5}. We present the performance of these coils when operating the end magnets with currents that differ in ±10% from the one used in the mappings that originated the coils copper leads. For one of the magnets, adjusting conveniently the current of the correcting coils, made it possible to homogenize field distributions of different intensities, once their shapes are practically identical to those that originated the coils. For the other one, the shapes are changed and the coils are less efficient. This is related to intrinsic factors that determine the inhomogeneities. However, in both cases we obtained uniformity of 10^{-5}, much better than necessary.

1 INTRODUCTION

The end magnets of the IFUSP race-track microtron booster were designed, with the aid of numerical field computations (Poisson code) and of ray-tracing calculations (Ptrace code), to deflect an electron beam of 5.1 MeV in a semicircular trajectory of about 36.0 cm diameter. They incorporate active field clamps [2] that avoid the vertical defocusing and the radial displacement of the beam. The method of correction employed [3,4] to homogenize the IFUSP race-track microtron booster accelerator magnets assured uniformity of 10^{-5} in an average field of 0.1 T, over an area of 700 cm^2. Several tests were done to investigate the behavior of these inhomogeneities and the performance of the correcting coils when the magnets are operated with currents that differ in ±10% from the one (27.4 A) that was used in the mappings that originated them.

2 EXPERIMENTAL PROCEDURE

The magnetic field measurements were done with differential Hall probes connected to a gaussmeter (F.W.Bell model 640) with resolution given by ±1.5µT.
The magnets were submitted to a well defined cycling procedure, empirically determined. This cycle provided reproducibility of 10^{-5} for a magnetic field distribution of about 0.1 T. Stability of the same order was obtained.

For each magnet, the correcting coils were obtained by the arithmetic mean of four field maps taken in different planes, two situated 12 mm above and two 12 mm bellow the middle plane [1] and with 27.4 A for the current of operation. The coils were made of etched printed circuit boards and the copper leads ($4x10^{-5}$ m thickness) were shaped like the lines of equal magnetic field separated by a distance of 7.4µT. Two identical double sided etched circuits, done for each magnet, were placed at their pole faces. In each point of the coils, an adequate current density provided tangential magnetic field components, identical to those that have to be compensated. Figures 1 and 2 show the two magnets correcting coils.

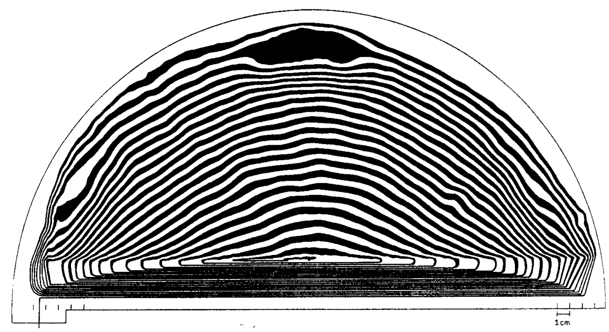

Figure 1 - The correcting coils used for the first magnet. The interval between the copper leads is 7.4µT.

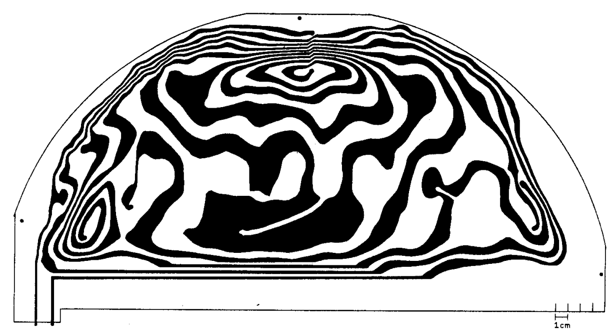

Figure 2 - The correcting coils used for the second magnet. The interval between the copper leads is 7.4µT.

3 THE PERFORMANCE OF THE CORRECTING COILS

Figures 3 and 4 show field distributions in the middle plane between the pole faces of the magnets operated at 27.4 A (the points indicate the coordinates, in millimeter, of each magnetic field difference measurement). The magnets exhibit differences in terms of the shape and magnitude of their inhomogeneities. In the first one,

$\Delta B\ /\ B = \pm\ 1.4\text{x}10^{-3}$ and in the other $\Delta B\ /\ B = \pm\ 6\text{x}10^{-4}$. The optimal currents for the correcting coils of each magnet, 122.2 mA for one of them and 115.7 mA for the other one, were found empirically and are in good agreement with the theoretical value (117.8 mA).

The standard deviation, 65.1μT, for the field distribution shown in figure 3, becomes 1.8μT (figure 5a) using for the correcting coils the optimal current value, 122.2 mA . Although the shape of the inhomogeneity changes almost nothing when the current of operation is altered, there is variation in its intensity. Then we adjusted conveniently the current of the correcting coils in order to obtain field distributions as uniform as the one for 27.4 A .

When the current of operation is raised from 27.4 A up to 30.0 A, the correction done by 122.2 mA current becomes increasingly excessive as can be seen by the growth of the standard deviations (figure 6). Then we used for the correcting coils currents successively smaller and always lower than 122.2 mA (figures 7). On the other hand, when the current of operation is raised from 24.7 A up to 27.4 A, the correction performed by 122.2 mA current becomes decreasingly insufficient, as shown by the lessening of the standard deviations (figure 6), and what explains the need for currents successively smaller but always higher than 122.2 mA (figure 7) to compensate this effect. The results obtained for this magnet lead us to conclude that the field distributions, before the corrections, for currents of operation higher than 27.4 A are closer to those that originated the correcting coils and of smaller variation. Figure 6 reveals the performance of the coils in the situations exposed and uniformity of 10^{-5} for all the cases as the standard deviation does not exceed 3.1μT.

Figure 4 shows the field distribution in the middle plane of the second magnet operated at 27.4 A , in which the standard deviation, 17.8μT, becomes 2.5μT (figure 5b), using the optimal value 115.7 mA for the correcting coils. When the current of operation is altered the shape of the inhomogeneity is changed, specially for currents smaller than 27.4 A . Even so, we adjusted the current of the correcting coils. Nevertheless we found few differences between the results (figure 8) mainly for currents smaller than 27.4 A, where the standard deviations are practically superimposed. When the magnet is operated with currents greater than 27.4 A the distributions of the difference field measurements are more similar to those that originated the correcting coils but of greater variation. This explains the achievement of the best corrections revealed by the standard deviations and the need to increase the correcting coils current in this interval of operation (figure 9). Contrarily to the other magnet, in this case, the shape of the correcting coils copper leads does not exactly correspond to the inhomogeneity that has to be compensated and that is why the correction performed by the coils is less efficient. However, the uniformity obtained is of about 10^{-5} .

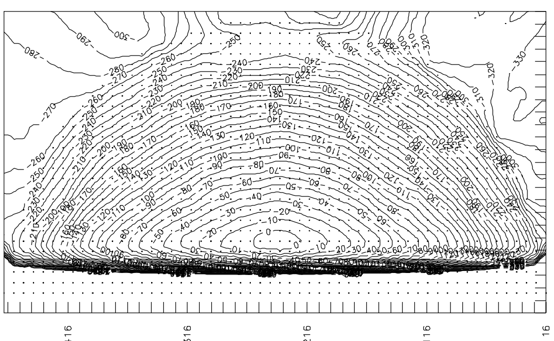

Figure 3 **-** Field distribution in the middle plane of the first magnet. Difference between two lines is 10μT.

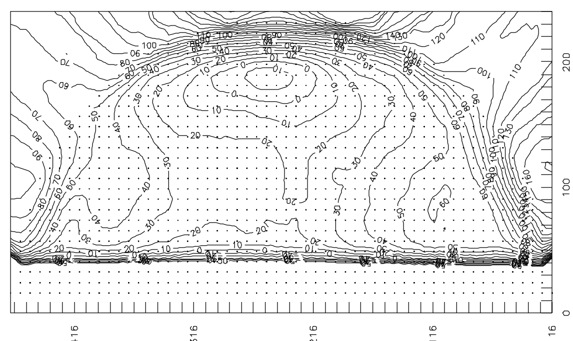

Figure 4 **-** Field distribution in the middle plane of the second magnet. Difference between two lines is 10μT.

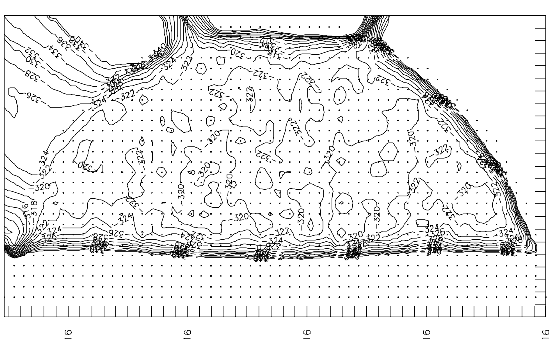

Figure 5a **-** Field distribution in the middle plane of the first magnet using for the correcting coils the optimal current (122.2 mA). Difference between two lines is 2μT.

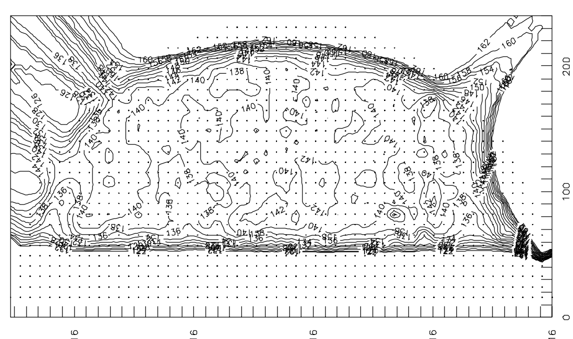

Figure 5b **-** Field distribution in the middle plane of the second magnet using for the correcting coils the optimal current (115.7 mA). Difference between two lines is 2μT.

4 CONCLUSIONS

The magnets present inhomogeneities that differ in terms of their shapes and strenghts what lead them to behave differently when the current of operation is altered.

Through the results obtained we come to the conclusion that the success of the method of correction employed is related to the fact that the correcting coils must represent copies of the inhomogeneities. Once the shape of the inhomogeneities is not altered, intensity changes can be compensated adjusting conveniently the correcting coils current as it was done for the first magnet. For the second magnet the change in the inhomogeneity shape compromises the performance of the correcting coils. Besides, we should add that the first magnet, with a well defined inhomogeneity, in spite of being initially less uniform, is more susceptible to the correction but less to changes in the shape of the field distribution. This suggests that a greater uniformity represents a tendency of a less stable field distribution. These effects are related to intrinsic factors that determine the inhomogeneities. However both of the recirculating magnets present uniformity of 10^{-5} when operated in the interval studied.

5 ACKNOWLEDGMENTS

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REFERENCES

[1] L.R.P. Kassab: ‘Projeto, construção e teste do sistema de ímãs principais do acelerador microtron booster do IFUSP’, PhD Thesis, IFUSP (1996).

[2] H.Babic, M.Sedlacek: ‘Nuclear Instruments and Methods’, 56,170 (1967).

[3] U.Czok, G.Moritz, H.Wollnik, ‘Nuclear Instruments and Methods’, 140, 135(1977).

[4] J.Friedrich, L.Tiator, Jahresbericht, Institut Fur Kernphysik, Johannes Gutenberg, Universitat Mainz (1986 -1987).

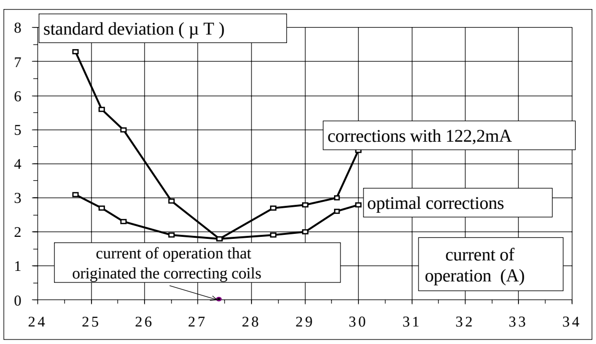

Figure 6 - Standard deviations of magnetic induction difference measurements for different currents of operation (first magnet).

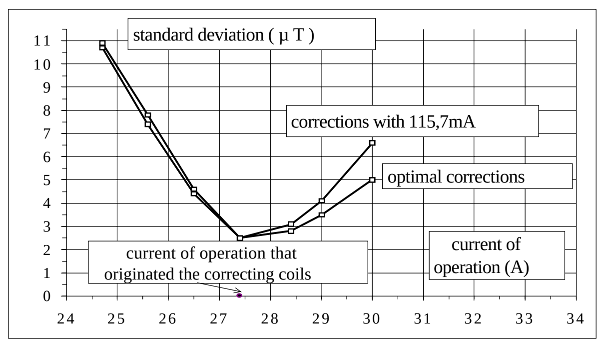

Figure 8 - Standard deviations of magnetic induction difference measurements for different currents of operation (second magnet).

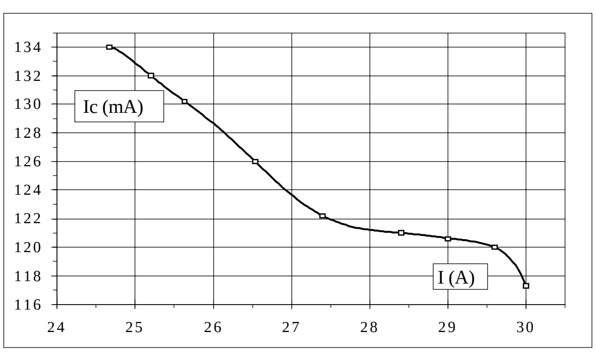

Figure 7 - Correcting coils currents for different currents of operation (first magnet).

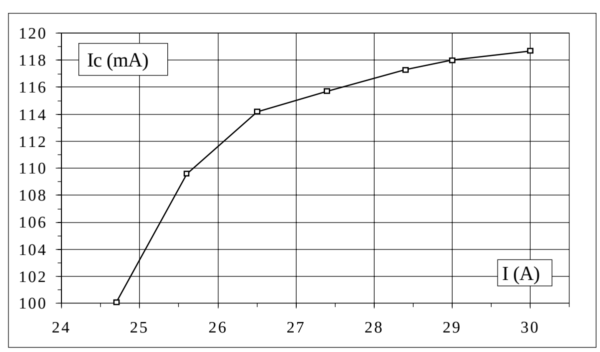

Figure 9 - Correcting coils currents for different currents of operation (second magnet).