DESIGN OF THE MAX IV/SOLARIS 1.5 GEV STORAGE RING MAGNETS

M. Johansson*, MAX-lab, Lund, Sweden

Abstract

The MAX IV synchrotron light source [1], currently under construction, will consist of a 3 GeV storage ring, a 1.5 GeV storage ring, and a full energy linac injector/SPF/FEL driver. The Solaris facility [2], which will be built in Krakow, Poland, will use an identical 1.5 GeV storage ring, injected at 500 MeV. The magnet design for the 1.5 GeV storage ring is conceptually identical to the MAX III [3] and the MAX IV 3 GeV storage ring magnets [4], with several magnet elements machined out of one solid iron block. Detailed design is made in Opera3D, with a model of the full magnet block being simulated, to be iterated against the lattice design.

BASIC SPECIFICATIONS

The MAX IV/Solaris 1.5 GeV storage ring consists of 12 double bend achromats (DBA). The starting point for the magnet design is the initial lattice [4], in which all magnets are defined as hard edge elements. The lattice elements are listed in table 1 with the specified bend angles and focusing strengths, together with the corresponding field values at 1.5 GeV. A sketch of the DBA, according to this lattice design, is shown in Fig. 1.

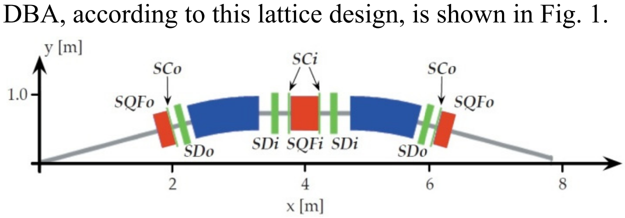

Figure 1: Schematic of one achromat of the MAX IV/Solaris 1.5 GeV storage ring.

Further basic specifications are

- All magnet elements within each DBA are machined out of one solid iron block, i.e. twelve magnet blocks per storage ring, each ca 4.5 m long. As for the 3 GeV ring, the rationale behind this is compactness, vibration stability, alignment within block and time spent on installation and alignment.
- Elliptical vacuum chamber, inner dim. 56x28 mm through SDi-SDi, 40x20 mm elsewhere. Wall thickness 1.5 mm.
- The first dipole in each DBA shall have synchrotron light beam ports at 3 and 7.5°.
- All magnet elements of the same family are powered electrically in series (except SCo/SCi).
- Coolant water Δp = 2 bar, max dT = 10 °C.
- The magnet design is optimized for 1.5 GeV, but also evaluated from 500 MeV to 1.5 GeV.

As for the MAX III and MAX IV 3 GeV ring magnets, the alignment of magnetic centres within each magnet block is determined by the mechanical tolerances of the yoke block halves. The function critical surfaces (pole profiles, guiding slots and mating faces) will be specified to ±0.02 mm tolerance, as representing what we believe to be at the achievable limit for conventional CNC-milling of pieces of this size. Thus, the yoke block halves will be the most challenging parts in the manufacturing of these magnets. We consider the MAX III magnets [5] and MAX IV prototype magnet [6] as indicative of this tolerance level being possible to reach. Another indication is the MAX II girders, ca 6 m long, that were machined to within this tolerance level. [7]

Table 1: From Initial Lattice File "m5-20110201-501-bare.opa", Elements Constituting ½ straight and ½ DBA.

element	l [m]	t [°]	k [/m²]	m [/m³]	B [T]	B' [T/m]	B''/2 [T/m²]
7×str0250	1.75						
bpm	0.05						
SQFo	0.2		5.7367	36.677		-28.713	-183.57
SCo *	0.05			±30			±150
str0080	0.08						
SDo	0.1			-91.922			460.1
str0090	0.09						
DIP #	1	15	-1.3480		-1.3103	6.7468	
str0190	0.19						
SDi	0.1			-73.226			366.5
str0140	0.14						
SCi *	0.05			±30			±150
SQFi	0.2		4.9985	28.040		-25.018	-140.35

* to include x- and y-corrector windings providing ±0.25mrad
# to include pole face strips providing ±2% gradient adjustment

2D DESIGN

The 2D design of the different magnet elements has been made using the FEMM [8] finite element code.

The "DIP" Gradient Dipole

DIP is the magnet element requiring the largest cross section for the coils and return yoke. This in turn defines the outer dimensions of the other magnet elements in the block. The 2D model is shown in Fig. 2. Simulated $B_y(x)$ is shown in Fig. 7.

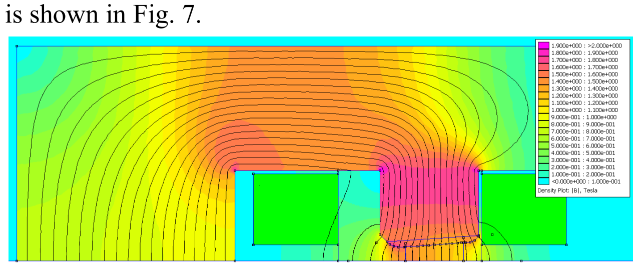

Figure 2: 2D model "MJ110623-05a, DIP.FEM", B field in the xy-plane. Colour scale: 0-2 T. The coil cross section is marked green. The field in the pole root is 1.7-1.8 T.

* Martin.Johansson@maxlab.lu.se

The high saturation in the return yoke, seen in Fig. 2 had to be accepted since the height of the yoke half, 185 mm, is given by the maximum avaliable thickness of hot rolled low carbon steel plate.

The pole face strips are yet to be included. 2 mm per pole is reserved for this purpose.

"SQFo" and "SQFi" Combined qpole/6poles

The combined function qpole/6pole magnets are designed as quadrupoles, but instead of a pure hyperbola, the central part of the pole profile is given by magnetic scalar potential $\varphi = kxy+m(x^2y-y^3/3)$, where k and m are the focusing strengths from table 1. The SQFo 2D model is shown in Fig. 3. Simulated $B_y(x)$ is shown in Fig. 4.

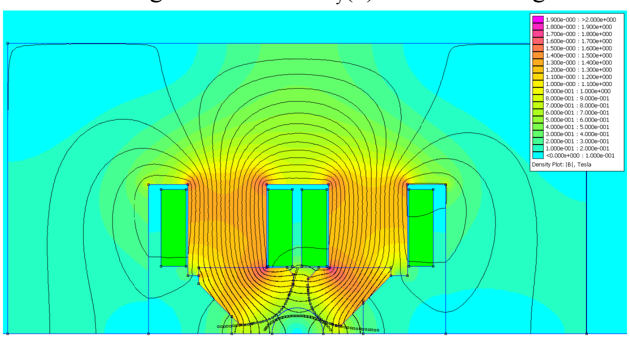

Figure 3: 2D model "SQFo, MJ110803-13.FEM", B field in the xy-plane. Colour scale: 0-2 T. The coil cross section is marked green. The field in the pole root is 1.2-1.3 T.

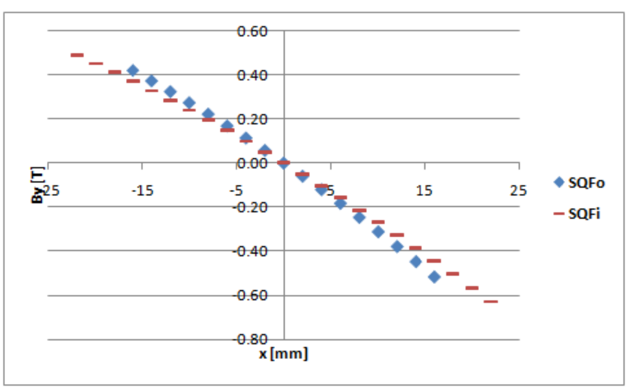

Figure 4: 2D field simulation results for SQFo and SQFi, $B_y(x)$ in the mid plane. The 6pole content is 183.58 T/m^2 for SQFo and 140.39 /m^2 for SQFi, which is close to the table 1 specifications. Residual between $B_y(x)$ and $B'x+(B''/2)x$ is < 2 G for both.

3D DESIGN

A 3D model of the entire magnet block has been made in Opera3D [9]. The model is shown in Fig 5. We consider the Opera3D simulations of the 3 GeV ring mc prototype magnet block to be a benchmark for this magnet design [6]. The first iteration of the magnet design is currently being prepared and will be given as feedback to lattice design.

The "DIP" Gradient Dipole

Initial studies of the DIP design have been made simulating half of the magnet, by imposing a boundary condition halfway along the pole. The model is shown in Fig. 6. As for the prototype magnet [6], the dipole is evaluated by calculating int$B_y(x)$ds in longitudinal slices, followed by polynomial fit. Central slice $B_y(x)$ is shown in Fig. 8, together with the 2D simulation result. The gradient differs slightly between 2D and 3D simulation. We are proceeding with the pole profile that produces the specified gradient in the 3D simulation.

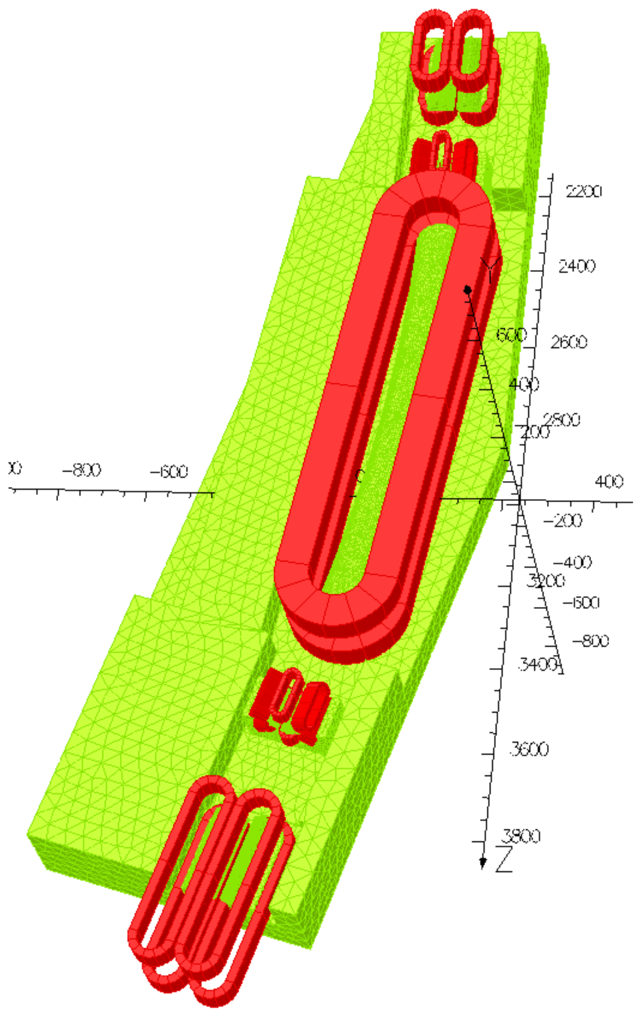

Figure 5: Opera3D model "MJ110829-01.opc". The model has a boundary condition halfway into SQFi, utilizing the symmetry of the DBA.

As seen in Fig. 6, the DIP pole entrance is completely saturated. The initial studies indicate we cannot improve this while restricting DIP mech. length to that available in the initial lattice design. We are therefore redesigning DIP with a longer mech. pole length (but same l_{eff}). As a consequence, SDo will be moved away from DIP.

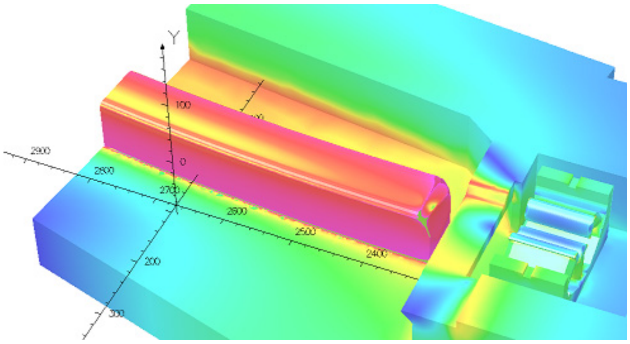

Figure 6: 3D model "MJ110704-04.opc", B field in the iron surface for DIP coils at nom. I. Colour scale: 0-2 T. The coils are hidden from view. The field clamp between DIP and SDo is necessary to decrease DIP fringe field distribution sensitivy to coil shape/position.

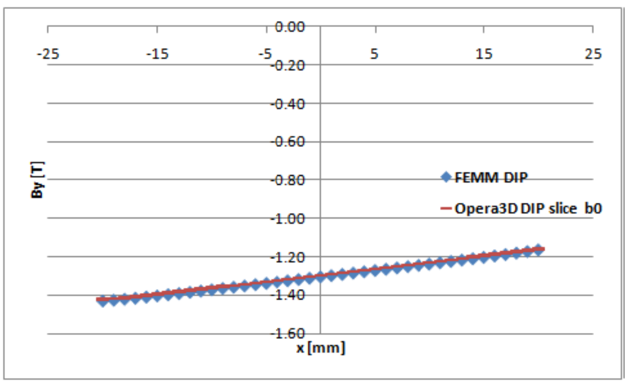

Figure 7: By(x) in the mid plane for the models shown in Fig. 2 and 6. In FEMM, linear fit B' = 6.7321 T/m. For the Opera3D central slice, B' = 6.7467 T/m, which is close to the table 1 spec. Residual between By(x) and linear fit is < 2G over x=±10 mm for both simulations.

"SQFo" and "SQFi" combined qpole/6poles

First iteration design is complete for SQFo and SQFi. The model is shown in Fig. 8.

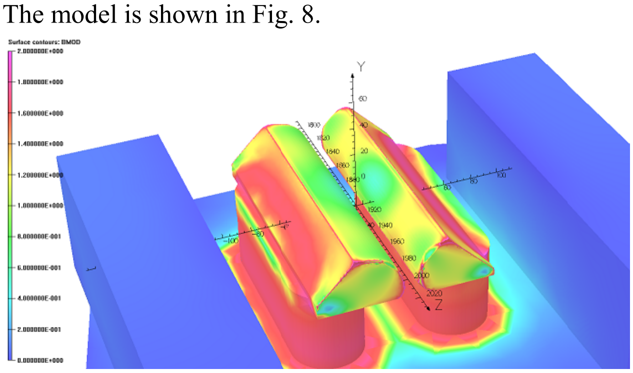

Figure 8: 3D model "MJ110829-01.opc", B field in the iron surface for SQFo coils at nom. I. Colour scale: 0-2 T. The coils are hidden from view.

We accept the high saturation in the pole root to get the mechanical length of the coils within 200 mm, same as the l_{eff} specified in table 1. For SQFi it was necessary to extend the mechanical length to 430 mm, i.e. the SCi are moved outward.

For both SQFo and SQFi, it was not possible to get the qpole and 6pole l_{eff} equal. The first iteration design has the qpole l_{eff} and central 6pole strength equal to specified. In feedback to lattice design, these magnet elements will be defined as consisting of bulk + fringe slices. The central 6pole strength will then be increased in the second iteration lattice. [10]

SDo/SDi and SCo/SCi

First iteration 3D design (seen in Fig. 5) was completed for SDo/SDi, but this is not valid after the advent of the the beam ports spec., as the 7.5° pipe would be in conflict with the coils. The magnet design will be updated.

The SCo/SCi will be finalized only after the first iteration 3D design is complete for all other magnet elements, at which point the available space is known. Preliminary calculations indicate that they need to be lengthened to reach the specified strength.

Since both SDo and Sci are moved from their initial lattice positions, their strength will increase in the second iteration lattice. [10]

Cross Talk

The only significant cross talk field indicated by the 3D simulations this far is a dipole content of ca 1 mT in the SDo, caused by DIP return flux. Consequences are being investigated.

REFERENCES

[1] M. Eriksson et al. "The MAX IV Synchrotron Light Source", THPC058, this conference
[2] C. Bocchetta et al. "Project Status of the Polish Synchrotron Radiation Facility Solaris", THPC054, this conference
[3] M. Sjöström et al. Nucl. Instr. And Meth. A 601 (2009)
[4] MAX IV Detailed Design Report, http://www.maxlab.lu.se/maxlab/max4/index.html
[5] B. Anderberg (private communication).
[6] M. Johansson et al. "MAX IV 3 GeV Storage Ring Prototype Magnet", WEPO015, this conference
[7] M. Eriksson (private communication).
[8] D.C. Meeker, Finite Element Method Magnetics, version 4.2 02Nov2009 (Mathematica Build), http://www.femm.info.
[9] Opera Version 13.034 Professional Edition x64, http://www.vectorfields.com/
[10] S. C. Leemann, "Recent Improvements to the Lattices for the MAX IV Storage Rings", THPC059, this conference