DEVELOPMENT OF AN ELECTROMAGNETIC/PERMANENT MAGNET HELICAL UNDULATOR FOR FAST POLARISATION SWITCHING.

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Abstract

A new electromagnetic/permanent magnets helical undulator, with a 65 mm magnetic period is under development at SOLEIL for providing a rapid switching (10 Hz) of the photon polarization required to perform dichroïsm experiments. The vertical field will be produced by coils fed by a fast switching power supply, with a maximum current of 280 A and a polarity switching time shorter than 100ms. The coils consist of copper sheets shaped by water jet cutting. 25 layers of copper will be stacked together and 9 of them will be cooled with thermal drain to a water piping. The current-regulated power supply should be able to operate in the 4 (A, V) quadrants with a 50 ppm current resolution over the full scale. The horizontal field is generated by NdFeB permanent magnets. The design vertical and horizontal peak field values in the helical configuration are 0.25 T at the minimum 15.5 mm gap. The magnetic design and the correction scheme are described. A prototype was built to characterise and validate the technical choices, and the results are discussed. The efficiency of the cooling system and the results of the magnetic measurements are also presented.

INTRODUCTION

The EMPHU consists of 26 periods of 65 mm length. The overall length is 1750 mm. The EMPHU is made of coils, steel poles and permanent magnets fixed on two girders (upper and lower ones). The two girders are attached to a motorized carriage which can move the girders vertically with a gap varying between 15.5 mm and 250 mm. The vertical movement is needed to change the peak field values. The EMPHU will use permanent magnets for the horizontal field and coils around poles for the vertical one. This configuration offers the flexibility to provide a pure helical field or a linear horizontal field when the power supply is switched off.

DESIGN

As the period is too short for using classical racetrack coils, the EMPHU comports serpentine coil on the same principle as the one developped at ESRF [1] but derived from a copper sheet concept as in Jefferson Lab [2]. With such an approach, the coil design is simpler than an impregnated epoxy one and the space ratio between poles and coils is efficiently optimized to produce the vertical field. Indeed, we use the space between the poles to install an array of permanent magnets to produce the horizontal field (see figure 1).

At the entrance and at the exit, the design integrates two different poles with a limited number of turns in order to compensate the first and second field integrals. Around the first and last poles, corrector coils will be installed in order to finely tune the vertical magnetic field integral during fast switching transition. Extra horizontal and vertical steerers are added on both sides of the undulator.

Figure 1: Prototype detail with permanent magnets, poles and copper sheets.

Vertical Field

Standard silicon-steel (Powercore M270) was selected because of AC application. The coil is fed by a 280 A current which polarity can be switched in less than 100 ms. In order to centre the wiggling of the electron beam on the axis, the structure starting from a 25%, 75%, 100% repartition is adjusted so that a trade off between number of turns around the poles and longitudinal length of those poles is found.

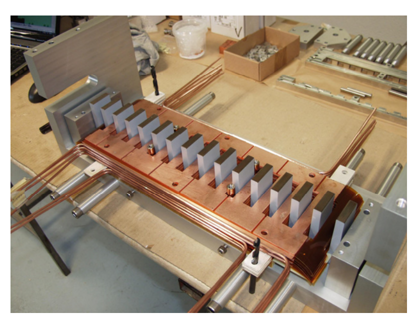

Figure 2: Assembling of the serpentine coil on the prototype.

The laminations will be stacked and glued before machining. The pole will be wire cut in order to achieve very tight tolerances on the shape. The elementary serpentine coil will be made of two current carrier sheets (CCS) and a thermal drain sheet (TDS). The shape of those sheets will be water cut. After machining, the serpentine coil is stacked around the pole as shown in figure 2.

Horizontal Field

The horizontal field will be generated by an array of permanent magnets. Those magnets are made of NdFeB with a remanent magnetic field of 1.26 T. The direction of magnetisation is vertical. We will install two permanent magnets between two poles. The magnetic field configuration is designed in such way that the vertical trajectory of the electron beam wiggles around the axis. As for the vertical field, the classical 25%, 75% and 100 % field structure is slightly adapted by adjusting the longitudinal length of the permanent magnets. Also, during the assembling of the undulator, we will have the ability to move vertically and horizontally every single magnet to finely tune the horizontal field from magnetic measurements.

RADIA 3D Simulation

The 3D simulation has been done with the help of RADIA Code [3]. A cross check has been done with OPERA 3D (Vector fields) for some specific configurations. The model is a short version of the undulator. (see figure 3). The complete geometry had to be modelled because of the lack of symmetry. The computation was done with the magnetic properties provided by the steel manufacturer. Figure 4 presents the resulting magnetic calculated with such a model.

The pole width (60mm) was optimized to ensure the necessary vertical field homogeneity along the radial and vertical coordinates, and thus to limit the perturbations due to non-linearity on the electron beam.

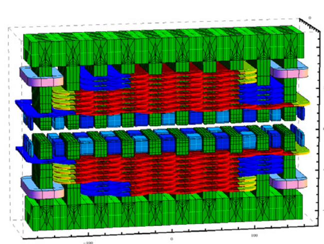

Figure 3 Radia model of a short version of the undulator (5 periods).

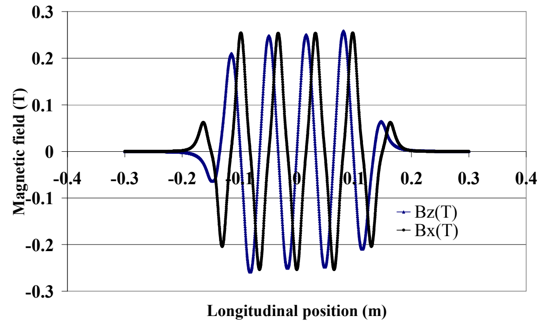

Figure 4: Computed magnetic fields at 15.5 mm gap using the RADIA model.

Cooling System

The copper will be cooled by a thermal drain. Between CCS, a TDS is inserted with two brazed pipes at the edges. Those pipes will be fed by cooled water. The cooling calculations are shown in Figure 5. With a 33°C water, the temperature increases up to 44°C in the middle of the CCS at 44 °C with 30 W dissipated in the elementary serpentine coils. Between each copper sheet (CCS and TDS), a thin layer of Kapton will be inserted in order to guarantee the insulation.

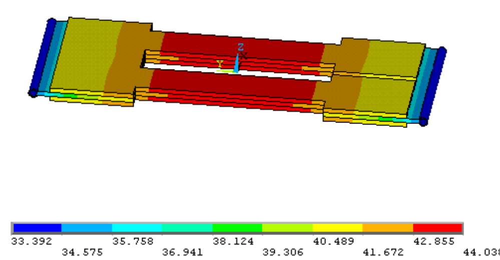

Figure 5 : ANSYS thermal calculations.

PROTOTYPE

Description

A prototype has been built for checking the efficiency of the cooling system and 3D magnetic model. This mini undulator has a fixed gap of 16mm, the pole width is 40 mm and the period is the same as the EMPHU i.e. 65 mm.

Magnetic Field Measurements

As shown in figure 6, an important discrepancy (about 20% less) was observed between the measured vertical field and the computed one. It could be explained by the difference of effective magnetic properties of the steel compared to the ones used for the simulation (see figure 7). Once the steel measured magnetic properties were introduced into the modelling, the measured vertical field properly fitted nicely the computed one.

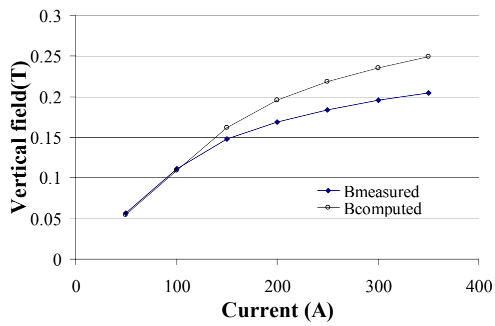

Figure 6: Comparison of measured with Bell GH701 Hall probe and computed vertical field .

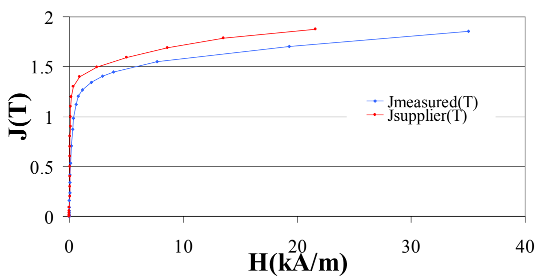

Figure 7: Magnetisation J vs magnetic filed excitation H for silicon steel.

Temperature Measurements

To test the efficiency of the cooling system, we stacked two platinum resistances directly on a CCS. We fed the prototype with a 350A. The water temperature in the two brazed pipes of this CCS is 37 °C. In this setup, the power in the elementary serpentine coil is 33 W, the temperature of the CCS is 52 °C after adjusting the water flow at the same value as the thermal calculation. The temperature rise of 15 °C shown in figure 8 is in good agreement with the simulated one of 11 °C for 30 W (see figure 5).

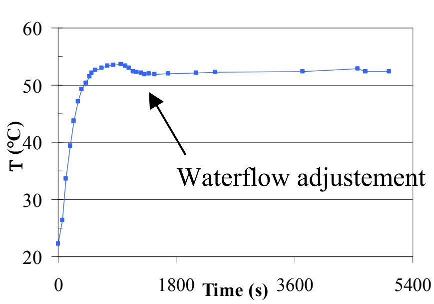

Figure 8 : Temperature with 350 A.

POWER SUPPLY AND CORRECTION SCHEME

The main power supply has been designed in-house. The main current will be switched from +280 A to -280 A in less than 50 ms. The current stability is about +/-50ppm without any overshoot. The corrector power supply will be fast enough to compensate any closed orbit distortion during transition and will be synchronised on the main power supply. The regulation of the main current is based on digital pulse width modulation. The theoretical efficiency is 85%.

We will use a set of six correction coils (four vertical fields and two horizontal fields) split between the entrance and the exit of the undulator. In order to keep the (horizontal and vertical) transition effects as low as possible, each corrector power supply will be able to generate arbitrary waveforms (see Eq. 1) with the help of a digital signal processor.

$$I_{cor}(t) = \alpha I_{main}(t+\tau_1) + \beta \frac{dI_{main}}{dt}(t+\tau_2) \qquad (1)$$

The applied correction current I_{cor} is the sum of the main current I_{main} applied with a certain delay τ_1 and the derivative of the main current applied with another delay τ_2 as given in Eq (1). The second term aims at compensating the Eddy current in the vacuum chamber.

CONCLUSION

The prototype validated the design concerning the thermal efficiency and pointed out the sensitivity of the magnetic field regarding the steel quality. The manufacturing of the EMPHU will start in the next few weeks.

REFERENCES

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[3] P. Elleaume, O. Chubar, J. Chavanne, Computing 3D magnetic fields from insertion devices, in: Proceedings of PAC 97, p.3509.