BEAM TRANSPORT MAGNETS WITH 2.2TESLA [*]

U. Ludwig-Mertin, K.-H. Kaiser, P. Jennewein, University of Mainz, Germany
S. Ratschow, Technical University, Darmstadt, Germany

Abstract

The existing beam guiding system for the electron beam from the 855MeV-microtron cascade MAMI (Mainz Microtron) to three experimental areas had to be upgraded to the transport of a 1.5GeV beam delivered from the fourth stage which is under construction at present. In order to minimise costs and to avoid the complete reconstruction of the system the existing dipoles of two 90° bending-systems were modified to reach 2.2T in the gap. This was possible because of the large dimensions of the magnets with respect to both iron yoke and copper coil, and because of the low emittance of the electron beam allowing for a small gap height. Adding specially designed pole plates was sufficient to achieve the conversion from the 1.6T dipoles, originally used in the electron-positron storage ring DCI in Saclay, France, to the high field bending magnets. In the paper the results of three dimensional field calculations are presented and compared to magnetic field measurements.

1 INTRODCTION

At the Institute of Nuclear Physics of the university of Mainz, Germany, the normal conducting three staged microtron cascade MAMI B delivering a cw electron beam of up to 883MeV is in operation since 1991 for experiments in nuclear physics [1]. Its upgrading to 1.5GeV by a subsequent Harmonic Double Sided Microtron (HDSM) is under way at present [2,3]. In order to adapt the existing beam transport system to the experimental areas to the future 1.5GeV beam, it was decided to increase the field of the dipoles in the 93.7°- and 81.6°-bending systems to 2.2T resp. 1.9T instead of installing additional magnets. This was possible because of the large dimensions of these dipoles that come from the former Double Electron-Positron Storage Ring DCI at Orsay, France, and because of the low emittance expected for the 1.5GeV MAMI [3].

2 DESIGN OF THE POLE GEOMETRY

2.1 Principle

The principle of realizing high fields in normal conducting magnets is well known and described e.g. in the book of Schnell [4]. For the cylindrical geometry shown in fig.1 with pole tips at saturation maximum homogeneity around the axis is achieved for a conus angle α=63°. By increasing the outer diameter of the pole magnetic fields higher than the saturation value B_s are obtained. As a consequence of the conical pole shape the flux density within the iron decreases quickly with increasing distance from the pole surface. From this point of view high values of α should be chosen. On the other hand, the stray field would become higher in this case, leading to inreased iron saturation. Therefore, for a given geometry an optimum value for α exists with respect to maximum homogeneity or with respect to maximum field strength at the centre.

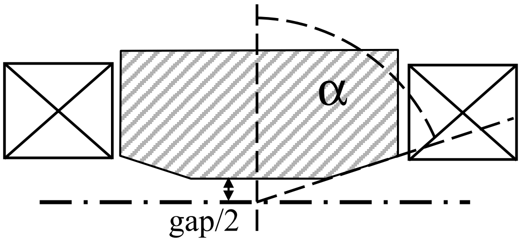

Figure 1: Conical magnet pole.

2.2 Magnet geometry

In fig.2 the fundamental geometry of the 30° DCI-magnet is shown, and its most important parameters in both its original and future operation within the 93.7° bending system are given in table 1 (for simplicity we only consider the 46.85°-magnets of this system in the following). The poles are already shaped slightly conical from the beginning to reduce saturation effects at the nominal field. Thanks to the large gap height of 110mm additional pole plates of 42mm thickness could be installed to reach high fields at reduced electrical power consumption. They are thick enough to be sloped in a similar way as shown in fig.1.

Table 1: Bending magnet data

	original magnet	modified magnet (93.7°-system)
Bending angle	30°	46.85°
Bending radius	3820mm	2326mm
Field in the gap	1.66T	2.2T
Gap distance	110 mm	26mm
Pole width at gap	340 mm	220 mm
Angles of pole conus	10.7°/21.7°	10.7°/21.7°, 55°
Current (2*42 w.)	1950A	625A
copper profile	26.6 x 26.5 mm, bore diam.13.5 mm	

---

[*] Work supported by DFG (SFB 443)

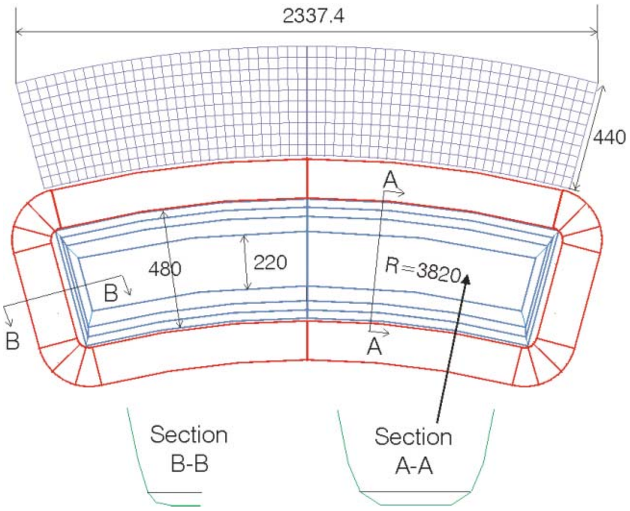

Fig.2: DCI-Magnet with additional pole plates

2.3 Numerical Calculations

In order to find the optimum value of α for the more complicated geometry of the DCI magnets, numerical calculations with TOSCA [5] have been carried out. For higher flexibility the cone tip position (see fig.1) was no more constrained to the symmetry plane. Optimum homogeity (10^{-3} over a radial length of 150mm) in the midst of the magnet was obtained for α=55° (s. fig.6).At higher coil current some enhancement appears at the borders indicating a stronger increase of saturation in the centre. The distribution of the flux density over the magnet profile in the symmetry planes is shown in fig.3. Saturation occurs only in a small depth of the pole tips, and the mean flux density in the yoke is below 1.4Tesla. Therefore, the required coil exitation at 2.2Tesla is only 24% higher than in case of infinite permeability.

2.4 Influence to the electron beam

The optical properties of the magnet have been calculated by means of the particle tracing option of the TOSCA-code. It turned out that the values for the horizontal and vertical matrix elements are close to those of the ideal magnet. The largest difference of about -9% was found for the vertical focal strength. In the horizontal direction the focal strength is reduced by 5%. It can be compensated easily by the quadrupoles of the bending system. Nonlinearities in the fringe fields and in the inner part of the magnet are the reason for small sextupole errors of the deflecting angle. With a horizontal deflection error of -0.2µrad for 1mm displacement at the entrance and -7.3nrad for an energy deviation of 10^{-4} the errors have practically no effekt on the beam quality. The same holds for the vertical motion: Because of symmetry the lowest multipole in this plane is an octupole. It produces a negligable additional focusing of -40nrad for +1mm displacement.

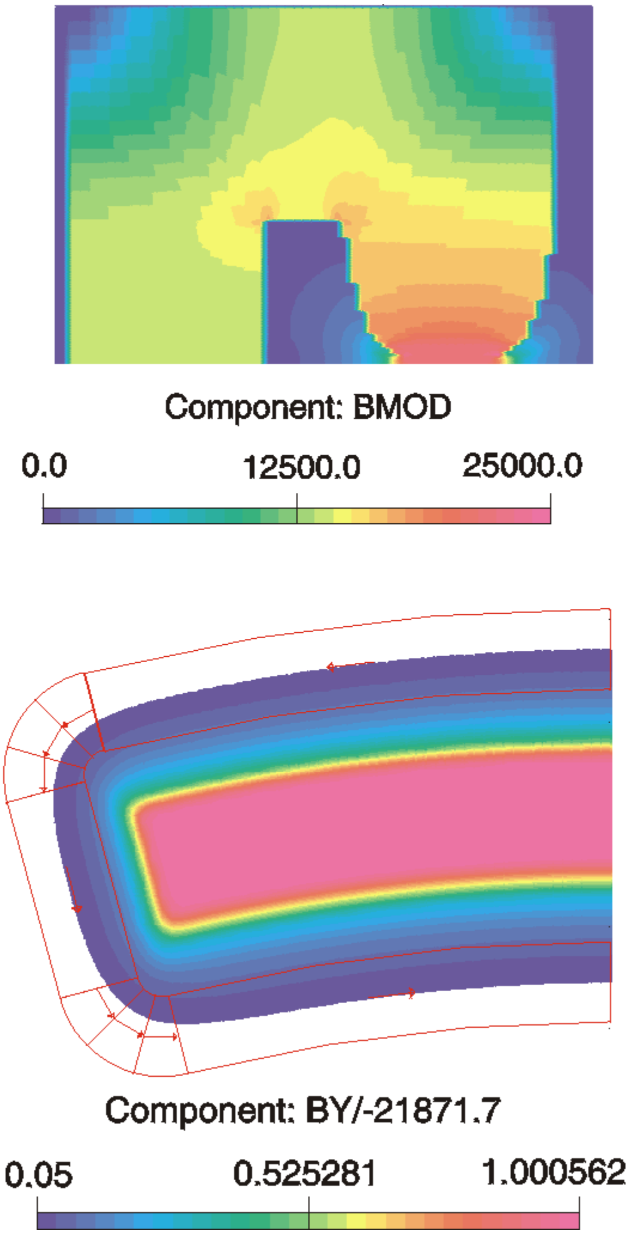

Fig.3: Flux density in the yoke and in the midplane of the modified DCI-magnet

3 RESULTS

After fabricating the pole plates from ARMCO steel [6] and screwing them to the poles the field distribution of one of the four dipoles had been mapped in situ for different coil currents (fig.5) and its exitation curve was measured (fig.4). (there was not enough time within the shutdown period to do detailed measurements for the other three dipoles.). As it can be seen from fig.4 the current requirement for 2.2Tesla is very close (2.4% lower) to the calculated value. The region of 10^{-3} radial homogeneity (s. fig.6) is about 1cm longer in practice. In the fig. 4 the measured isoinduction lines are depicted in comparision to the TOSCA results. Apart from some structures presumably produced from machining and measurement errors the distributions are very close to each other. In the fringe field region the beam, with its inclination of 8.4° to the normal of the pole edge, passes through curved isoinduction lines giving rise to sextupole errors. The curvature of the measured isoinduction line at 5% of B_{max} - as an example for comparision – is 2.33/m compared to 1.25/m for the calculated distribution. Compared with the results of particle tracing, we have to count on a somewhat higher sextupole error in reality.

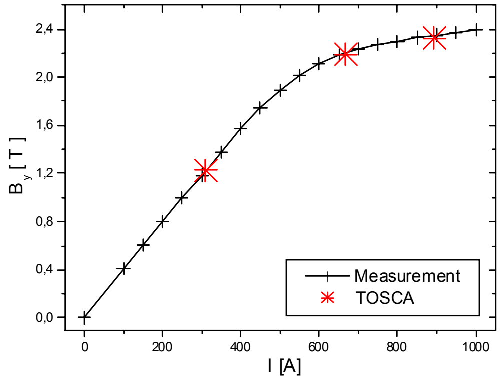

Fig.4: Exitation curve for the modified DCI magnet

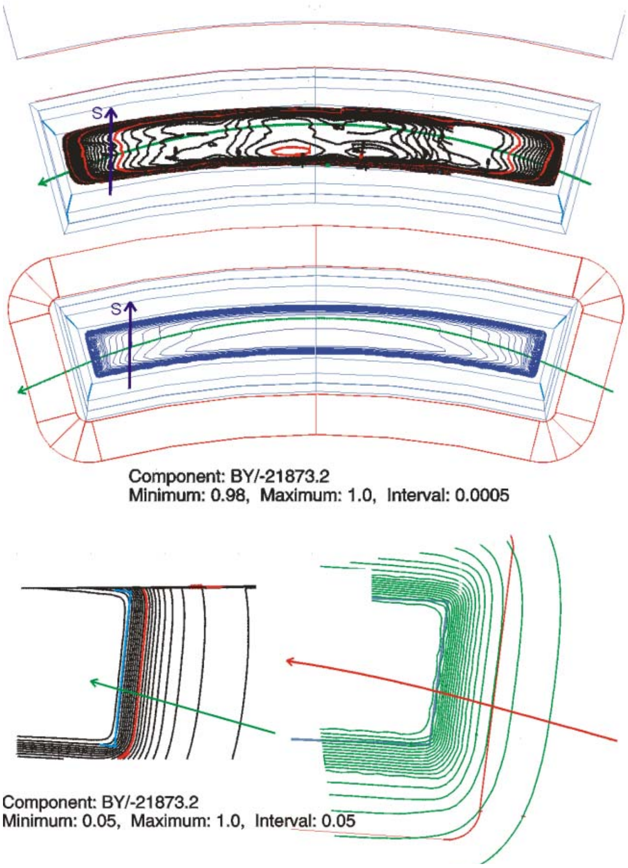

Fig.5: Measured (above and left) and calculated isoinduction lines in the magnet midplane (0.05% and 5% rel. field difference between neighboured lines in the inner rep. fringe region)

4 CONCLUSION

The use of normal conducting magnets with gap fields above iron saturation for the transport of low emittance beams seem to be advantageous in case of space limitations. Thanks to the very good precision of three dimensional calculations and to the power of today's computers, allowing for fast calculations with a large number of mesh points, the magnets can be designed in a safe way. In our case, the final test with the electron beam can only be done after the completion of the fourth stage which is expected for 2004.

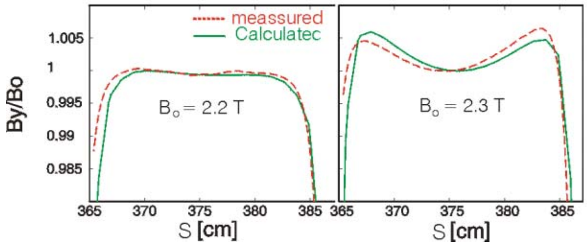

Fig.6: Calculated and meassured field distribution along the lines across the pole indicated in fig. 5

5 REFERENCES

[1] Euteneuer et al.,"Beam Meassurements and Operating Experiences at MAMI", EPAC'94, London, June 1994

[2] S. Ratschow, "Strahldynamische Untersuchungen zu einem doppelseitgen Mikrotron als vierte Stufe von MAMI", PhD Thesis, Univ. Mainz, April 2000.

[3] Jankowiak, "Design and Status of the 1.5GeV-Harmonic Double Sided Microtron for MAMI", EPAC'2002, Paris, Juni 2002

[4] G. Schnell, "Magnete" Verlag Karl Thiemig München, 1973, ISBN3-521-06082-9

[5] TOSCA, 3D-Software for magnet Calculations, VectorFields, U.K.

[6] Unternehmensbereich Armco Eisen Köln, Technical information sheet