DEVELOPMENT OF THE MECHANICAL STRUCTURE FOR FERMI@ELETTRA APPLE II UNDULATORS

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Abstract

A conceptual design study of the mechanical structure for the APPLE II undulators of the FERMI@Elettra project has been carried out using FEM structural analysis and multiobjective optimization software. In this paper the predicted undulator performance is presented taking into account the mechanical deformations due to the variable magnetic forces. The resultant magnetic field and optical phase errors are shown to be negligibly small.

INTRODUCTION

The FERMI@Elettra FEL [1] foresees installation of both linear and elliptical polarization undulators (EPU) as indicated in Table 1.

Table 1: Main parameters of the FERMI EPUs

	EU65	**EU50**
Period (λ0)	65 mm	50 mm
Magnetic length of each segment	~2,5 m	~2,5 m
Number of segments	6	10

The undulators conceptual design starts from the experience gained with the design and construction of Apple II undulators built for Elettra. The different requirements of the FERMI and Elettra undulators are shown in Table 2.

Table 2: Main mechanical specification of the FERMI and Elettra undulators

	FERMI	**Elettra**
Minimum gap	10 mm	19 mm
Maximum magnetic gap error	30 μm	60 μm
Backing beam length	2.5 m	2 m
Backing beam planarity	15 μm	25 μm
Gap and phase positioning accuracy	5 μm	10 μm

Our efforts were dedicated to analyze the already constructed structures in order to highlight the critical mechanical aspects and in order to achieve the required mechanical tolerances.

Figure 1 shows a model of the typical EPU carriage made of rectangular steel tubes welded together to form a rigid C-type frame. This carriage consists of two symmetrically placed vertical posts. Each of two stainless steel backing beams (upper and lower), moving on rails fastened to the main support posts, carries one longitudinally movable and one fixed aluminium beam, hosting the magnet arrays. The undulator gap is changed by moving the backing beams, driven by four synchronized motors. The relative longitudinal position of the two aluminium beams carrying the magnet arrays (driven by two additional servomotors) determines the polarization of the magnetic field.

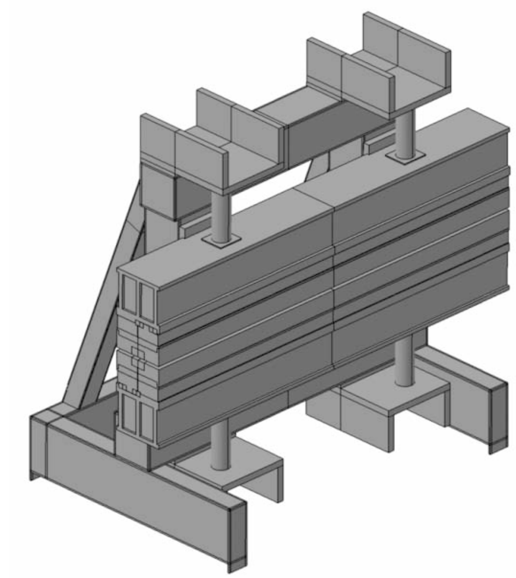

Figure 1: 3D model of an EPU carriage.

We analysed an Elettra undulator in order to obtain useful information for the new FERMI undulator design. In the following we consider the design of the undulator beam assembly.

FEM MODEL

In an EPU the magnetic forces between mobile and fixed arrays and upper and lower beam change the magnitude and the direction as a function of the polarization; consequently we observe variable deformations.

A model of EU10.0 (an Elettra EPU) backing beam, linear bearings and magnets arrays has been created and inserted in Ansys Multiphysics FEM code. We modelled linear guides using brick elements for the main guide and 3D nonlinear spring elements for the small one, since it works only in compression case (see Figure 2). The forces applied on the model are shown in Figure 3.

Measurements performed on the actual EU10.0 undulator provided detailed information on the local transverse displacements of the fixed and mobile magnet arrays as a function of the phase setting [2]. Results are shown in Figure 4; displacements sign convention is shown in Figure 5.

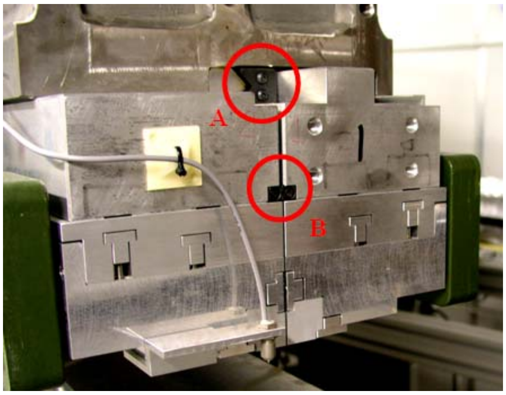

Figure 2: Linear bearing position: A is the main guide and B the small one.

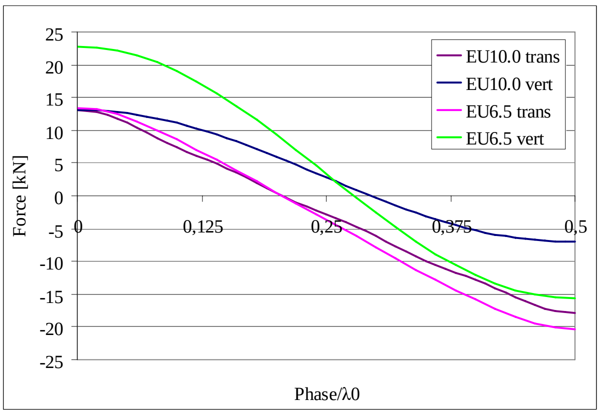

Figure 3: Vertical and transverse magnetic forces of the lower fixed array vs. phase for EU10.0 and EU6.5.

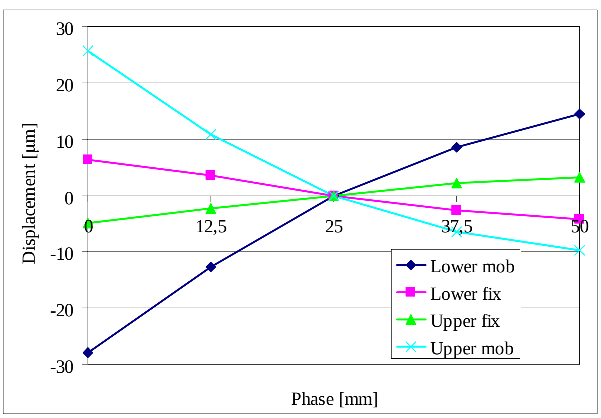

Figure 4: Measured transverse displacements of the four arrays of EU10.0 vs. phase.

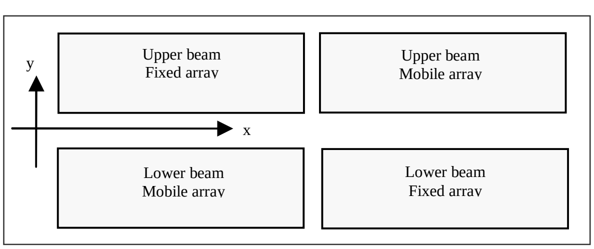

Figure 5: Axis convention.

Initial comparison with the predicted deformations showed good agreement (within 3µm at any phase value) for the fixed array but quite large differences (up to 20 µm) for the movable array. This difference was caused by an insufficiently detailed modelling of the linear bearings and wrong stiffness values, leading to underestimated deformations. To find out the right elasticity modulus a data fitting process of experimental data with modeFRONTIER [3] (multiobjective optimization software) has been carried out. The fitting procedure, based on genetic algorithm, allowed the variation of the elastic modulus of the main linear bearing and of the stiffness of the small one. Optimization minimized the absolute difference between measured and computed displacements at five phase values between minimum and maximum.

Final result is shown in Figure 6: the difference between measured and computed displacements has been reduced to 3µm.

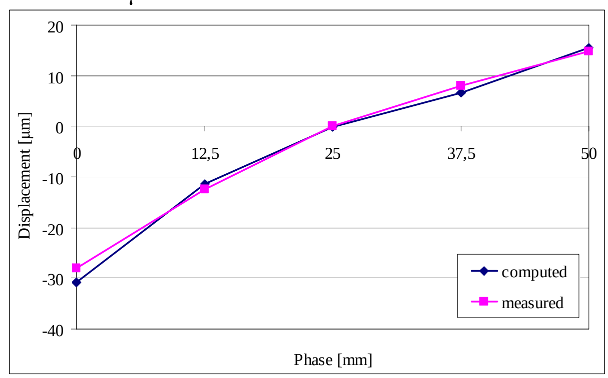

Figure 6: Mobile array: computed and measured transverse displacements.

As a next step, we optimized the EU65 backing beam taking into account its magnetic forces (see Figure 3) and its mechanical requirements (see Table 2). We considered a stainless steel beam (AISI 316L) made of elements welded together to form a H shape beam with additional braces positioned in longitudinal and transverse direction (see Figure 7).

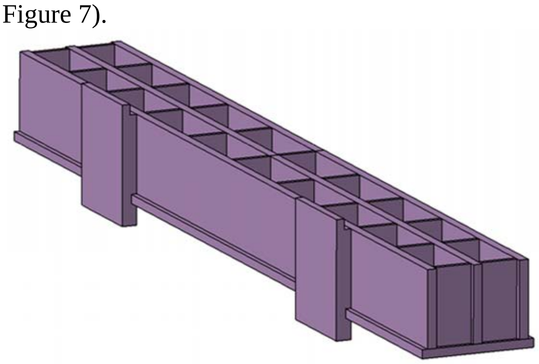

Figure 7: 3D model of backing beam without upper flange.

The dimensions of each welded structure component (web, flanges and braces) have been optimized by modeFRONTIER and Ansys to achieve minimum deformation versus phase, while keeping the overall mass within reasonable limits. The optimization gave a total mass lower than 850Kg and vertical peak to peak deformation lower than 8µm.

EU65 PERFORMANCE EVALUATION

As a final step the previously optimized backing beam model has been refined including magnets, aluminium holders, and linear bearings (as described in the previous paragraph) in order to obtain the array displacements.

The magnet centre as a function of the position along the beam at different phase value are shown in Figure 8-9.

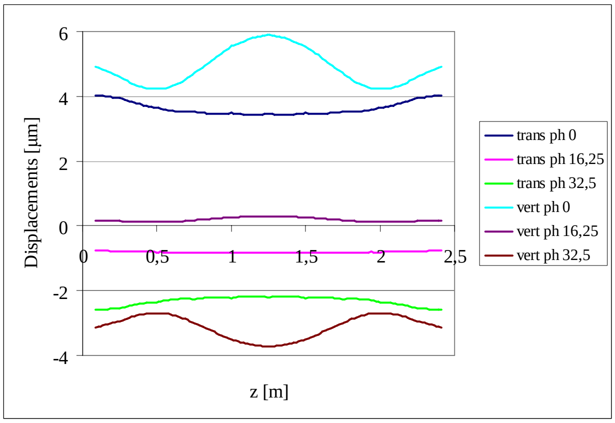

Figure 8: Lower fixed array transverse and vertical displacements vs. longitudinal position at different phase value.

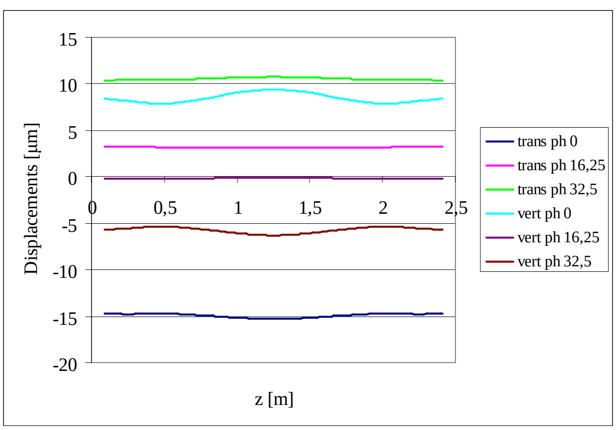

Figure 9: Lower movable array transverse and vertical displacements vs. longitudinal position at different phase value.

Finally, we have examined the magnetic effect caused by these mechanical displacements. The calculation of the magnetic field was performed using 3D magnetostatic code RADIA [4]. Figure 10 shows the resultant error in the peak field. The maximum error is about 0.04% for the vertical field (at zero phase) and 0.08% for the horizontal field (at maximum phase).

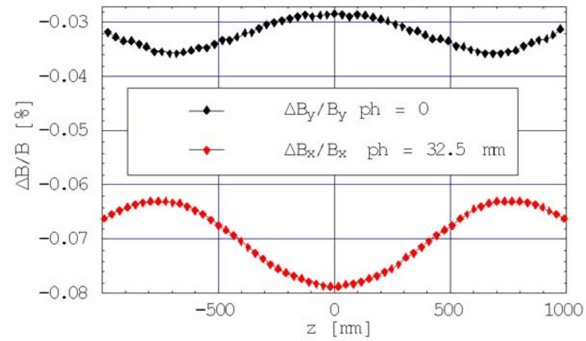

Figure 10: Peak field variation at zero phase and maximum phase.

Figure 11 shows the associated phase error calculated at the poles in the periodic part of the undulator. The rms phase is considered a more meaningful figure of merit compared to the field error [5].

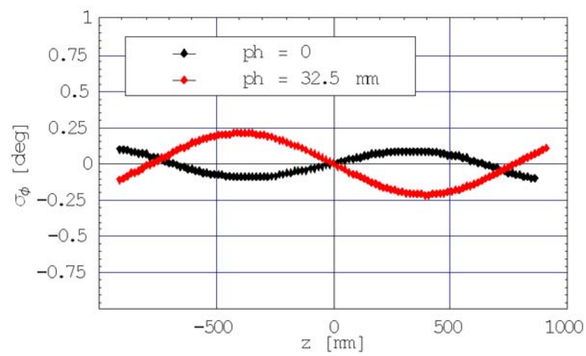

Figure 11: Phase error at zero phase and maximum phase.

We notice that the values of the phase error are negligibly small (<0.2 deg), so that no effect has to be expected on the performance of the FEL.

REFERENCES

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