USING RADIA TO MODEL SUPERCONDUCTING WIGGLERS AT THE CANADIAN LIGHT SOURCE

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Abstract

The Canadian Light Source (CLS) operates two superconducting wigglers (SCW): a 2 Tesla, 63 pole wiggler, and a 4 Tesla, 27 pole wiggler. Both SCWs have a negative impact on the facility's injection efficiency. Beam based measurements indicate a larger than expected sextupole moment, and the 4T wiggler produces a horizontal tune shift. To better understand these effects, computer models were developed for the SCWs using the magnetic modeling software package, RADIA [1]. The RADIA models accurately predict the wiggler on-axis field strength and vertical tune shift. By introducing physical misalignments, the models can also produce sextupole moments on the same order of magnitude as the measured quantities. However, the modeled horizontal tune shift is orders of magnitude smaller than the 4T wiggler's observed tune shift. Various model parameters were investigated for their effect on horizontal tune shift, but the cause of the 4T wiggler's horizontal tune shift remains unknown.

MODEL CONSTRUCTION

Overview

The RADIA model was built according to the design drawings represented in Fig. 1 and Fig. 2. As indicated, the pole model can be considered as three main components: the core, the yoke, and the coils. The core is the lowermost section of an ARMCO-iron yoke and is partly enclosed by the current-carrying coils. The yoke returns magnetic flux and supports the coils.

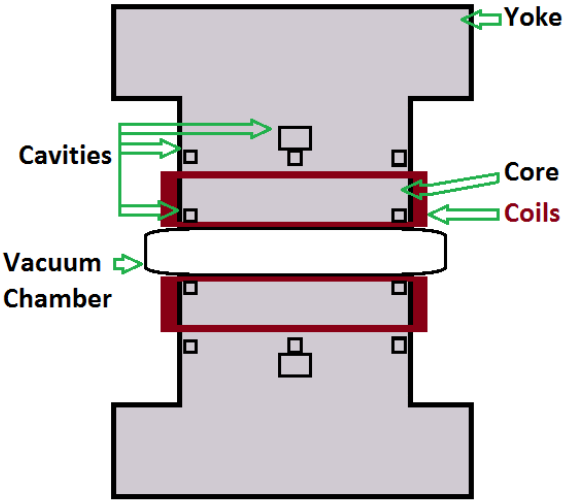

Figure 1: 2T SCW pole, side view.

For the purpose of orientation and alignment, special pins with rounded heads are molded into the cores. In order to include these pin cavities in the model, the core is modeled in upper and lower sections, as shown in Fig. 3.

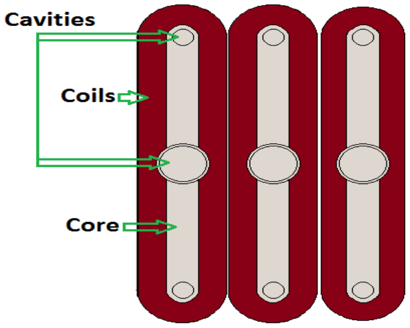

Figure 2: 2T SCW cores and coils, bottom view.

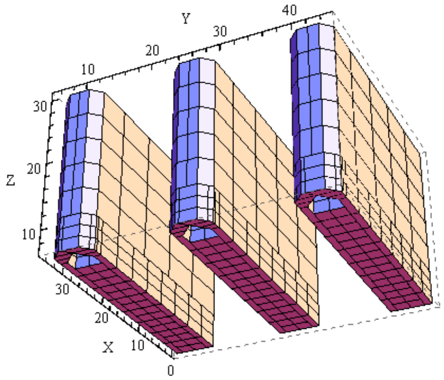

Figure 3: Three half-cores modeled in RADIA.

The SCW's superconducting coil is modeled as uniform current-carrying racetracks. Coil design differs slightly between the two SCWs; while the central poles of the 4T device each have two separately powered windings (see Fig. 4), the 2T device only has one coil per core.

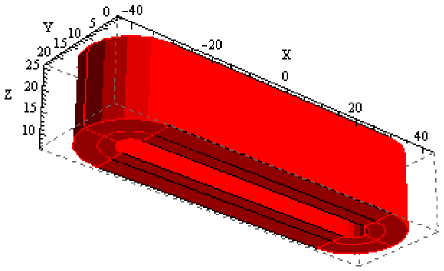

Figure 4: 4T SCW's dual coil winding.

ISBN 978-3-95450-115-1

Figure 5 shows the cores, yoke, and current-carrying coils combined to form a model SCW with six poles.

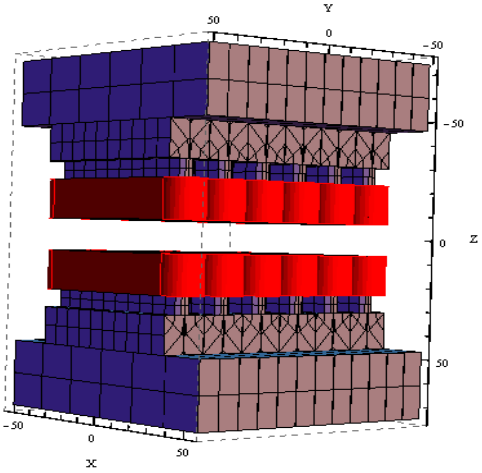

Figure 5: Six pole SCW model in RADIA.

Summary of Assumptions and Approximations

Construction of the RADIA models made use of the following approximations:

- Modeled superconducting current windings as uniform current-carrying racetracks.
- Approximated pin cavity's cylindrical shape.
- Approximated core's rounded edge.
- Ignored stainless steel structural components.
- Manufacturer (Budker) design reports describe core and yoke's material as ARMCO-iron, the magnetic properties of which we do not know in detail. The RADIA model uses the built-in material RadMatXc06, which is "an inexpensive low carbon steel with C<0.06%".
- Ignored vacuum chamber.

MODEL PERFORMANCE

Field Strength

The initial benchmark for the RADIA models was ramp tables, which were supplied by the device manufacturer and later refined by CLS; these tables map power supply current to the device's peak field. As shown in Fig. 6, the models and ramp tables agree very well for fields above 1T. Results diverge for lower field strengths, but there is no foreseeable reason to use the model (or the devices) at such fields.

Integrated Sextupole Moment

Measurements of the 2T and 4T SCWs show sextupole terms of -670 ± 230 G/cm and -680 ± 120 G/cm, respectively [2]. RADIA models containing no misalignments do not produce sextupole moments of this order; the 2T SCW model predicts 50 G/cm, and the 4T SCW model predicts 215 G/cm.

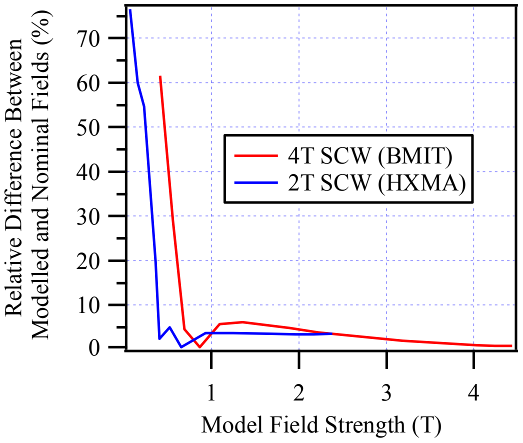

Figure 6: Performance of modeled magnetic field.

To see if misalignments could explain the large observed sextupole moments, the models were adapted to include both rotational and translational misalignments of the poles (see Fig. 7). The misalignments shown are exaggerated for visibility. For the actual analysis, misalignments followed a Gaussian distribution with a mean of 0.5mm and 3mrad.

It was found that each misalignment in the device has a linear effect on the overall sextupole moment. A single 100µm translational misalignment will change the predicted sextupole moment of the 4T SCW by 40 G/cm and the 2T SCW by 15 G/cm (values are approximate); a single 1mrad rotational misalignment will change the sextupole moments of both devices by approximately 13 G/cm. The sign of the change depends on the misalignment's location within the device.

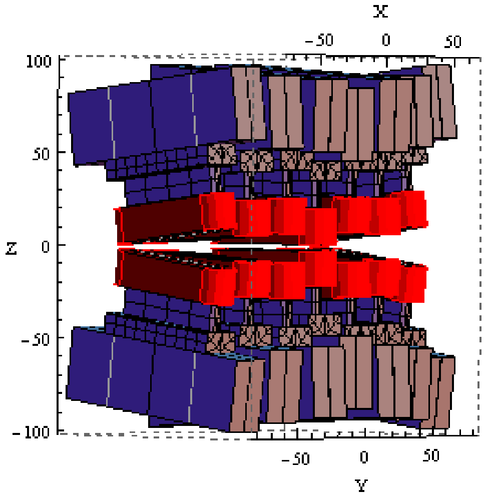

Figure 7: Exaggerated misalignments in a seven pole RADIA model.

Given how the sextupole moment reacts to small misalignments, it seems plausible that a combination of such misalignments could be responsible for the observed sextupole moments in the actual devices. With the described misalignments, the RADIA models can produce sextupole moments of magnitude similar to the measured quantities.

Tune Shift

The RADIA model can be used to generate kickmaps [3] for the SCWs (see Fig. 8). The devices' tune shifts can be determined from the kickmaps using elegant [4]. Tables 1 and 2 show the measured and predicted tune shifts for both SCWs.

Table 1: 2T SCW Tune Shifts at 2.1T

HXMA (2.1T)	**Tune Shift (Measured)**	**Tune Shift (Kickmap)**
Horizontal	0.0001 ± 0.0002	0
Vertical	0.0061 ± 0.0002	0.0061

Table 2: 4T SCW Tune Shifts at 4.3T

BMIT (4.3T)	**Tune Shift (Measured)**	**Tune Shift (Kickmap)**
Horizontal	-0.0014 ± 0.0002	0
Vertical	0.0146 ± 0.0002	0.0149

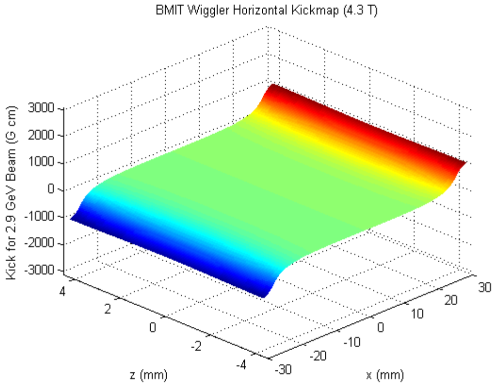

Figure 8: Horizontal kickmap for 4T SCW.

There is reasonable agreement between the measured and predicted values for vertical tune shift. However, the horizontal tune shift is predicted to be virtually zero for both devices; this does not agree with the observed tune shift of the 4T SCW.

Following the above findings, the model was altered in numerous ways in an attempt to describe the large observed horizontal tune shift. Alterations included:

- Rotational and translational misalignments.
- Adjusting the material parameters of the modeled yoke and cores (e.g. switching from low carbon steel to Vanadium Permendur).
- Increasing the SCW's period length.
- Decreasing the SCW's pole width.

The final alteration was motivated by the nonlinear dynamics observed in the SPEAR BL11 wiggler, which had narrow poles [5].

None of the other alterations studied had an appreciable effect on the horizontal tune shift. As expected, though, decreasing pole width resulted in a sharper rise to the horizontal kick (see Fig. 9). Moreover, the peak field remained unaffected.

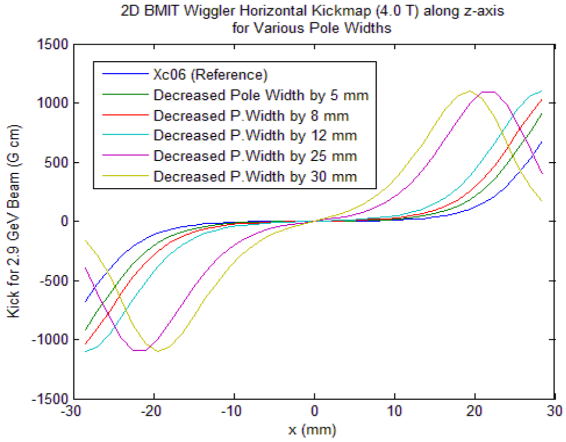

Figure 9: 2D horizontal kickmap for 4T SCW model using various pole widths.

Unfortunately, for the model to produce horizontal tune shifts comparable to the observed amount, the pole width must be reduced by 30mm. Given that the nominal pole width is 60mm, this is a highly unrealistic deviation from the design drawings.

CONCLUDING OBSERVATIONS

RADIA models developed for the two SCWs at the CLS accurately predict peak magnetic field. Moreover, one can introduce reasonably small misalignments to the models that result in an integrated sextupole moment comparable to the observed values.

However, despite various tests examining the behavior of horizontal tune shift, no realistic change was found that could produce the tune shift observed in the 4T SCW. The factor causing this device's horizontal tune shift remains unknown.

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