MAGNETIC SIMULATION OF A SUPERCONDUCTING UNDULATOR FOR THE ADVANCED PHOTON SOURCE*

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Abstract

A superconducting planar undulator is under development at the Advanced Photon Source (APS). The initial R&D phase of the project includes intensive magnetic modeling performed with the Opera 2d and 3d software packages. This simulation addresses questions of magnetic design of the undulator including calculation of peak field on the undulator axis and maximum field in the conductor, superconductor load line optimization, and design of the undulator ends and correction coils. Results of the magnetic simulation are presented in the paper.

INTRODUCTION

The APS Magnetic Devices Group is running an extensive R&D program aimed at development of superconducting planar undulator for the APS users [1]. An essential part of the R&D phase of the project is magnetic simulation of the undulator magnetic structure. This simulation was performed using the Opera electromagnetic simulation software package by Vector Fields [2]. The simulation addressed questions of the winding geometry of the undulator coils, calculation of the superconductor load line, and design of the end windings and correction coils. The results of the magnetic simulation are presented in this paper.

THE APS SUPERCONDUCTING UNDULATOR

A description of the main parameters to be achieved in the APS superconducting undulator is given in Table. 1.

Table 1: APS Superconducting Undulator Specification

Electron beam energy	7 GeV
Photon energy at 1st hamonic	20-25 keV
Undulator period	16 mm or less
Magnetic gap	9 mm
Magnetic length	2400 mm

The magnetic gap is defined by a beam stay-clear requirement for the APS storage ring of 7 mm in the vertical direction (and 36 mm in the horizontal). Taking into account the thickness of the beam chamber walls, a magnetic gap of about 9 mm could be achievable. The magnetic length of the superconducting device is a standard length for APS undulators [3].

A superconducting undulator period of 14-16 mm is expected to be achievable. This is about half of the period length of the APS undulator A. As is shown herein, a period length of 16 mm allows for superconductor operation below 80% of the critical current.

MAGNETIC MODELS

Magnetic simulation of the superconducting undulator was performed using the Opera software package from Vector Fields. Both 2d and 3d magnetic models, shown correspondingly in Fig. 1 and Fig. 2, were used for the simulation.

As can be seen in the figures, the magnetic structure of the planar superconducting undulator consists of two half-magnets, each made with a set of small race-track superconducting coils wound into the grooves cut in the core. The currents flow in opposite directions in adjacent

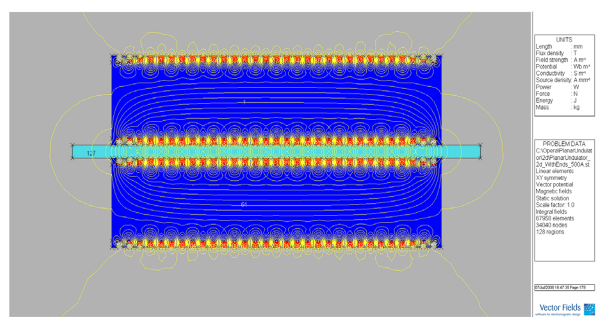

Figure 1: 2d Opera model of the undulator with coil windings shown in red and the core shown in blue. The magnetic flux lines (in yellow) are also shown.

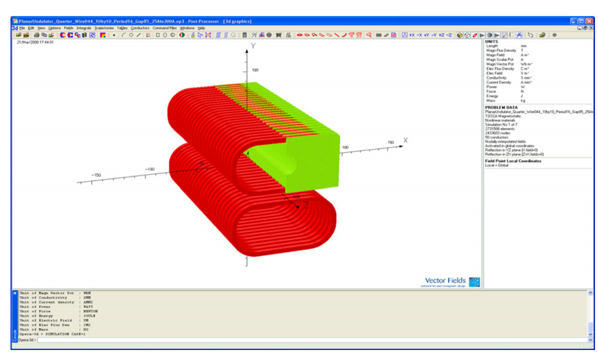

Figure 2: 3d Opera model of the undulator section with coil windings shown in red and a quarter of the core shown in green.

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windings.

The task of magnetic modeling was to find the shortest period length that would give the tuning range requested by the user without violating the storage ring required beam stay-clear.

EFFECT OF CORE MATERIAL

In the undulator structure, the winding core (or the former) could be made of either non-magnetic (e.g., an Al alloy) or magnetic material (a soft steel 1006-1010). An additional model was considered at this stage, a so-called 'iron tube'-core model in which the only magnetic material is the material between windings (the poles) and a thin internal layer, as shown in Fig. 3.

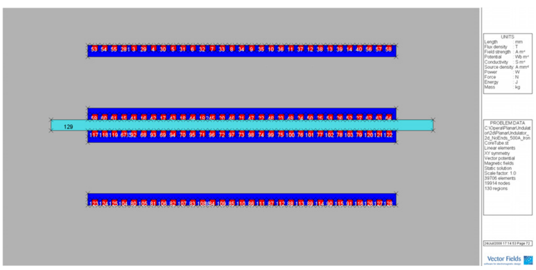

Figure 3: 2d model with 'iron tube' core.

The effect of magnetic material in the core on the undulator peak field, the maximum vertical field on the undulator axis, and the maximum field in the conductor was analyzed using a 2d model. The results are shown in Table 2 for models with a period of 16 mm and a magnetic gap of 9 mm.

Table 2: Effect of Magnetic Material in the Core Calculated Using 2d Models for 500-A Operating Current

	Non-magnetic core	Iron core	'Iron tube' core
Max field on the undulator axis	0.415 T (1 arb.unit)	0.71 T (1 arb.unit)	0.70 T (1 arb.unit)
Max field in the conductor	1.37 T (3.3 arb.unit)	1.96T (2.8 arb.unit)	2.09T (3.0 arb.unit)
Max field in the pole region	1.58 T (3.8 arb.unit)	3.76 T (5.3 arb.unit)	3.87 T (5.5 arb.unit)

According to the simulation, the magnetic core increases the peak field value by about 71% as compared to that of the non-magnetic core. Only a relatively thin layer of magnetic material in the core around the coil winding is required, however, as shown by the results for the 'iron tube'-case.

The ratio of the maximum field in the conductor to the on-axis peak field is the lowest for the iron core case, at about 2.8, as compared to 3.3 for the non-magnetic core case.

LOAD LINE CALCULATION

The load line for the superconductor in the planar undulator was calculated based on the data for a NbTi superconductor produced by Supercon Inc. [4]. In this calculation a round wire with 0.75-mm outside diameter (including insulation) was used. The calculated load line for a period of 16 mm and magnetic gap of 9 mm is shown in Fig. 4.

An on-axis field of 0.64 T is required for a first harmonic energy of 20 keV. As can be seen in the figure, the operating current needed for this field is about 429 A. At this current the superconductor is at 65% of its critical current value at the temperature of 4.2 K. The calculated temperature margin is about 2.1 K.

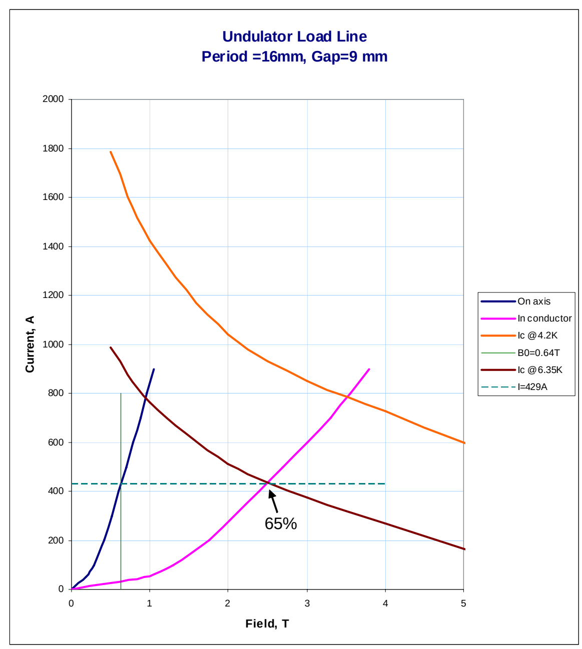

Figure 4: Undulator load line.

CORRECTION COILS

The quality of the magnetic field produced by a superconducting undulator is related to the quality of manufacturing of the superconducting coil. This requires a high precision winding on a high-precision former. It is assumed that the achievable tolerance in coil manufacture is in the region of 50 μm for coils with a length of about 1 m. Therefore correction of the magnetic field profile will be necessary.

The effect of magnetic field correction was calculated using a 2d model that includes a pair of correction coils, one at each end of the main coil. In principle, a correction coil could be wound on top of the main coil in the first groove that contains only a reduced number of 17 turns for the main coil. The effect of adding a single layer of turns of correction winding on the second field integral is shown in Fig. 5 for a relatively short undulator. In such a case, the required correction current is about half of the current in the main coil. The correction current can be reduced if the correction coil contains more turns. This approach was taken for the design of a 42-pole test magnet that contains 22 turns of correction winding. This will allow the correction current to be 20% of the main current.

A pair of 42-pole test coils was fabricated and is being tested. The results will be compared with the simulation.

CONCLUSION

A planar superconducting undulator is under development at the APS. As a part of the R&D phase of the project, magnetic modeling was performed using the Opera software package.

The results indicate that the required photon energy range of 20-25 keV can be achieved with a superconducting undulator having a period length of 16 mm and a magnetic gap of 9 mm.

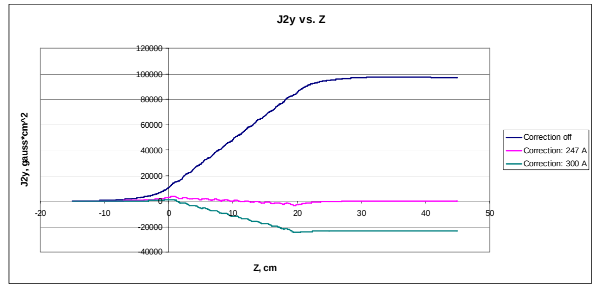

Figure 5: Effect of operating a pair of correction coils on the second field integral.

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