FERMI@ELETTRA UNDULATOR FRAME STUDY

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Abstract

The FERMI@Elettra project foresees installation of both linear (LPU) and elliptical polarization undulators (EPU). Following the girder study presented last year [1], a detailed design of the undulator frame has been now carried out. The aim of this work was to find out a mechanical structure that guarantees minimum displacement of the girders supporting the magnet arrays. At the same time the undulator overall dimensions have been taken into account and the mechanical structure mass minimized. In this paper topology optimization result, finite element simulation and multi-objective optimization analysis are presented.

INTRODUCTION

From the mechanical point of view an undulator is a device that supports magnet arrays and has to guarantee their remote positioning with high accuracy and reproducibility.

The undulator main mechanical components are: backing beams, frame, gap and phase movement mechanical components. Generally the frame is a C-type carbon steel welded truss that through brackets and screw jacks supports the upper and lower beams that in turn carry the magnet arrays.

The undulator structure, subjected to self weight and strong magnetic forces that change magnitude and direction as function of gap and phase, has to be designed to minimize magnet array displacements that cause systematic magnetic errors. The structure has also to match requirements on the undulator hall , transportation and alignment.

The main parameters of the undulators for the first FEL phase (FEL1) are summarized in table 1.

Table 1 : Main parameters of the FEL1 undulators.

	LPU	EPU
Period [mm]	100	55
Number of segment	1	8
Length. [m]	3.2	2.5
Minimum gap [mm]	12	10
Max attractive force [kN]	30	30
Max repulsive force [kN]	-	20

The LPU frame is subjected to vertical magnetic forces due to the attraction between upper and lower beams. In the case of the EPU the force can change from attractive to repulsive as the polarization is changed, as shown in table 1. The maximum vertical magnetic load is at minimum gap.

In both cases the force variation causes a frame deformation that entails that beams and magnets move in vertical and transversal direction [2]. Consequently the undulator magnetic axis changes. Vertical displacements can be correct via encoder but transversal movements can not be compensed and therefore the aim of the design is to minimize the transversal frame deformation.

Our design process started with a topological analysis to find out the best arrangement of the frame welded elements, followed by a dimensional optimization of the main components.

TOPOLOGICAL ANALYSIS

The topological analysis is a form of shape optimization. The goal is to find the best use of material for a body such that an objective criteria (global stiffness) takes out a maximum value subject to given constraints (volume reduction) [3]. The designer defines the maximum overall dimensions, the loads, the boundary condition and the volume reduction ratio; the program minimizes the energy of the structural compliance thus maximizing the global structural static stiffness [4]. The result is a rough (depending on mesh quality) body that shows the optimum mass distribution.

The undulator overall dimensions were fixed to 1.8x1.4x2.4m (length, width, height) and we chose 60% volume reduction ratio, as the best trade-off between frame mass and global stiffness. Figure 1 shows the result of topology optimization.

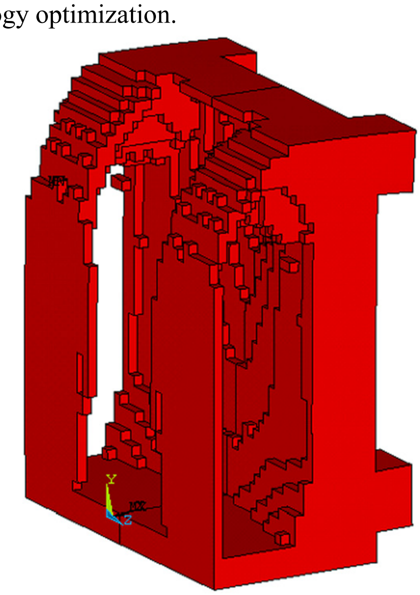

Figure 1: Topology optimization results.

The optimized frame is a structure with two main front vertical columns and a rear secondary structure that strengthens the assembly.

FRAME DESIGN

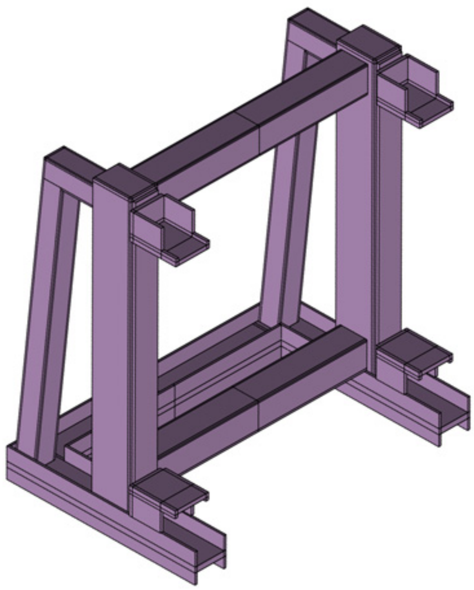

Figure 2: Preliminary frame design.

Based on the results of the above described process, we designed the frame shown in figure 2 using commercially available square and rectangular bar elements (300x200x12mm for the vertical columns, 150x150x12mm for the rear stiffening and 200x200x10 for the horizontal bars). The total weight is about 1.6 tons. The basement is made of three welded H-shape bars acting as link element between the upper main part of the structure and four adjustable feet (not shown in the picture). This basement also fits the transportation requirements by either air cushions, wheels or dolly.

First, based on FEM analysis, we carried out a sensitivity analysis on stiffening position and tilt (A and B variables, see figure 3) in order to understand their effects on mechanical performance.

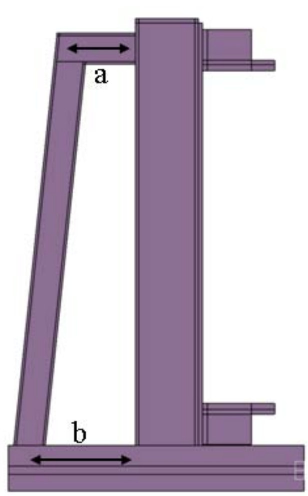

Figure 3: Sensitivity analysis variables.

The structure described above was subjected to attractive magnetic forces (see table 1), vertical and transversal displacements versus A and B length was considered.

Results are shown in figure 4 and 5; displacements refer on the top of the undulator structure. The analysis showed that, in our case study, to increase the frame stiffness the distance between lower part of the rear bar and vertical column (B variable) has to be the maximum possible value (about 425mm), while the upper arm length (A variable) about 150mm. Transversal displacement is more influenced by A and B variation than the vertical one: transversal deformation range is about 30µm, while vertical one is about 3µm. Fixing B at the maximum value, the vertical deformation constantly decreases when A increases, instead the transversal deformation has a minimum and increases when A increases.

Although rear truss 45 degrees tilt angle is the best mechanical solution but it is forbidden by space limitation.

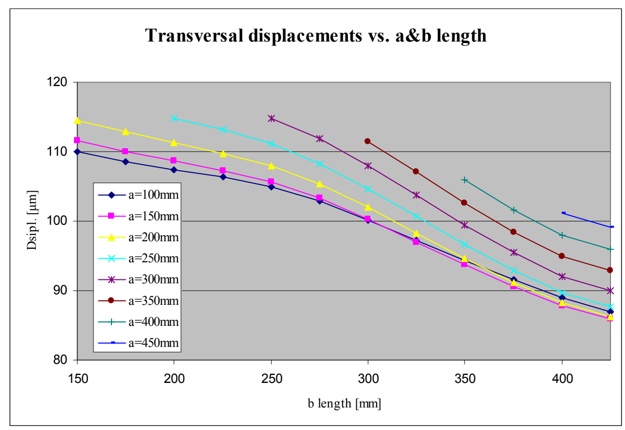

Figure 4 : Transversal frame displ. vs. A and B length.

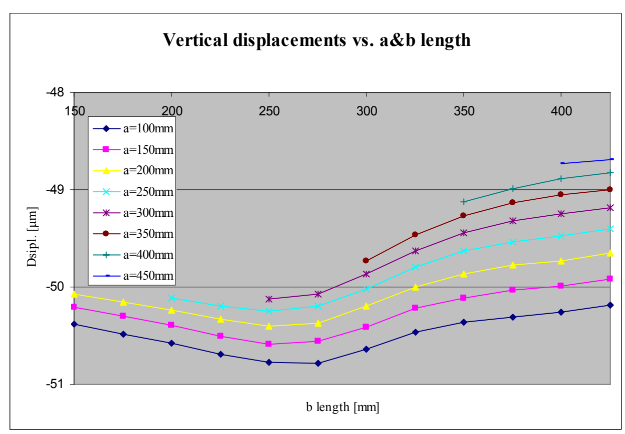

Figure 5 : Vertical frame displ. vs. A and B length.

As a next step we carried out a main components dimensional optimization with modeFRONTIER [5] (multi-objective optimization software). Simultaneously the dimension and the thickness of the vertical columns and of the rear stiffening truss and tilt of the latter have been optimized to achieve minimum transversal deformation, taking into account the vertical deformation and keeping the overall mass within reasonable limits (2 tons). Optimization process brought the vertical column dimension to 400x200x16mm, the rear upright bar dimension to 200x200x12mm and the total weight to about 1.9 tons.

Recent changes in the building design, forced us to reduce the undulator width from 1.4m to 1.1m. The new available transversal space does not allow installation of both vertical column and rear stiffening with appropriate dimensions. Therefore a single vertical column solution was considered (see figure 6).

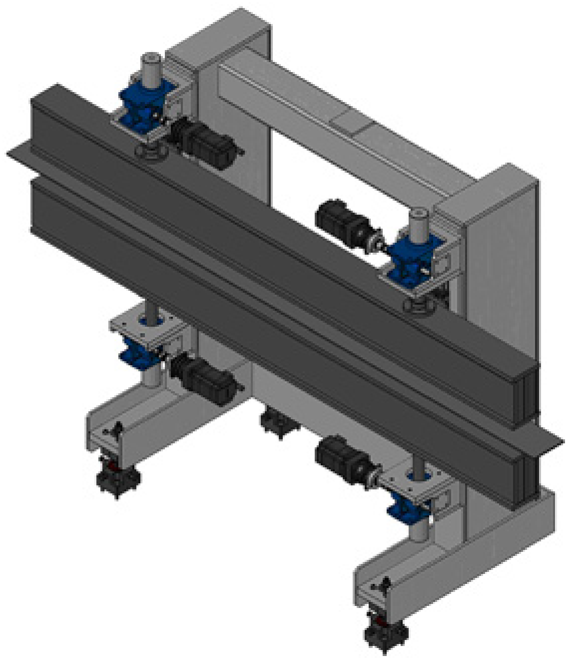

Figure 6 : Undulator frame single column design.

The vertical column has external dimensions of 500x200mm and is made of I-shape beam (IPE500) with 16mm thick additional welded braces (see figure 7). The frame mass is about 1.9 tons.

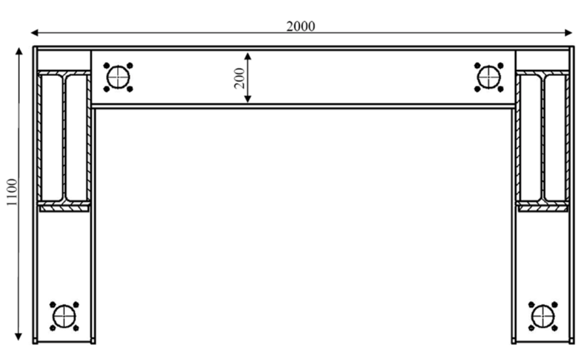

Figure 7 : Undulator frame horizontal cross section.

RESULTS SUMMARY

LPU and EPU frame have the same topology and bar dimension, but due to their different length (3.2m vs. 2.4m) the longitudinal distance between the columns is different (1.8m vs. 1.6m).

LPU Frame Mechanical Performance

Deformations under LPU maximum magnetic load (see table 1) for the various design considered are summarized in table 2. The values refer to the top of the structure.

Table 2: Deformations under LPU magnetic load.

Displacement [μm]	Prelim. design	Optimized frame	Single column des.
Total	104	67	107
Vertical	-37	-33	-29
Transversal	97	58	103

EPU Frame Mechanical Performance

Deformations under EPU maximum attractive and repulsive magnetic load (see table 1) for the optimized frame and for the single column design are summarized in table 3. The values refer to the top of the structure.

Table 3: Deformations under EPU magnetic load.

Displ. [μm]	Optimized frame		Single column des.	
	Attract.	Repul.	Attract.	Repul.
Total	84	47	123	58
Vertical	-45	-20	-42	-19
Transversal	71	43	115	55

Table 2 and 3 show that the performance of the optimized frame is better than that of the single column design. However the chosen solution satisfies the FEL1 physical requirements (magnetic axis stability and field quality) and the dimensional constraints.

ACKNOWLEDGMENTS

This work was supported in part by the Italian Ministry of University and Research under grants FIRB-RBAP045JF2 and FIRB-RBAP06AWK3. A special thanks goes to Prof. C. Poloni and Prof. L. Bregant (University of Trieste, Mechanical Engineering Department) for the constant help and useful suggestions and to ESTECO-srl for the support on modeFRONTIER usage.

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