Experimental results and theoretical comparison between hybrid and electromagnetic wigglers

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Abstract

Extensive magnetic measurements have been carried out on two models, hybrid and electromagnetic of the wiggler for the ELFA project. Transverse pole shaping for horizontal beam focusing, PM assisting and different solutions for field error correction systems have been tested on the models. In this paper the analysis of the magnetic field measurements in the whole gap volume is presented and discussed, and a comparison between the two configurations and with the predictions of the 2D codes and 3D semi-analytical model is done.

1 INTRODUCTION

The ELFA wiggler (λ_w =12 cm, B_w = 3600 Gauss, nominal gap = 3.6 cm) is currently under study. Two full scale one λ_w models have been built in order to compare performances and costs of hybrid and electromagnetic construction schemes and to find the proper transverse pole profile needed for horizontal focusing. The magnetic measurements on the models were performed using a Hall probe; the vertical component of the magnetic field has been measured following a symmetric grid, of 55 × 15 points with a 2 mm step size on three different planes each 5 mm apart. This has been done for different excitation currents for the em model and different gap values for the hybrid. Further measurements have been done on the em model at fixed probe position and variable current.

A complete description of the models and of the experimental apparatus used can be found in ref. [1], presented in this Conference.

2 EXPERIMENTAL RESULTS

2.1 Peak field level

Flat poles (gap = 36 mm) have been used on both models for preliminary measurements, obtaining for the em model at the nominal current (300 A) a peak field about 6 % less than the one obtained with 2D POISSON simulations, whereas for the hybrid model a difference of ~ 20% with the 2D simulations performed with the PANDIRA code.

Comparing the on-axis peak field measured using the curved poles with 2D simulations (at the on-axis values for the gap), we found substantially the same percentage difference, showing that in our case, since the curvature is large compared to the gap dimensions, the field in the midplane is well correlated to the local gap value.

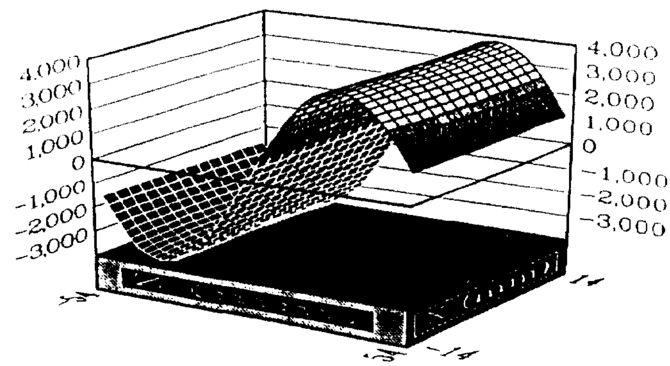

Figure 1: Measured field intensity (in Gauss) in the midplane of the em model (Excitation current = 7200 A turns). The transverse field profile is not apparent due to the scale.

Good agreement with the experimental data is found using a 3–D semi-analytical model [2]. The 2–D model extrapolated from the 3–D case agrees with the PANDIRA predictions.

For the em model with curved poles, we have also tested the PM assisting technique [3], obtaining a maximum peak field increase of 3 %. It should be noted that for this test we used a group of scrap $SmCo_5$ magnets of small dimensions (35 mm × 12 mm × 14.7 mm for the easy axis, with a total magnetic moment M = 4 A m^2); further tests will be performed with bigger NdFeB blocks, that should ensure a more appreciable peak field increase.

Fig. 1 shows the field profile in the midplane for the em model with curved poles.

Fig. 2 and 3 show the peak on-axis field as a function of the current, for the em model, and at different gap values, for the hybrid model, compared with simulations and semi-analytical model results.

2.2 Field harmonic contents

The harmonic contents of the field's vertical component have been determined via least-squares parametric fit. The expected values were 0.18 % (of the fundamental) for the

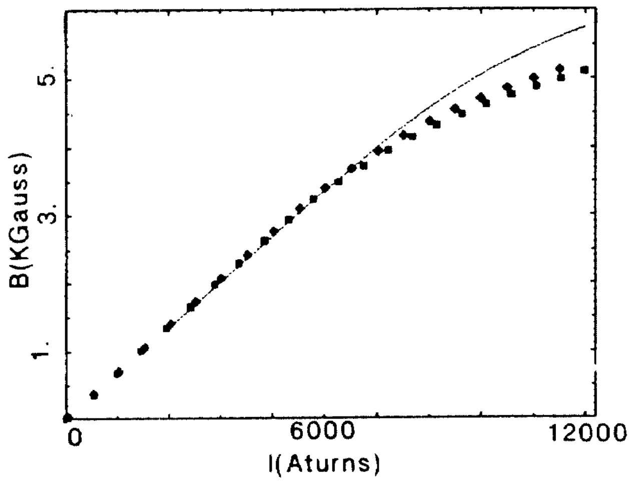

Figure 2: Peak on-axis field for em curved poles model as a function of current with (symbols◆) and without (symbols■) PM assisting, compared with 2D POISSON simulations results (dashed line)

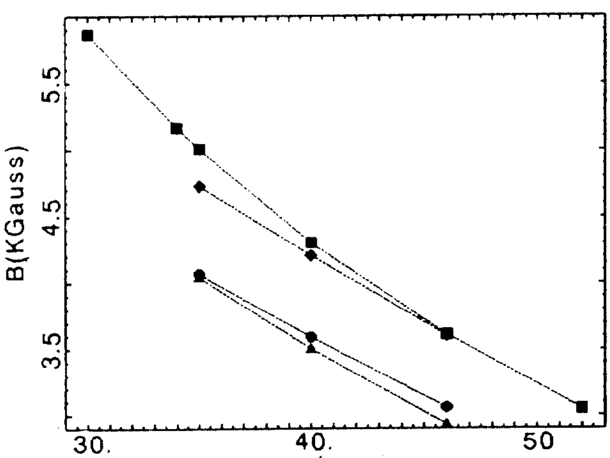

Figure 3: Peak on-axis field for hybrid curved poles model at different on-axis gap values (symbol▲), compared with: 2D PANDIRA runs (symbol■), 2D (symbol◆) and 3D semi-analytical model (symbol ●) predictions

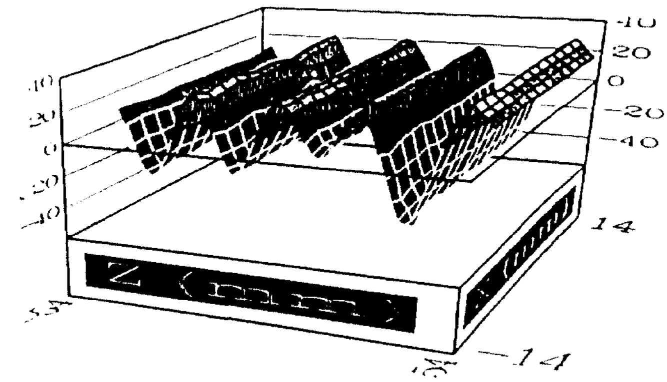

Figure 4: Global harmonic contents on the midplane of the em model (Excitation current = 7200 A turns).

third, 0.5 % for the fifth, and complete absence of the even harmonics. The relevant field harmonics measured were: $\sim$ 0.3 % for the second , 0.3 % for the third, and 0.5 % for the fifth . The value of the second harmonic is therefore a measure of field error. The values for both models are reported in table 1; as can be seen no major difference exists between the two models.

Table 1: Harmonic on-axis contents in % of the fundamental for the em curved poles model and the hybrid curved poles model

Harmonic No	Design	EM	Hybrid
2^{nd}	-	-0.34	-0.23
3^{rd}	-0.18	0.30	0.32
5^{th}	-0.50	-0.50	-0.50
Others	< 0.1	< 0.1	< 0.1

Fig. 4 shows the total harmonic contents in the midplane, which results $\lesssim 1$ % of the fundamental. It can also be noted that, in the entire measured region, it is quite uniform in the transverse direction.

Out of the midplane, the fundamental increases like cosh $k_y y$, [4] where y is the vertical position and k_y depends on the pole's transverse profile and must satisfy the condition $k_y^2 + k_x^2 = k_w^2$. In our case $k_y = 0.95 \cdot k_w = 0.5$ cm^{-1}. Since the nth harmonic intensity grows like cosh $nk_y y$, harmonic contents increase out of the midplane. This is evident in fig. 5, where the on-axis field at different vertical positions is plotted as a function of z.

Fig. 4 and 5 refer to the em model, but also in this case no major differences have been found between the two models.

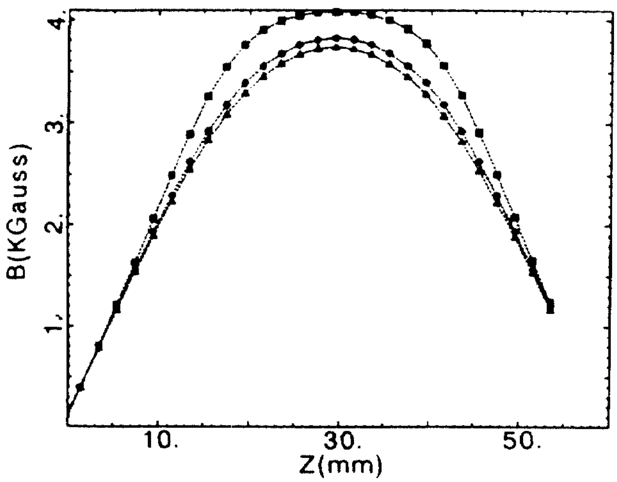

Figure 5: Measured field intensity in a $\lambda_w/2$ region at midplane (symbol ▲), at 5 mm (symbol ●) and at 10 mm above midplane (symbol ■).

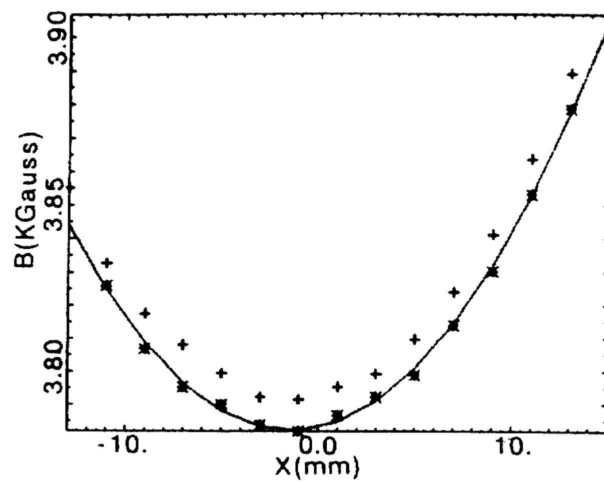

Figure 6: Measured transverse peak field intensity (symbol ✳) compared with the fundamental harmonic as a function of transverse position (symbol ✚).

2.3 *Transverse field profile*

The transverse profile of the field follows the desired shape with good approximation. The horizontal focusing parameter k_x [4], calculated by least-squares nonlinear fit is 0.157 cm^{-1}, while the predicted value is 0.166 cm^{-1}. In addition the good field region has been found to extend well beyond the region occupied by the electron beam. Fig. 6 shows the transverse field profile.

2.4 *Field integral and field error correction systems*

The value of the field integral evaluated from field measurements is $\approx$ 70 gauss cm for the em model and $\approx$ 40 gauss cm for the hybrid; the hybrid has shown also a dependence of the field integral from transverse position.

It should be noted that these values can only be an indication for what we can espect in the full wiggler, due to the forced periodicity of the models; in the full wiggler we will also use integral coils, better suited than point measurements, for this kind of evaluation.

Two kind of correction systems have been tested on the models, i.e. active PM blocks on the side of poles for the hybrid, and correction coils for the em model. The maximum variation of the on-axis peak field achieved with PM side blocks was of 1.7 %, and the effect was found to be global in the transverse direction. The transverse profile of the field remained the same due to the homogeneous distribution of the flux. NdFeB cylindrical blocks, with dimensions diameter 1 cm and length 1.4 cm, were used.

The correction coils were made of copper foils with a maximum current of 72 A turns; with an appropriate current setting the field integral value was reduced to -8.4 gauss cm.

3 CONCLUSIONS

Experimental measurements on both construction techniques that have been explored give adequate performances for the full wiggler, and no major differences have been found in the field quality and distribution. The choice between the two will be based on flexibility and costs of costruction and operation. It can be noted that during model development we have found that hybrid wiggler construction can be quite expensive and time consuming. As we mentioned before, the true value of the field integral can be determined only in the full wiggler.

4 ACKOWLEDGMENTS

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5 REFERENCES

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