THREE DIMENSIONAL DESIGN OF THE BENDING MAGNETS FOR A 1.5 GEV DOUBLE SIDED MICROTRON[1]

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Abstract

A Double Sided Microtron (DSM) is planned to upgrade the three staged cw racetrack microtron (RTM) cascade MAMI from 0.855GeV to 1.5GeV. The DSM consists of two rf linacs connected to each other by two identical achromatic 180° bending systems. Each of these consists of a symmetrical pair of 90° segment magnets with common entrance and exit pole edges. While the horizontal optics of the bending magnets corresponds to a simple (energy dependent) drift length, the vertical motion is more complicated. This is due to the 45°-pole face inclination at both the beam entrance and exit. Therefore, in our design the vertical defocusing is compensated in the whole energy range by an appropriate field gradient normal to the pole edge.

In this paper the design of the segment magnets with respect to optimum field distribution and minimum iron consumption is given. In order to achieve the required field accuracy of 0.01%, thin current sheet correction coils located in the air gap close to the pole surfaces were simulated. The three dimensional calculations were done with TOSCA.

1 DSM OVERVIEW

A Double Sided Microtron(s. fig. 1) has been planned as a fourth stage for the microtron cascade MAMI[1] to fulfil the requirement of an intense 1.5GeV cw electron beam for experiments in nuclear and particle physics. Compared with the RTM the DSM has the advantage of much smaller bending magnets and of a higher energy gain per turn. However, these magnets act strongly defocusing in the vertical plane, an effect due to the inclination of the pole edge with respect to the direction of the beam. In our design the defocusing is compensated in the whole energy range by a field gradient normal to the front edge of the dipoles (s. fig. 2). As a consequence, the central phase angle of the particles with respect to the accelerating 4.9GHz-wave is shifting by 25° during acceleration. This is made possible by the large longitudinal stability range of the DSM.

Since the bending systems so do not introduce net focusing, the beam has to be focused by quadrupole lenses on each accelerator axis. This is sufficient to keep the beta function below 17m during the acceleration from 0.855 to 1.5GeV.

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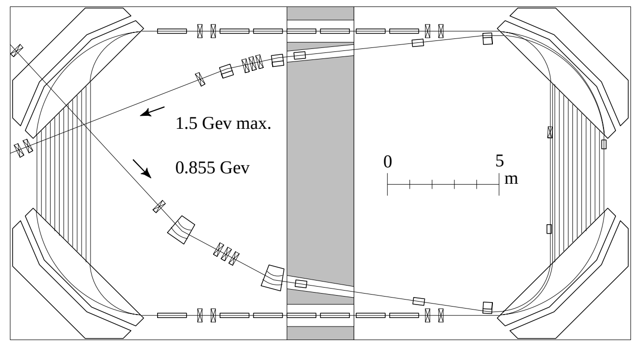

Figure 1: Scheme of the DSM in two of the existing experimental halls.

2 THE DESIGN OF THE DSM BENDING MAGNETS

The design of the dipoles presented in the following was generated by means of the three dimensional code TOSCA[2]. At the beginning, the code was checked with respect to the measured field of the 180°-bending magnets (1.3T) of the RTM3 of MAMI. The calculated field distribution proved to agree very well with the measured one. Merely the maximum decay in the inner part of the gap was predicted slightly too pessimistically ($6*10^{-3}$ instead of $4*10^{-3}$). TOSCA was also found to be in very good accordance with the three dimensional code PROFI [3] that was used for the calculation of the RTM2 dipoles.

The overall geometry of the dipoles was designed for minimum space and iron consumption. In the maximum field region the gap was fixed to 85 mm in order to obtain enough space for the vacuum chamber and for pole face windings (s. below). Furthermore, the relatively large gap makes sure that there are no short range field deviations in the midplane.

The exact dimensions of the pole and yoke segments (parameter d1, d2, etc. in fig.2) are optimised for maximum extension of the „good field"-region (ΔB<1.5mT with respect to the design field).

The small top and bottom plates, primarily introduced to compensate for the material lost by the coil channel, turned out to influence the field curve $B_y(z)$ selectively in the central part of the dipole. Their size can easily be modified after the construction of the magnets to correct for the deviation between design and realisation. In order to avoid iron saturation in the beam entrance and exit regions and to keep the field distribution as far independent on small changes of the absolute flux density as possible a Rogowski profile was introduced along the front edge. As a side effect of this, the good field region was widened by almost 50cm at each pole corner.

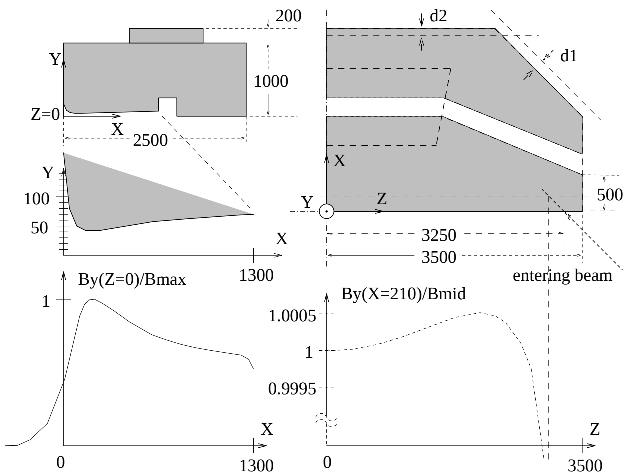

Figure 2: Dimensions and field curves of the DSM magnets (mm, Tesla).

The quality of the fringe field was checked by calculating the field integral along several 45°-lines displaced parallel to each other along the front edge. It was found that for the planned location of the linac axes, the bending angle is slightly too low (1.1mrad at 1 GeV) and that the beam would be focused weakly in the horizontal direction (150m at 1GeV). Therefore, this quadrupole and also the higher multipole components are small and need not to be corrected. For the compensation of the bending error small collective magnets can be installed on both ends of the accelerator axes.

Table 1: Main parameters of one DSM dipole

Field strength [Tesla]	1.53-0.95
Gap distance [mm]	85-138
Mech. Length of front edge [m]	7.0
Usable length of front edge [m]	6.5
Iron weight [t]	250
Copper profile outside/hole [mm^2]	$15*15/3^2*\pi$
Number of windings	2*143
Voltage/current [V/A]	180/400
Copper weight [t]	8.0

2 FIELD CORRECTION

The field quality has to meet the requirements from the beam dynamics in the DSM. While the demands from vertical beam optics on the field gradient shape can be met by an accuracy of a few tenths of a percent, the requirements arising from longitudinal dynamics are much harder to satisfy. For optimum beam transmission through the 10 mm aperture of the 20 m long rf-structures the beam has to be aligned exactly on the linac axes. Errors of deflection angles can be corrected for each turn separately by small dipoles on both ends of the dispersive straight sections as long as they do not exceed a few tenth of a milliradian. Otherwise, the displacements would become too large, leading to unacceptable path length changes. This implies that the field has to be constant to 10^{-4} with respect to the z-coordinate (parallel to front edge) and that the two paired dipoles likewise correspond to each other.

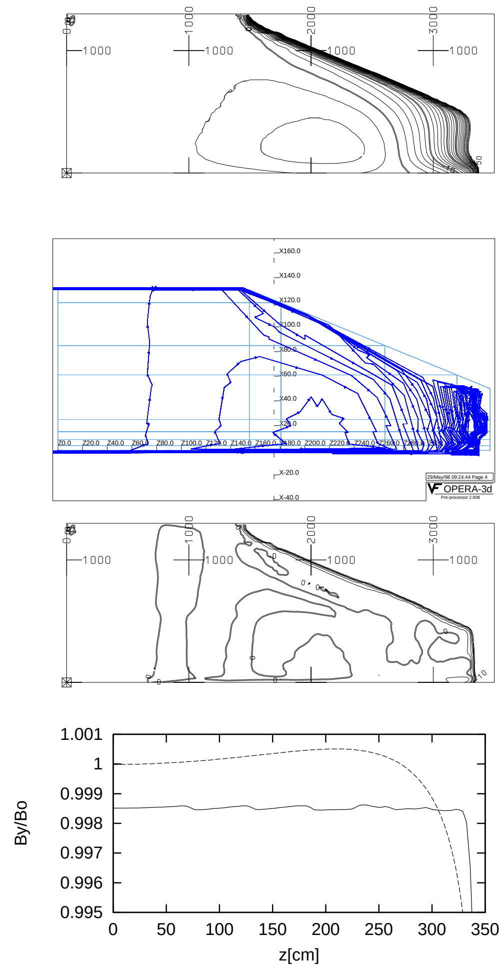

Figure 3: 1st and 3rd picture: Lines of constant field deviations in steps of 0.3mT without and with correction. 2nd picture: Current lines at 3.5cm distance from the symmetry plane for the field correction. 4th picture: Field curves along z for x=21cm before and after correction.

Since manufacturing precision is expected to be only in the order of some 10^{-3}, additional measures have to be taken after delivery. Therefore, we are planning to apply the surface correction coil technology developed for the RTM dipoles of MAMI ([4],[5]) and to extend it to the inhomogeneous DSM magnets.

In case of mirror symmetry and under the assumption that the z-dependence of the field is small compared with the x-dependence (direction of field gradient), the multipole components a_m of the two dimensional field distribution in the (x,y)-plane at any point $(x_1,0,z_1)$ can be calculated from the measured field curve $B_y(x,0,z1)$. The designed field at the same point be given by the components d_m. By applying Ampere´s law, the correction current I_c to be added in the gap is given by

$$I_c = \frac{2}{\mu_0} \cdot \sum_{n=0}^{\infty} \left[(-1)^n \cdot (d_{2\cdot n} - a_{2\cdot n}) \cdot \frac{h^{2\cdot n+1}}{2\cdot n+1} \right] + \Delta L_{iron} \qquad (1)$$

at the resp. observation point. In this formula the sum represents the difference of the line integrals of B_y along the y-axis through the air gap with its variable half distance h=h(x). The multipoles described by odd indices (quadrupole, octupole, etc.) do not appear in the formula since they have no B_y component on the y-axis. The integral in the gap, of course, is dominated by the dipole components. Numerical calculations have shown that higher multipoles contribute only about 1% at most in our case. The last term in the equation is the difference of the line integrals along the path in the iron for the designed resp. measured field in the gap. Its value, however, depends on the influence of the complete correction coil to the flux density in the yoke.

In order to get the shape of the pole face correction windings, I_c is determined at every point of a dense lattice covering the whole gap. From this, the lines of I_c=const. are drawn for different values of I_c separated by ΔI_c. The coil is constructed in such a way that the ΔI_c flows between these lines.

This procedure was simulated with TOSCA for the DSM dipole described above. Fig. 3 shows the improvement of the primary field distribution by surface windings calculated by means of (1), neglecting the contribution of all multipole components higher than the dipole. For simplification the current was flowing along thin lines I_c=const. Since the coil consists of clockwise and anti clockwise parts, the mean flux density does not change very much in the yoke. Therefore, ΔL_{iron} was assumed to be zero.

The real magnet, however, is not perfectly symmetric because of material and manufacturing tolerances. In order to describe the general distribution the field is separated in symmetric and antisymmetric multipole expansions. The latter can be determined completely, in principle, by measuring the distribution of horizontal components $B_x(x,0,z)$ and $B_z(x,0,z)$. However, it may be very difficult to detect them with the required precision in the whole area of the gap because of the presence of the strong B_y component,. Instead of this, the vertical component $B_y(x,\pm y_1,z)$ can be measured at the maximum possible off midplane displacements $\pm y_1$. From these two curves the antisymmetric part $B_{as}(x,\pm y_1,z)$ can be separated and displayed in a contour plot. If the geometry of the plot is simple, one may find coordinate systems (ξ,ζ) for which ξ is approximately normal to the lines of constant B_{as}. In this case the function B_{as} is reduced to two dimensions so that it can be used for the calculation of the higher antisymmetric multipoles. Unfortunately, the antisymmetric dipole cannot be found by analysing B_{as} since it has no y-component. It can be detected, however, by measuring carefully the x- and z-components of the flux density at one point in a region where B_{as} equals zero.

At present, we are investigating the practical possibilities for the suppression of asymmetric field deviations by means of TOSCA simulations. In addition, a 17to-dipole magnet is used for tests of the field correction at nominal flux densities.

4 CONCLUSION

The inhomogeneous bending magnets for the planned 1.5 GeV-DSM have been calculated with the three dimensional code TOSCA. In order to achieve a field quality of 10^{-4}, required from transverse and longitudinal beam dynamics, surface coils have to be installed at the poles. A TOSCA simulation has shown that mirror symmetric field deviations of some 10^{-3} can be corrected to 10^{-4}. The procedure is being extended to antisymmetric field errors. For practical tests the pole of an existing dipole was modified to realise the DSM-field gradient along a distance of 80 cm.

5 REFERENCES

[1] H. Herminghaus: First Operation of the 850 MeV C.W. Eletron Accelerator MAMI, Proc. 1990 Linac Conf., Albuquerque, USA, LA-12004-C, p. 362

[2] TOSCA: Vector Fields, Software for Electromagnetic Design, Oxford, GB

[3] W.Müller et al.: Numerical Solution of Two Or Three Dimensional Nonlinear Field Problems by means of the Computer Program PROFI, Archiv für Elektrotechnik, Bd 65 (1982) p.299

[4] H. Herminghaus et al.: The reversing Magnets of the 850MeV stage of MAMI, Proc. EPAC88, Rome, p. 1151

[5] H. Herminghaus et al.: Beam Optics and Magnet Technology of the Microtron in Mainz, NIM187(1991)103