DESIGN AND STATUS OF THE 250T-BENDING MAGNETS FOR THE 1.5GEV HARMONIC DOUBLE SIDED MICROTRON FOR MAMI*

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Abstract

The recirculating system of the Harmonic Double Sided Microtron (HDSM) [1] for MAMI (Mainz Microtron) consists of four large bending magnets, which act like 90°-mirrors for all beams. For the compensation of the strong vertical defocusing resulting from the -45deg. pole face rotation a special pole profile was chosen, leading to the appropriate field decay normal to the straight front edge. The machining procedure for a high quality and precise surface of the partly concave poles was worked out in collaboration with the manufacturer. 3D-codes (TOSCA and IDEAS) were used to optimise both magnetic and mechanical properties of the magnets. As a result, it was decided to build the iron core essentially only from two 125t-pieces made of high permeable cast iron. The coils were designed for a minimum temperature increase at a given power consumption and for high reliability by avoiding internal tube brazing. The first of the four magnets has been delivered end of 2001 and was transported through narrow building apertures into the underground accelerator hall. First measurements of its magnetic and mechanical properties started in December.

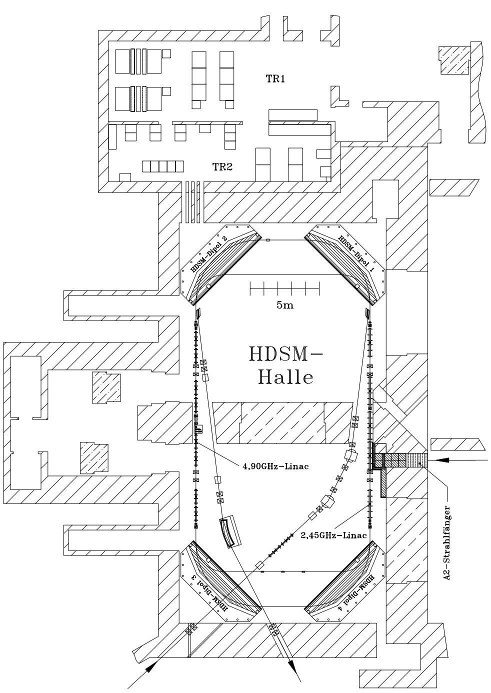

Figure 1: Floor plan of the Harmonic Double Sided Microtron (HDSM)

* *Work supported by Deutsche Forschungsgemeinschaft (SFB443).*

1 HDSM OVERVIEW

In the last year an upgrade of the three staged microtron cascade MAMI has been started to reach an electron energy of 1.5GeV. Since a fourth racetrack microtron (RTM) would be impractical at this energy because of the extermely high weight of its 180° bending magnets a Harmonic Double Sided Microtron (HDSM) was developed. It consists essentially of four normal conducting bending magnets and two antiparallel linear accelerators, operation at different frequencies of 2.45GHz and 4.90GHz. The new apparatus has to fit into the existing underground experimental halls (see Fig.1), which limits by its geometric dimensions the size of the new accelerator stage.

2 DESIGN OF THE BENDING MAGNETS

2.1 Optimisation of the magnetic properties

The field distribution in the gap of the HDSM bending magnets was calculated for the compensation of the vertical edge defocusing [2].

Therefore the three dimensional code TOSCA[3] was used to design the 250t-bending magnets (main parameters in table 1) with respect to high field accuracy, minimum weight and spacial constraints (for details see [4]).

Table 1: Main parameters of one HDSM bending magnet

Field strength[Tesla]	1.53-0.95
Gap distance[mm]	85-138
Mech. Length of front edge [m]	7
Usable length of front edge [m]	6.5m
Iron weight[t]	250
Coils copper profile outside[mm^2]	12*12
Coils copper hole diameter [mm]	8
Number of windings	2*256
Voltage/current [V/A]	180/400
Copper weight [t]	8

2.2 Optimisation of the coil

Following the suggestion of the manufacurer (Sigmaphi, France) the coils were wound with two conductors in a hand in order to avoid internal tube brazing to get a high reliability. The serial connection of the overall 32 conductors per coil were done in a scheme, that is similar to the formation for the 3rd microtron magnet coils developed by the company Bruker, Karlsruhe (see fig. 2).

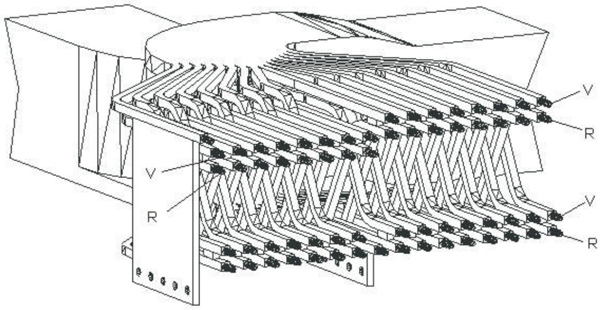

Figure 2: Connection scheme for the coils (V: water inlet, R: Water outlet)

2.3 Optimisation of the mechanical properties

The iron core of the HDSM magnets essentially consist of two 125t peaces that are clamped together by 10 pre-stressed tie-rods (see fig.3). Additonal plates of 200mm thickness at the upper and lower side of the yoke compensate for the loss of material cross section caused by the coil channel.

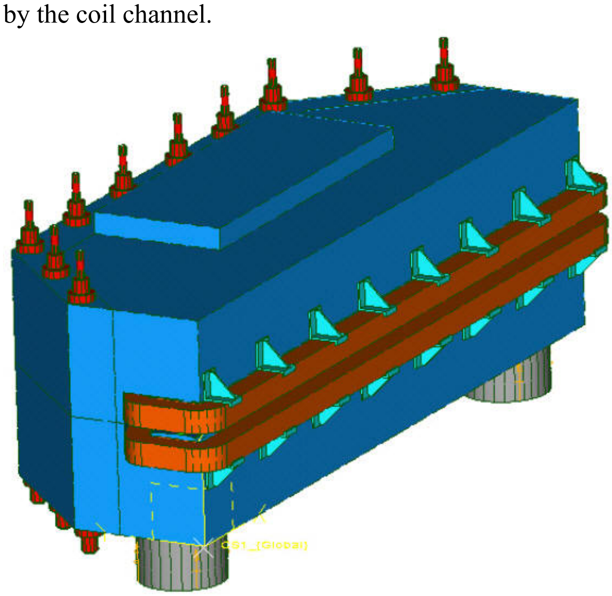

Figure 3: Mechanical set up of the HDSM magnets

The Finite Element Method (FEM) three dimensional program code IDEAS[5] has been used to calculate the deformation due to magnetic forces and gravity.
It was used a Youngs modulus of E=210 kN/mm^2 for the iron core and the rods and a Poisson ratio of 0.3. Other important parameters for the calculation were the minimum tensile strength of R_m>260 N/mm^2 and deformation strength R_{p02}>120 N/mm^2 given by the manufacturer.
The pole face is divided in plane, but inclined stripes with a width of 124mm. The force per area on this surfaces was calculated using the formula

$$\frac{F}{A} = \frac{1}{2\mu_0}\int B^2(x)dx \, .$$

In a first approach a version with 5 spacers was designed to minimise the reduction of the gap by the fection of the yoke. As can be seen in Figure the gap reduction for this configuration is in the order of 0.1mm but quite inhomogeneous along the z-axis. Without spacers the deformation is bigger by a factor of 3 but still not sufficiently homogenous. In order to further decrease the gap distance in the outer regions of the magnet, it was decided to insert an additional gap at the contact area to get an improved bending line and thus a more homogeneous deformation scheme. The results are shown in figures 4 and 5.

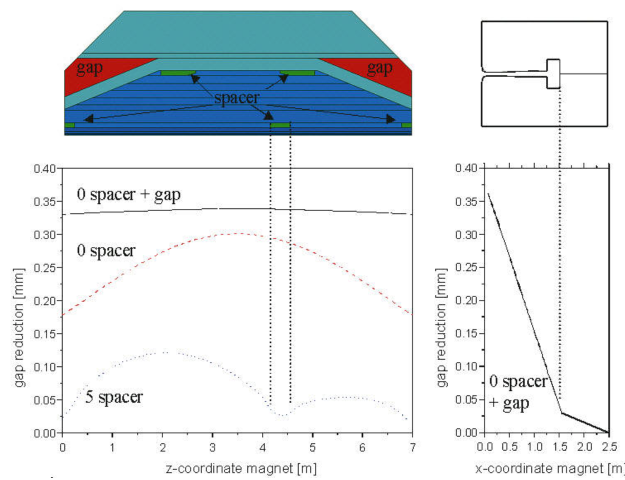

Figure 4:Deformations for different mechanical designs

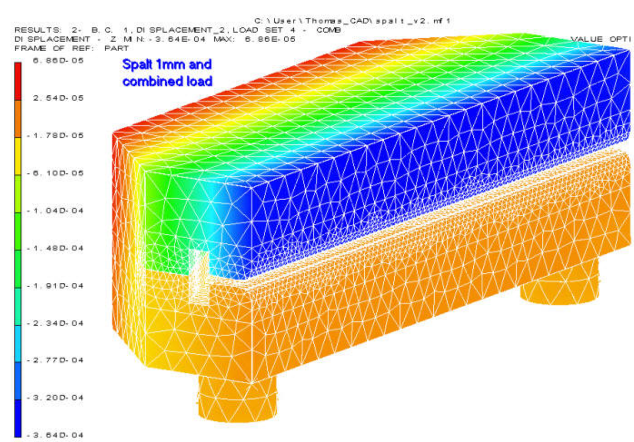

Figure 5: Calculated deformation with optimised design

Finally, the deformation depends linearly on the x-coordinate of the magnet and it is only weakly depending on the z-coordinate. Consequently the deformation in x-direction was taken into account in the drawings of the pole geometry.

3 STATUS AND FIRST MEASUREMENTS OF THE MECHANICAL AND MAGNETIC PROPERTIES OF THE MAGNETS

The coil for all four magnets have been delivered in the last year.

All eight iron blanks for the magnets have been casted at the company Usinor (Le Creusot, France) and the machining is still being done by SFAR (Montchanin, France). It was used a steel with a low carbon content (<0.02%) and a high chemical purity. The decision to build up the magnets from essentially two 125t parts was taken to provide a high mechanical stability and a very good reproducibility in the set up of the magnets.

Each magnet half is checked on site in France with respect to its geometry using a template for the pole profile and a theodolite for linearity and planarity of important faces. With the exeption of one part, which had to be remachined, all dimensions were found within the allowed tolerance of ±0.1mm. A special problem arose from inclusions which showed up in the pole face of thelower part of the second magnet, maybe caused by fragments from the ceramic coating of the casting stoves. After investigating different possibilities for repair by means of steal plates which could be installed as pole plates in a small test magnet it was decided to repair the affected part by countersinking and shrinking in a steel plate of dimensions 500mm*300mm*100mm. A control measurement with an induction coil after this procedure showed no further problems.

The first of the four magnets has been delivered end of 2001. It was transported from the manufacturer in France to Mainz using a train and a heavy load truck. Because of the narrow building apertures into the underground accelerator hall (see fig.1) a computer controlled hydraulic steel cable lifting system has to be used to allow a rotation and fine positioning of the 125t magnet parts. The company ATTOLLO (Görlitz, Germany) developed a solution with minimum construction work for the existing experimental halls.

The first dipoles magnet has been mounted completely and put in its final position. A measurement of the reduction of the gap caused by the magnetic forces has shown a good agreement with the FEM-calculation (see fig. 5). The deformation of the magnet with field switched on leads to the designed value of 85mm for the gap. A fine tuning of the deformation was possible by changing the pre-stress in the rods and by inserting small, thin brass plates (400mm*100mm*0.4mm) in the contact area

Recently a field map of this magnet was measured using hall probes. The result is shown in Figure 8. In this plot one line represents 10^{-4} Tesla. There was done a correction with the measured profile in the middle plane. It can be seen that a correction of the inhomogeneities is possible using correction coils.

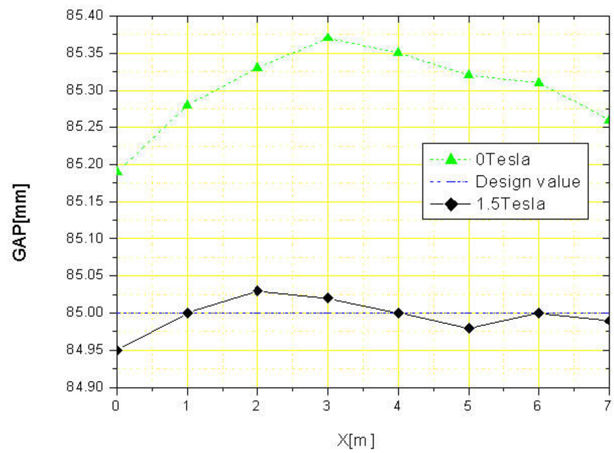

Figure 6: Measured gap reduction due to magnetic forces

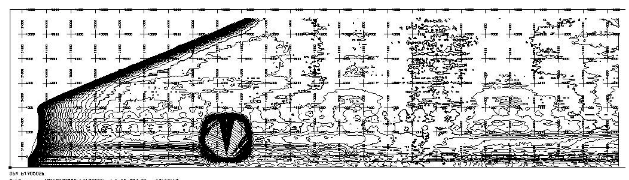

Figure 7: Field map of the first HDSM magnet

4 CONCLUSIONS

The first of the four 250t-bending magnets of the Harmonic Double Sided Microtron for MAMI is operational in Mainz. First measurements of the mechanical and magnetic properties show a good agreement with the calculation done with three dimensional computer codes TOSCA and IDEAS.

The magnetic measurements will be used to build up a system of surface correction coils like for the RTM3 dipoles of MAMI[6] to reach a field quality of 10^{-4} for the requirements of the beam optics.

The remaining three magnets have been casted and will be delivered to Mainz within this year, it is expected that the required specifications will be reached.

5 REFERENCES

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