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MAGNETIC FIELD ERRORS AND POSSIBLE CORRECTION SCHEMES IN SCUs

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Abstract

One of the challenges of superconducting undulators (SCUs) is the fulfilment of tight mechanical tolerances. Simulations show that to guarantee high quality of the emitted radiation local mechanical errors must be below a few tens of micrometres. Such requirements are at the limit of the most precise machines and techniques for mechanical manufacturing. In addition, once the SCU is assembled with the support structure, mechanical deformations can affect the device in the long range. This paper outlines potential errors that may occur in the SCU, both over long and short distances. Additionally, it introduces several techniques that rely on shim coils to address a portion of these errors.

INTRODUCTION

Superconducting Undulators (SCUs) generate a higher peak magnetic field on axis B_0 for a fixed period length λ_u and vacuum gap with respect to other technologies: permanent magnet undulators (PMUs), in-vacuum undulators (IVUs) and cryogenic permanent magnet undulators (CPMUs). Thanks to the higher peak field on axis, also the tunability range of the generated photon energy E_{ph} is broader compared to the other technologies if the electron beam energy γmc^2 is kept constant, as can be seen from the relation:

$$E_{ph} = \frac{hc}{\lambda_u} \cdot \frac{2\gamma^2}{1 + \frac{K^2}{2}}, \quad (1)$$

where h is the Planck constant, c is the speed of light, γ is the Lorentz factor, K is the undulator parameter defined by the following relation: $K \simeq 93.4 B_0[T]\lambda_u[m]$. Superconducting undulators based on NbTi are a well-developed technology and they are already used in the following synchrotron facilities: the KIT lightsource [1], the APS [2] and now also ANSTO [3].

Long and short-range deviations from the ideal geometry of the SCU coils impact negatively the performance of the Free-Electron Laser (FEL) process. Short range errors are caused by deviations in pole and groove width and height, as well as misalignment of winding packages and they result in local field errors. The short-range errors related to S-PRESSO have previously been examined in [4, 5]. Conversely, long-range errors can arise from yoke misalignment during installation or as a result of forces exerted on the undulator's support structure [6]. The purpose of this contribution is to present correction schemes based on so-called 'shim coils'. With shim coils we mean racetrack coils wound with a small diameter superconducting wire added on the side of the SCU coils facing the electron beam (see Fig. 1).

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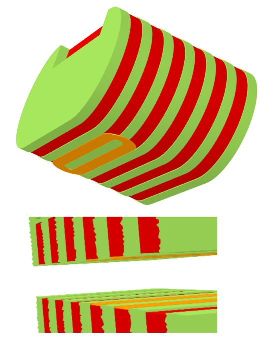

Figure 1: Shim coils on the SCU [7].

Shim coils are mainly meant to correct local errors that cannot be compensated with mechanical shims, used to compensate long-range errors.

SCU CASE UNDER STUDY

The geometry assumed in this study is the one of the S-PRESSO coils. S-PRESSO is the pre-series prototype for the superconducting afterburner for the European XFEL [8]. S-PRESSO is made by two sets of SCU coils, each 2 m long and with a period of 18 mm. In the simulations presented in this proceeding, the length of the SCU has been reduced to 15 periods to reduce the computing time. The vacuum gap of S-PRESSO is 5 mm and the magnetic gap is 6.5 mm and it enables the achievement of a peak field of 1.82 T and a K parameter of 3.06. The shim coils, wound with a thin NbTi wire with 0.152 mm diameter (insulated), can be operated at 5 A with 50% current margin with the main coils at nominal current. The needed accuracy for FEL process to occur is to achieve an RMS $\frac{\Delta K}{K} < 1.5 \times 10^{-3}$, which corresponds to a mechanical machining accuracy below 50 µm [9, 10]. If the machining accuracy is not achieved, the following shimming correction schemes are proposed.

CORRECTION OF POLE HEIGHT DEVIATION

We define as a signature the difference between the design field B_0 with the field where there is one deviation $\tilde{B}$, which can be either a pole height deviation, a pole or groove width deviation, or a winding package shift:

$$\Delta B = B_0 - \tilde{B}. \quad (2)$$

In the case of pole height deviation, the resulting signature has the shape of a Gaussian curve, as shown in Fig. 2. The pole height error can be corrected by shimming the two or four consecutive grooves, where the pole with the error lies in the middle, as shown in Fig. 3, depending on the amount

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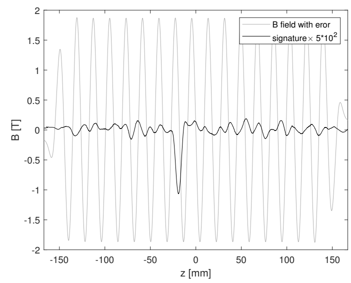

Figure 2: Signature of a pole height deviation of 50 µm.

of the error. Figure 4 shows the signature resulting from

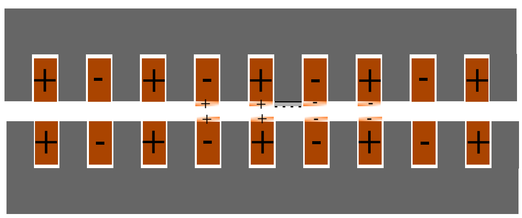

Figure 3: Sketch of undulator section with pole height error in the pole highlighted by a dashed contour line and proposed shimming correction scheme.

the shimming scheme chosen for the correction of the pole height error. The intensity of the correction can be controlled by the current applied in each coil and by the number of applied shims: the number of shims increases proportionally the intensity of the correction.

FEMM simulations [11] have been performed to validate

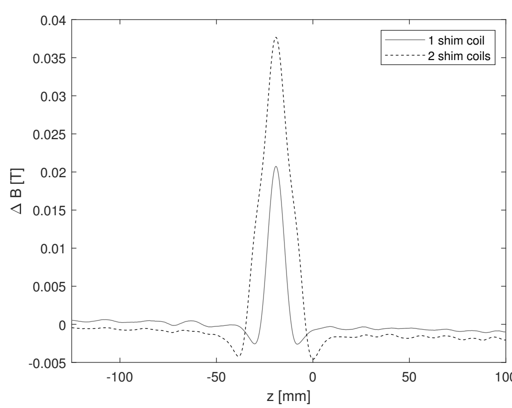

Figure 4: Correction from the shimming. The intensity can be increased if four grooves are shimmed.

that the shimming scheme proposed is able to correct an error in the pole height. The following simulations were carried out: undulator field without error and without shimming, undulator field with an error of 50 µm on a pole, and undulator field with both the pole error and the compensating shimming. The undulator K parameter has been calculated for each of the three simulations exploiting the output field.

The result is shown in Fig. 5. The deviation at coil number 12, given by the pole error, is completely compensated once the shimming is applied. For this case, a current of 0.8 A was sufficient to compensate a 50 µm pole deviation, by design a current up to 5 A might be used safely within the current margin.

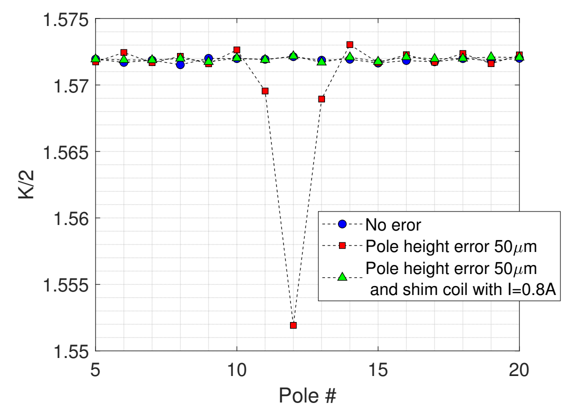

Figure 5: K/2 as a function of the pole number. In case of pole height error, the undulator K parameter is compensated by the proposed shimming scheme.

CORRECTION OF A VERTICAL SHIFT OF A WINDING PACKAGE

The typical signature of a vertical shift of one of the winding packages of the considered undulator can be described by the derivative function of a Gaussian, as shown in Fig. 6.

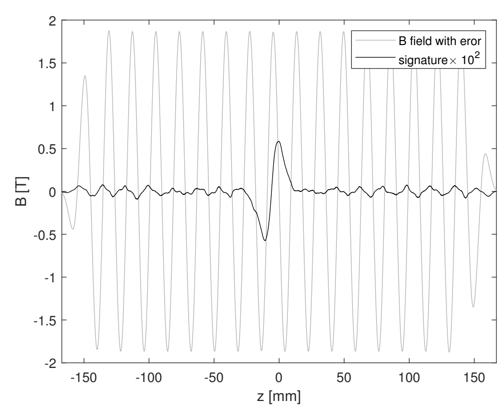

Figure 6: Signature of a vertical shift by 50 µm of one winding package.

A possible shimming scheme compensating a vertical shift of a winding package is shown schematically in Fig. 7. Here, one shim is positioned above the package with the vertical shift and on the right of it, another shim with an opposite current direction is placed. The shims facing the ones in the upper yoke are shifted to the left by one position to be able to compensate for the error signature.

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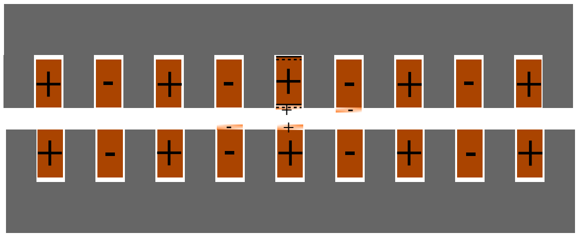

Figure 7: Shimming scheme compensating a vertical shift in one of the winding packages.

The proposed shimming scheme has been tested with FEMM simulations. The following simulations have been performed: undulator field without error, undulator field with a groove where the winding package has a vertical shift of 50 μm and the undulator field with winding package with vertical shift and correspondent correction with the proposed shimming scheme. For each resulting magnetic field, the K parameter at each half period has been extracted. In Fig. 8 it is visible that, when the vertical shift is present, a significant deviation in the K parameter is registered at the position between the thirteen and fourteen coils. This deviation is then successfully corrected when the shimming scheme is applied, as the deviation in the K parameter is recovered.

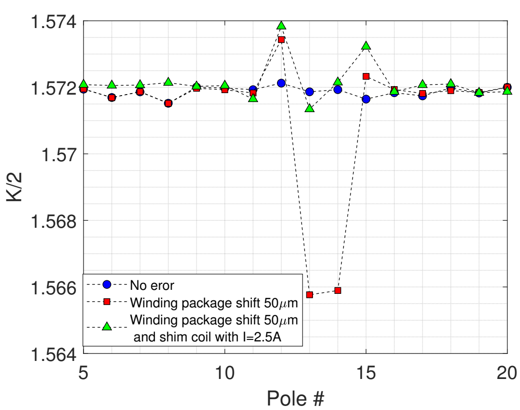

Figure 8: K/2 as a function of the pole number. In case of pole height error, the undulator K parameter is compensated by the proposed shimming scheme..

CORRECTION OF LONG-RANGE ERRORS

In case of constant field error, for example in the case of the effect of the offset given by the earth's magnetic field ($\approx 25 - 65$ μT), a possible shimming compensating scheme is shown in Fig. 9. In this case, a dipole field is generated by placing a total of six shims with an opposite current orientation at the extremes of the undulator extending all over the undulator length. The resulting field generated by such a shimming is shown in Fig. 10. In this figure, the signature of the shim is obtained by subtracting the undulator field without any perturbation, with the field where the presented

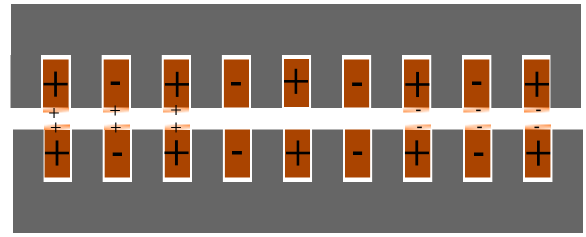

Figure 9: Proposed shimming correction scheme to compensate a constant field error.

shimming scheme has been applied. The achieved field correction achieved by applying a current of 5 A to the shims is 0.016 T.

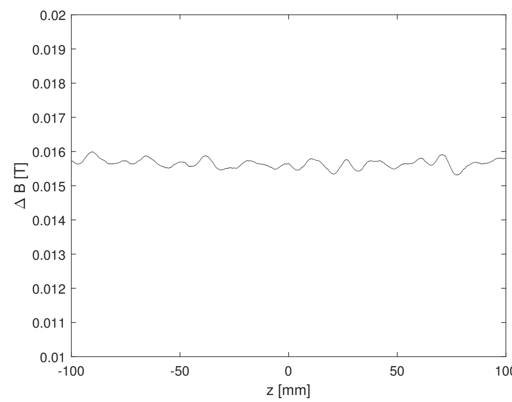

Figure 10: Signature of the shimming scheme compensating a constant field error.

CONCLUSIONS AND OUTLOOK

In this contribution, the authors have presented a study on the correction of field errors caused both by short and long-range errors which cannot be corrected by mechanical shims placed along the support structure. In this study shim coils have been used to compensate the magnetic field of a superconducting undulator affected by different errors. In particular, a pole height deviation from the ideal geometry can be corrected by placing a racetrack shimming coil wound around the pole affected by the error. In case a correction with higher magnetic field is needed, an additional shim coil can be added to the neighbouring grooves. A vertical deviation of the winding package from the ideal geometry can be corrected by shim coils with an asymmetric scheme, as shown in Fig. 8. Finally, a constant field offset as the one generated by the earth's magnetic field, can be compensated by assembling a dipole with racetrack shim coils extending through the complete undulator length.
As an outlook, the authors will investigate possible shim coils schemes allowing the correction of pole and groove width deviations.

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