ISBN: 978-3-95450-188-5 doi:10.18429/JACoW-MEDSI2016-TUPE44

OPTIMIZATION FOR THE APS-U MAGNET SUPPORT STRUCTURE *

Zunping Liu †, Jeremy Nudell, Curt Preissner, Jeff Collins, and Herman Cease
Advance Photon Source, Argonne National Laboratory, Argonne, IL 60439, USA

Abstract

The Advanced Photon Source Upgrade (APS-U) is to replace the existing storage ring with a multi-bend achromat (MBA) accelerator lattice [1]. For the APS-U removal and installation, current planning calls for a 12-month shutdown and testing period, prior to resumption of operations. It calls for quick installation of the magnet support system within assembly and installation alignment tolerances. A three-point semi-kinematic vertical mount for the magnet modules is the approach to reduce time for alignment. The longest section is the curved Focusing-Defocusing (FODO) section (four quads with three Q-bends interleaved, and a three-pole wiggler). All magnets of the FODO module sit on a single piece of support structure in order to have good control over the magnet-to-magnet alignment tolerance. It brings challenge to minimize the top surface deflection and maximize the first mode frequency of the magnet support structure that is supported at three points. These constraints require optimizing the magnet support structures. Details of the optimization, including three-point positioning, material selection, and topology optimization, are reported in this study.

INTRODUCTION

Optimization is subjected to constraints. For example, the APS-U removal and installation is planned for a 12-month shutdown and testing period prior to resumption of operations, and the assembly and installation alignment tolerance is specified as 100 microns RMS for girder-to-girder alignment [1]. To meet such specifications within a one-year period, a three-point semi-kinematic vertical mount for the magnet modules is considered as the best approach, in comparison with four-point and/or non-kinematic vertical mount. The conceptual design is based on the three-point semi-kinematic vertical mount, and the goal of optimization is to meet the technique specifications.

The APS-U specifies 9 nm RMS as magnet-to-magnet vibration tolerance and 30 microns RMS as magnet-to-magnet static tolerance within a girder [1], a common term for the magnet support structure. Spacing of the three-point support can be optimized, which helps to minimize the magnet-to-magnet static tolerance due to surface deflection of the support structure. The vibration tolerance is related to the ground vibration spectrum. The floor vibration spectrum in the APS storage ring has 1 nm absolute value at 50 Hz [2,3]. It indicates that the first mode frequency around 50 Hz of an assembled module is guaranteed to meet the magnet-to-magnet vibration tolerance. It leads to a goal, 50 Hz as the lower bound of mode frequency, for optimization. A parametric study of girder height is performed during optimization.

For conceptual design and optimization, topology optimization is an ideal tool. It allows selecting the best elements in a given design space that maximizes the use of material. Research on numerical topology optimization started three decades ago [4] and Genesis® incorporated the discipline nearly two decades ago [5]. It's available for statics, eigenvalue, buckling, frequency response and random response load cases. Among a bunch number of commercially available topology optimization software, the Genesis Topology for Ansys Mechancial (GTAM) [6] is utilized in this study. Two major constraints, minimizing strain energy and maximizing frequency response, are applied during the optimization process.

For a given structure, material of higher elastic modulus produces a higher natural frequency. Fabrication capacity by vendors constrains in material selection because of the structure size and complexity. Fabrication constraints are available in GTAM but not applied for the conceptual design and optimization. A cast iron design was chosen because of its design flexibility, low cost, and favorable vibration damping properties.

The FODO girder, the longest of the APS-U girders at approximating 5.6 meters long, is studied as a representative. All magnets of a FODO module sits on the girder, a single piece of support structure. The girder is then supported on a concrete plinth through a three-point semi-kinematic mount together with horizontal pushers. The plinth sits on a nominal 1-inch thick epoxy grout on floor. The pushers are ignored during optimization. This study focuses on the girder.

SPACING OPTIMIZATION OF VERTICAL SUPPORTS

The FODO girder has a top surface 5.568-meter long and 1.1-meter wide. As an initial step of the conceptual design, a 160mm thick plate is assumed as the girder. Because the length-to-width ratio is as large as 5 times, the three points are arranged with one point at center and the other two symmetrically toward two ends along the long side, as shown in Fig.1. The point at the center along the long side is set at one end along the short side and the other two points at the other end. The support span along the short side is maximized, which is preferred from the point view of stability and the rolling mode of vibration. In such a scheme, the spacing optimization is to find an optimized span between the two symmetrically arranged points along the long side. In the calculation the structure is supported by three bars, each 100mm in diameter and 200mm long. Figure 1 shows the total displacement when the span is set at 4 meters. When the span varies, the maximum value of

* Work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357
† zpliu@anl.gov

ISBN: 978-3-95450-188-5 doi:10.18429/JACoW-MEDSI2016-TUPE44

the displacements at the top and bottom surfaces changes as shown in Fig.2. The displacement along the vertical direction is at the nanometer level. Horizontal displacements make major contributions to the total displacement. When the span is 4 or 2.6 meters, the minimum values of displacement occur.

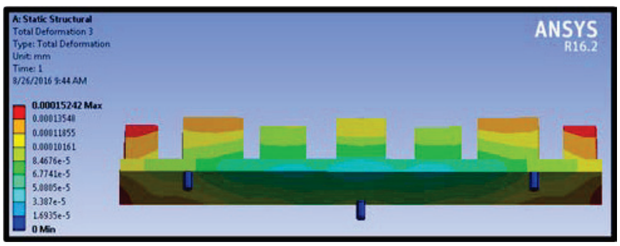

Figure 1: Deformation of girder supported by three bars.

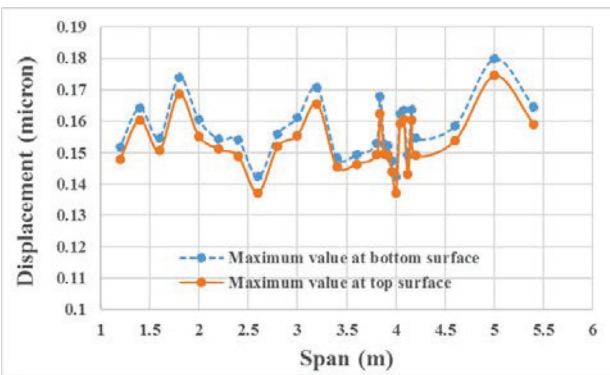

Figure 2: Maximum value of displacement at top and bottom surfaces of FODO girder.

1ST TOPOLOGY OPTIMIZATION

Topology optimization of the girder used software GTAM and ANSYS. The low bound of the 1st mode frequency is set to 60Hz. Minimizing the strain energy is another goal. The latter ensures that the static deflection along the beam path is minimized. The optimized geometry is then analyzed as a structure with the static structure and modal modules of ANSYS Workshop.

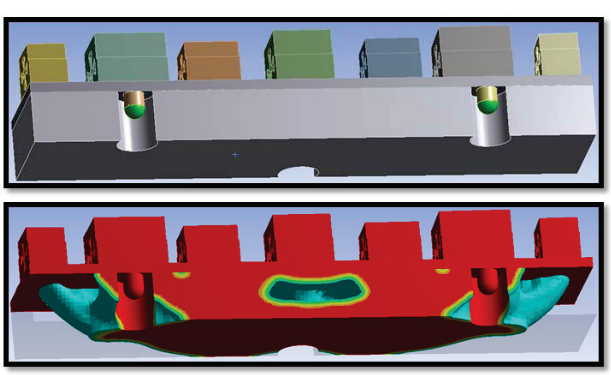
Figure 3: Topology optimization. Top, initial geometry seed. Bottom, optimized geometry.

Figure 3 shows the seed geometry used as an input (top) and the optimized one (bottom). The girder is assumed as a cast iron block of 5.568 m long and 1.1 m wide. Its height varies and is split into two parts. The top plate is excluded from topology optimization, but its thickness varies from 20 mm to 100 mm as part of the parametric study. The bottom part is the region for topology optimization, and its thickness varies from zero to 800mm also as part of the parametric study. Three vertical supports are simulated as ball-in-socket joints, allowing each socket freely rotating on a fixed ball. The vertical support has a diameter 200mm. The span is chosen as 3.5m with a smaller value preferred.

The parametric study showed that a top plate thickness of 50 mm gives the maximum value of the 1st mode frequency when the total thickness of girder is 850 mm. Figure 4 shows the corresponding static deflections due to gravity before and after topology optimization. The dots are in-plane deflection of points along the beam path. The dashed line is a best-fit of deflection before topology optimization, while the solid line is a best fit of deflection after optimization. A figure of error is derived from the deviation from the best fit line. The maximum figure of error decreases from 10 to 2 microns after optimization in this calculation.

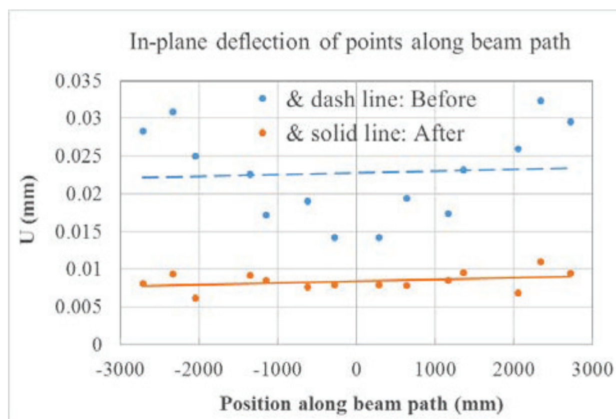

Figure 4: Static deflection before and after topology optimization

Figure 5 shows trends of the 1st mode frequency and the maximum figure of error when girder thickness increases and the top part of the girder stays at 50 mm thick. The 1st mode frequency increases monotonically before the girder thickness reaches 700mm. The trend is the same for both seed and optimized geometries. The maximum figure of error drops for seed geometry when its thickness increases. While for optimized geometry the decrease stops at a thickness of 600mm and stays at about 6.6 microns. When the girder thickness increases from 600 to 700 mm, the 1st mode frequency increases from 50.5 to 52.6 Hz, and the girder volume increases from 2.13 to 2.27 m^3. Less weight of the girder and more space for the plinth are preferred so that a girder thickness of 600 mm was chosen for preliminary design. As a result, contacts of the vertical support and girder are in a plane near the center of mass of magnets and girder assembly. This reduces the moment of inertia of the girder system.

ISBN: 978-3-95450-188-5 doi:10.18429/JACoW-MEDSI2016-TUPE44

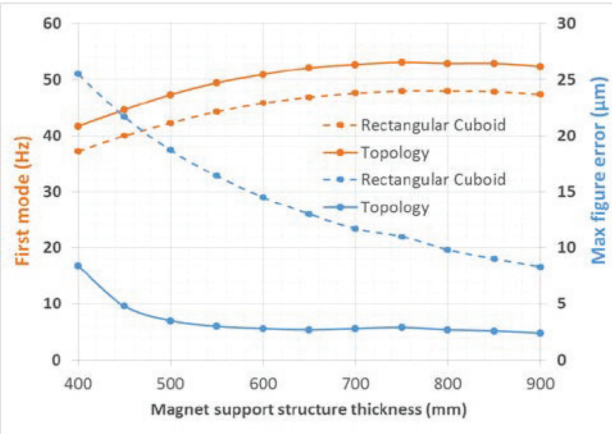

Figure 5: Max figure of error and the 1st mode frequency vs. girder thickness.

2ND TOPOLOGY OPTIMIZATION

The preliminary design of the girder is based on the optimized girder thickness of 600mm thick. The FODO module is shown in Fig.6, and the assembled FODO prototype module can be found in [2]. The span of vertical supports is changed to 3 m long. The thickness of top part of the girder is changed to 150 mm, and the contact surface of vertical support is 200 mm underneath the girder top surface. The girder material is ductile cast iron, A536, GR-60/40/18. The three-point vertical mount is realized with Airloc 414-KSKC wedge jacks. The maximum figure of error is 14 microns and the 1st mode frequency is 39 Hz [2]. The preliminary prototype is under test.

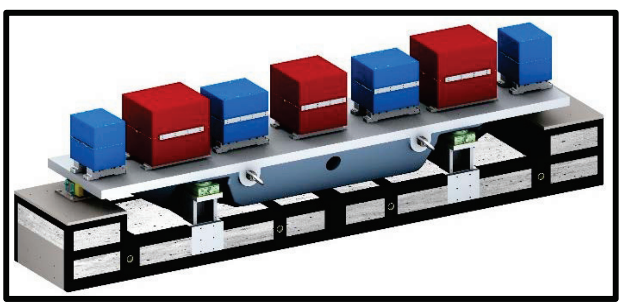

Figure 6: FODO module of preliminary design.

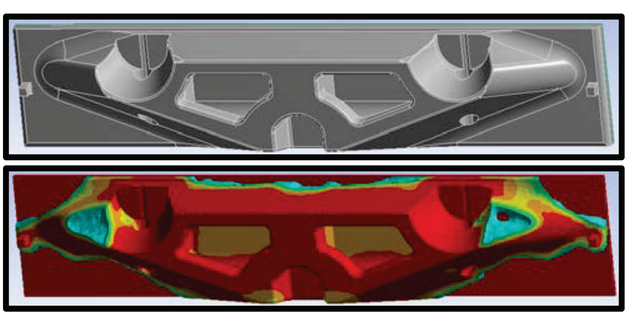

Figure 7: FODO girder 2ND topology optimization. Top, preliminary design as seed. Bottom, optimized geometry.

In case that the current prototype does not meet the specifications during test, the girder geometry is fed back into the model for further optimization. The stiffness of the Airloc 414-KSKC wedge jack is applied in this calculation. The resultant girder geometry is shown in Fig.7. The volume decreases from 1.83 m^3 to 1.57 m^3. This optimized geometry is not realized yet.

CONCLUSION

Structure optimization plays an important role in the conceptual design phase. It leads to the right direction for preliminary design in terms of mass reduction and sound performance. By using the FODO girder, the longest of the APS-U girders, as a representative, structure optimization gives an optimized structure in two steps. It first leads to the optimized spacing range for the three-point semi-kinematic vertical support. Static structure analysis is applied in this step. In the second step topology optimization is applied for a parametric study with goal of minimizing strain energy and maximizing the mode frequency response of the girder. It then leads to the optimized girder thickness and geometry. The material utilization is maximized in preliminary design of the girder, which meets the design specifications of 9 nm RMS as magnet-to-magnet vibration tolerance and 30 microns RMS as magnet-to-magnet static tolerance within a girder.

ACKNOWLEDGEMENT

Thank you to Patrick Den Hartog (leader of the Mechanical Engineering and Design group in the APS) for his help in editing this paper.

REFERENCES

[1] G. Decker, "Design Study of an MBA Lattice for the Advanced Photon Source," *Synchrotron Radiation News*, 27:6, 13-17, 2014, DOI: 10.1080/08940886.2014.970932.

[2] J. Nudell *et al.*, "Preliminary Design and Analysis of the FODO Module Support System for the APS-U Accelerator," in *Proceedings of MEDSI 2016*, 11~16 SEPT, 2016, Barcelona, Spain.

[3] C. Preissner *et al.*, "Nostradamus and the Synchrotron Engineer: Key Aspects of Predicting Accelerator Structural Response," in *Proceedings of MEDSI 2016*, 11~16 SEPT, 2016, Barcelona, Spain.

[4] M.P. Bendsoe and N. Kikuchi, "Generating Optimal Topologies in Structural Design Using a Homogenization Method," Comp. Meth. Appl. Mech. Eng., Vol.71, 1988, pp.197-224.

[5] J.P. Leiva and et al., "Modern Structural Optimization Concepts Applied to Topology Optimization," Proceedings of the 40th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Material Conference. St. Louis, MO, April 12-15, 1999, pp.1589-1596.

[6] http://www.vrand.com/GTAM.html