EPU ASSEMBLY BASED ON SUB-CASSETTES MAGNETIC CHARACTERIZATION

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Abstract

A procedure to speed up the magnetic field correction of an EPU type undulator is proposed and partial results are shown. Such procedures consists of segmenting each one of the four linear magnet arrays (cassettes) into six sub-cassettes and perform their magnetic and mechanical characterization individually. A perfect theoretical sub-cassette, composed of four segments per period in Halbach configuration, is used as the standard field profile. The difference in the trajectory length for each semi-period of one assembled sub-cassette compared to the same semi-period in the standard field profile the optimization parameter. This optimization parameter is improved by displacing the magnetic blocks in both vertical and horizontal directions (virtual shims). The sub-cassette magnetic measurements, initially made in the Hall bench employed for insertion devices characterization, are now performed with the Hall probes installed in the sub-cassette assembling table.

INTRODUCTION

The EPU undulator [1,2] under construction at Brazilian Synchrotron Light Source (LNLS) has its four linear magnet arrays (cassettes) sub-divided in sub-cassettes to facilitate the magnetic part assembly. The proposal is to use the sub-cassettes to make a pre-correction in the undulator magnetic field profile in addition to checking mechanical tolerances and magnetic field polarities. This pre-correction was suggested as a way to save effort during the short amount of time scheduled for the undulator field tuning, since pre-correction could be done during the mechanical structure development. However, such proposal requires a study to see how the field imperfections and their corrections in a sub-cassette are transferred to the entire undulator.

Corrections in a sub-cassette are made against a standard field profile derived from the Halbach configuration having four blocks per period. The magnetization is obtained from the best fit made over a measured field profile. In the standard field profile generation, the permeability was not considered, thus forcing the first integral to be null for each sub-cassette. All calculations are made for a distance corresponding to minimum gap (22 mm) on the undulator central axis, and horizontal, vertical and circular polarization phases are analyzed.

Deformations and errors in the rest of the mechanical construction, excluding the sub-cassette structure, are not taken in to account.

Figure 1 is a sub-cassette drawing where the semi-periods ($\lambda/2$) and the reference system are defined.

The magnetic structure of the undulator is composed of 54 magnetic periods of 50 mm in length. Each cassette has six sub-cassettes plus the terminations. Magnetic blocks are made of NdFeB having 12.3×40×40 mm3. Maximum peak fields for different polarization phases (vertical, circular and horizontal) are 0.53 T, 0.27 T and 0.31 T, respectively.

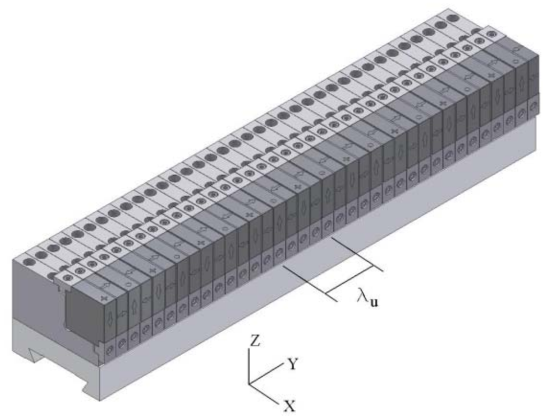

Figure 1: A sub-cassette and correlated definitions.

SUB-CASSETES AND UNDULATOR IMPERFECTIONS FIELD ANALYSIS

As the central idea is to pre-correct the undulator magnetic field even before it is assembled as a whole, a theoretical analysis verifying such possibility was made.

Sources of errors (imperfections) cited as possible causes of deviations in the ideal field profile (corresponding to perfect magnetic blocks correctly positioned), are:

1) Change in the value of the main magnetization component;

2) Existence of residual magnetization components in the directions perpendicular to the main component;

3) Blocks displaced from their reference positions;

4) Differently sized blocks;

5) Non-homogeneous magnetization of the blocks.

The first question is how one imperfection in the sub-cassette is correlated to the same defect in the undulator?

To find the answer Radia code for magnetic simulations [3] is used. The parameter chosen to compare the effect of one imperfection in the sub-cassette to the same imperfection in the undulator is basically the phase error used to optimize the radiation features [4], here defined as:

$$\Delta\Phi = \frac{2\pi}{\beta}\frac{\delta S}{\lambda_r} \tag{1}$$

where δS is the standard deviation of the trajectory length in the semi-periods, β is the rate between electron velocity and light speed and λr is the wavelength of emitted radiation.

Initially, one of the first four sources of errors cited above is applied on one block of the sub-cassette, having the magnitude listed below:

1) Blocks having main component magnetization 10% higher than the average.

2) Residual components 50× smaller than main component.

3) Blocks displaced 0.05 mm in the transverse directions (x and z).

4) Blocks size 0.05 mm bigger on the three edges.

All are worst-case conditions.

For item 5, the non-homogeneity only can change because the relative permeability is not equal to 1 and the magnetic neighborhood in the undulator is different to those present in the sub-cassette. This effect should reach the worst value for the blocks located at sub-cassette extremities, where the neighboring blocks are very different to that of the blocks in the undulator's central regions. In any case, as the relative permeability is around 1.1 for this kind of magnet, the field applied to non-homogeneities must vary by 1 T to have a magnetization variation of 10%. Based on these numbers and on typical undulator field magnitudes, this effect could initially be negligible.

Parallelly, the same error is applied to the same magnetic block, now placed in the undulator central region. Using the code, the field difference (ΔBsc) between a perfect sub-cassette and a sub-cassette containing an imperfect block is calculated for a distance related to the undulator minimum gap. The same is made for the undulator (ΔBu). If the permeability is equal to 1, the results will be the same in both cases (ΔBsc = ΔBu). To make the calculations, only the imperfect block is segmented in several parts (about 700) and has permeabilities of 1.06 for easy direction and 1.17 for hard direction. For all other blocks, 1 is attributed for their permeabilities. The permeability is applied only to one block due to computer processing speed and memory limitations.

Equations (2) and (3) show the field profile proposed to evaluate the phase error (equation (1)) caused by one imperfect block placed at the beginning of undulator (according to its position in the sub-cassette) considering the complete extent of the undulator.

$$B_u(y) = \Delta B_u(y) + B_0 \sin\left(\frac{2\pi y}{\lambda_u}\right) \tag{2}$$

$$B_{sc}(y) = \Delta B_{sc}(y) + B_0 \sin\left(\frac{2\pi y}{\lambda_u}\right) \tag{3}$$

where B0 is the undulator field amplitude of one of the components Bx or Bz, for a given polarization phase, and λu, the undulator period length.

Having the field expressions, the trajectory length Sx(y) on xy plane is obtained by the integration of equation (4):

$$dS_x(y) = dy\left[1 + \left(\frac{dx(y)}{dy}\right)^2\right]^{1/2} \tag{4}$$

where dx(y)/dy is given by

$$\frac{dx(y)}{dy} = \frac{e}{\gamma m_0 c}\int_0^y B_z(y')dy' \tag{5}$$

e being the electron charge, m0 the electron rest mass, c the light speed and Bz the field defined by equations (2) or (3). The same procedure is used to determine Sz(y). All calculation consider decoupled movements, i.e., x(y) only depends on Bz and z(y) only depends on Bx.

Concluding these analyses, it is verified that the differences of phase errors calculated for a sub-cassette and the entire undulator, considering one block and one kind of imperfection each time, reach the highest values of few hundredths degree, while the amplitude of the imperfection effect can produces some degrees in the undulator phase error. It means that the type of imperfection under analysis is more relevant than the effect of different neighborhoods acting on the block permeability. In other words, the effect of imperfections measured in a sub-cassette is approximately the same when the sub-cassette is installed to produce the undulator field.

SUB-CASSETTE CORRECTION

Virtual shims have been chosen as a way to correct the imperfection effect on the magnetic field. They are displacements of the blocks made in both transverse directions (x and z). Table 1 presents the field gradients (dB_x and dB_z) and integrated field gradients (dIB_x and dIB_z), given in arbitrary units from 0 to 7, having no correlation between dB and dIB, for blocks with magnetization **m** and displacement in **Δ**direction. These calculations were performed to the undulator minimum gap, not considering magnetic permeability. Blocks magnetized in the z direction have their field gradients calculated over the middle of the block, while blocks magnetized in the y direction have null values in this same plane. Therefore, values of dB indicated in table 1 were calculated over the midplane of the first neighbor blocks (1^{st}n).

Table 1. Field and integrated field gradients for corrections with virtual shims.

m	**Δ**	**dBz**	**dBx**	**dIBz**	**dIBx**
mz	dz	6	6	1	5
mz	dx	7	1	7	1
my	dz	3 (1^{st}n)	3	0	0
my	dx	3 (1^{st} n)	0	0	0

Some features of virtual shims can be taken from table 1.

1) There are more possibilities of effective correction for B_z profile than for B_x.
2) The correction procedure is not vry intuitive, since the displacements can change both field components B_z e B_x.
3) B_z could be corrected by displacing m_z in x direction, however, to correct only B_x, is necessary a composition of m_z displacements in both directions.
4) B_z integrated field is essentially corrected by dx displacements and B_x by dz displacements.

As the phase error has been chosen as the main parameter to be optimized, the sub-cassette correction is based on the standard deviation of the trajectory length (S) in each semi-period. Calculations are made for both field components (B_x e B_z) independently. The standard deviation is calculated by Equation (6):

$$\delta S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Sm_i - Ss_i\right)^2} \qquad (6)$$

N being the number of semi-periods plus the two end field regions, Sm the trajectory length in each semi-period calculated from the measured field after virtual shimming and Ss is the trajectory length obtained from standard field profile.

The main concern is if by correcting the field in the sub-cassette through virtual shims, the undulator magnetic field will also be automatically fixed. The same calculation made in the previous section, to evaluate the influence of the blocks displacement from their reference positions, is performed. However, the displacement amplitudes are higher: ± 0.25 mm for z displacement and 0.5mm for x. Now, the phase error difference between the sub-cassette and the undulator can reach the maximum value of 0.5^0 for one block with vertical magnetization (m_z), 0.5 mm horizontally displaced (dx) and shifting the cassettes in the phase for vertically polarized light. Observations on the block displacements, made to correct the field in a sub-cassette, show a few and small shifts. The procedure used in the sub-cassette makes the Undulator field go in the right direction and approach the ideal field.

Figure 2 shows the difference of the electron trajectory in the standard field profile and in measured fields, before and after virtual shimming.

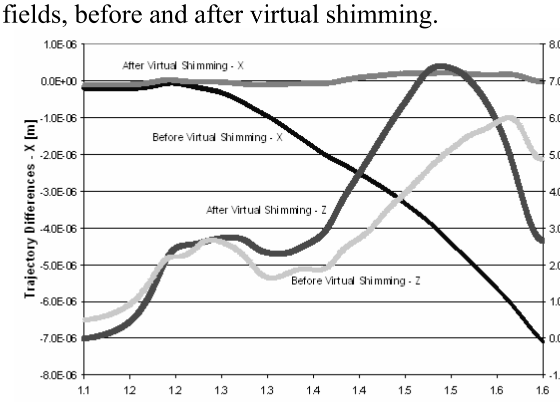

Figure 2: Effectiveness in the sub-cassette field correction.

SUB-CASSETTES ASSEMBLING

For the sub-cassettes assembling a special moveable table was designed (figure 3) which many feasibilities attached to it: one translation stage that allows for placing and removing the blocks, two linear encoders to check the transverse block positions, two orthogonal Hall probes for field verifications and pre-correction using virtual shims. As the biggest dimension is 1 meter, it was not difficult to hold the machining tolerances within ± 0.01mm. Another very important requirement is to assure the repeatability in the Hall probes position with respect to the sub-cassette block faces. Since on the measurement line there are gradients about 170 gauss/mm in all directions and field components, this compact and cohesive structure is a relevant advantage.

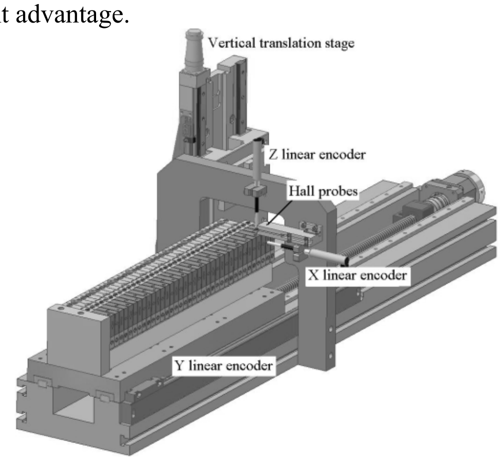

Figure 3: Sub-cassette assembly table.

CONCLUSIONS

Preliminary studies and ideas about an undulator field pre-correction procedure using virtual shims were presented. Such pre-correction is made in the sub-cassettes, which correspond to segments of the total magnetic structure, even before their installation in the undulator.

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