3D CALCULATIONS FOR THE MAX II LATTICE MAGNETS

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Abstract

3D calculations for the MAX-II lattice magnets [1] are made with a new free magnetostatic code Radia [2] developed at ESRF for undulator calculations. The results are compared to the magnet measurements.

1 INTRODUCTION

The Radia 3D magnetostatics code was developed in the Insertion Devices laboratory of the European Synchrotron Radiation Facility. The original purpose of the code was to allow high-precision and CPU-efficient computation of the magnetic field and field integrals from permanent magnet and hybrid type Insertion Devices. The code has been continuously developed over the last decade. The integrated effort for the development equals, at this moment, approximately 2 man-years.

The computation method used by Radia differs from the Finite Element Method, the latter being in common use by most of the currently available 3D magnetostatics codes. The Radia follows the Magnetisation Integral approach. It has a number of similarities and improvements with respect to the code GFUN-3D developed at the Rutherford Laboratory in 1970's [3]. Radia benefits from the extensive use of analytical expressions for magnetic field and field integrals produced by polyhedron-shape volumes with constant magnetisation. A flexible mechanism of segmentation, support of non-linear and linear anisotropic materials, symmetries, and a robust relaxation scheme [4, 5] make the code suitable for various magnet design related applications.

The code behaves especially well for the geometries opened to infinity. In such cases it typically outperforms the FEM based codes in CPU time for the solution and the precision for estimation of the field integrals.

The core part of Radia is written in C++. The code is interfaced to the Mathematica [6]. Pre- and post-processing of the field data is done in the Mathematica language.

2 LATTICE ELEMENTS STUDIED

2.1 Dipole Magnet

The dipole magnet shown in Figure 1 is a part of the MAX-II storage ring. It is a standard c-shaped dipole magnet with chamfered ends and shimmed poles. The magnets are ramped from 500 MeV injection energy to 1.5 GeV stored electron energy.

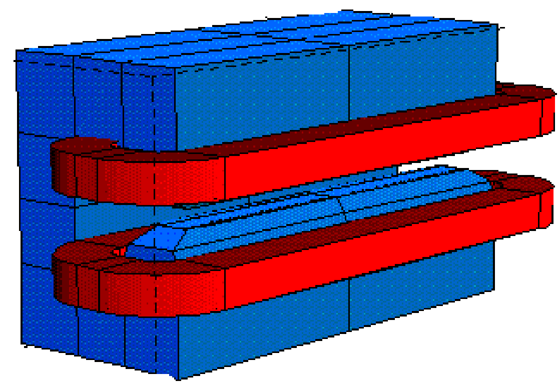

Figure 1: Dipole magnet.

2.2 Measurements and Radia Simulations for the Dipole Magnet

The end field of the dipole magnet was measured with a hall probe along a straight line making a 9 deg. angle to the normal of the magnet end face. Calculated and measured values are compared in Fig. 2. In this figure and in all the following figures calculated values are shown as open circles and measured values as filled rectangles.

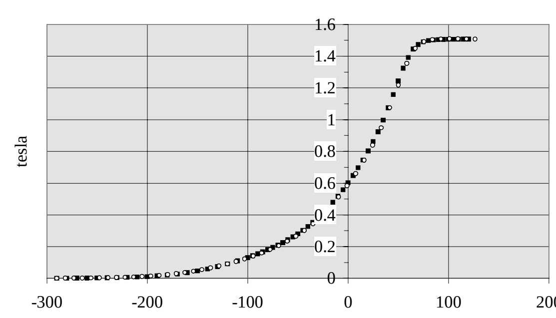

Figure 2: Dipole end field.

The transverse measurements in Figs. 3,4 for high and low excitation show that the shims are partly saturated at high excitation. The resulting sextupole components change sign in going from low to high excitation.

The Radia simulations turned out to be very sensitive to an exact modelling of the magnet .The chamfer angle and coil structure determine the end fields. With the correct parameters the simulations are in good agreement with the measurements. The absolute field calculated by Radia was however about 1% too low so in the figure below the calculations are normalised to the measurements. The Radia simulations in the transverse direction show the correct basic dependence on the excitation but the saturation of the shims is not reproduced completely.

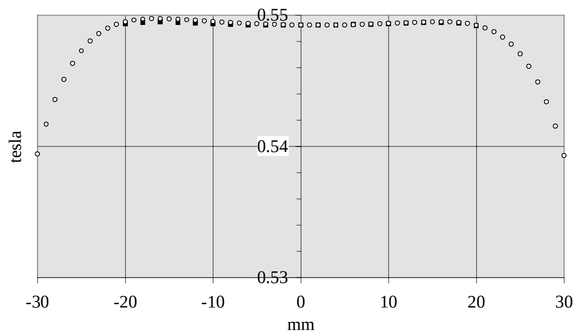

Figure 3: Transverse dipole field for low excitation.

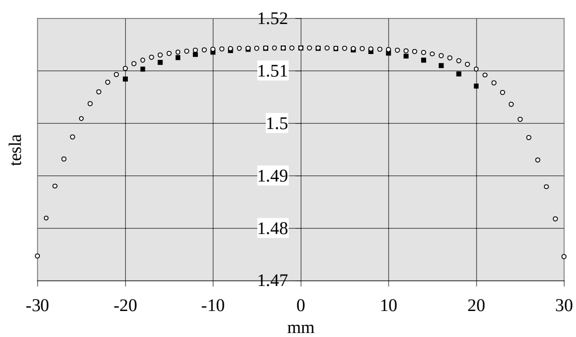

Figure 4: Transverse dipole field for high excitation.

2.3 *Quadrupole with Integrated Sextupole*

The quadrupole (Fig. 5) is a part of the MAX-II lattice. The sextupole part of the structure is used to correct chromaticity in the lattice. Fine tuning of the sextupole component is made using the back-leg coils.

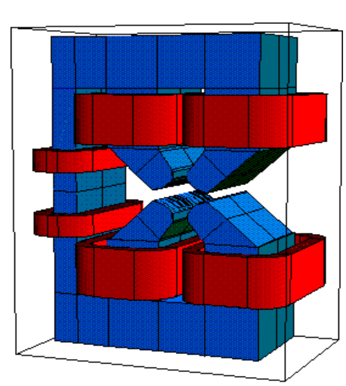

Figure 5: Quadrupole magnet.

2.4 *Measurements and Radia Simulations for the Quadrupole Magnet*

The end field is measured along a straight line at a constant distance from the quadrupole center axis. The Radia calculations reproduce the measurement very well (Fig. 6). The transverse measurements also show good agreement with the Radia calculations (Figs. 7,8). There is no normalisation in this case. The quadrupole/sextupole parts are extracted by harmonic analysis and compared in Table 1 below.

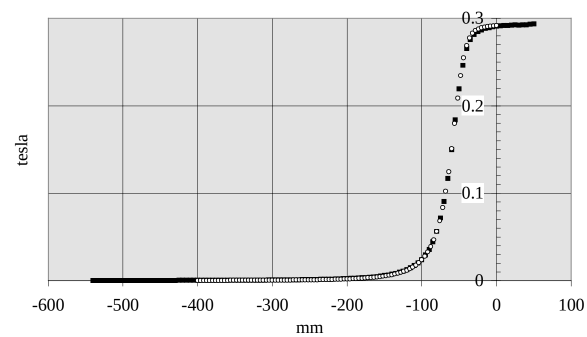

Figure 6: Quadrupole end field.

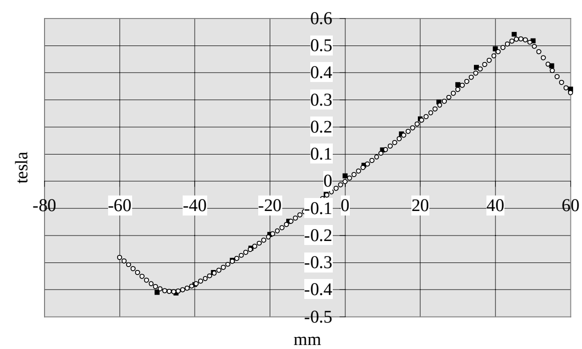

Figure 7: Transverse quadrupole field at low excitation.

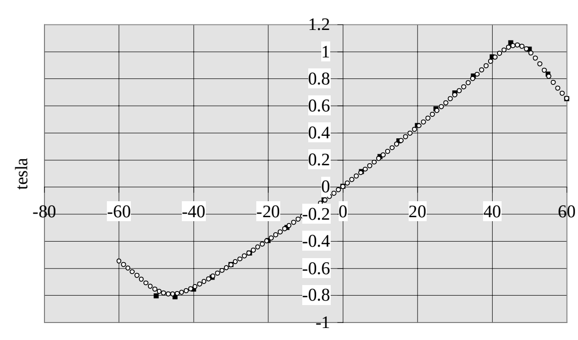

Figure 8: Transverse quadrupole field at high excitation.

Table 1. Quadrupole and sextupole components.

I=480A, Iback=1A	quadrupole	sextupole	magnetic length
Measured (mean value)	21.1 T/m	57 T/m^2	233 mm
Radia	21.1 T/m	54 T/m^2	234 mm

3 CONCLUSIONS

This comparison between the Radia simulations and old measured magnets was made in order to get a feeling of what can be obtained from the code.

One thing that is essential for a good computation result in the case of an iron-dominated geometry, is a proper subdivision of the iron parts into small blocks. A major step forward for the code was the inclusion of polar subdivision in the regions where the magnetic field lines are bent. This resulted in fewer blocks and a faster convergence toward the correct fields.

Still the basic Radia calculation method seems to introduce some “friction” for the magnetic flux resulting in absolute fields of the order of 1% too low. This circumstance can probably be compensated for, but to do so we need a lot more absolute magnet measurements as references. We have noticed that the absolute and relative agreement is enhanced by applying a magnetic material with a steeper B-H curve than the actual material.

Finally coming back to the present comparison, we can conclude that the Radia code gives excellent agreement in both the dipole and quadrupole case for the end fields and so for the magnetic length. There is a disagreement on the absolute scale especially for the dipole of about 1%. We have a very good agreement for the gradient in the quadrupole. There is a minor disagreement for the sextupole component, but its significance is small. The sextupole component is also influenced by the B-H curve for the magnetic material applied and, as discussed above, the agreement is enhanced by applying a steeper curve than the actual one.

We hope that the Radia support and further development will continue. Already during this work, new versions of the code have appeared several times.

REFERENCES

[1] Å.Andersson et al., Design Report for the MAXII ring. ISRN LUNTDX/NTMX—7019---SE.

[2] The Radia code is freely available for download from the ESRF Web site: “http://www.esrf.fr/machine/support/ids/Public/index.html”.

[3] C.W.Trowbridge, "Application of Integral Equation Methods to the Numerical Solution of Magnetostatic and Eddy-Current Problems”, in “Finite Elements in Electrical and Magnetics Field Problems”, John Wiley, edited by M.V.K. Chari and P.P. Silvester, 1980, chapter 10, p.191.

[4] P.Elleaume, O.Chubar and J.Chavanne, “Computing 3D Magnetic Fields from Insertion Devices”, proceedings of the IEEE PAC-97 conference (Vancouver, Canada, May 1997).

[5] O.Chubar, P.Elleaume and J.Chavanne, “A 3D Magnetostatics Computer Code for Insertion Devices”, Journal of Synchrotron Radiation, 1998, vol.5, p.481.

[6] Mathematica is a registered trademark of Wolfram Research, Inc.