PRELIMINARY DESIGN OF THE MAGNET SUPPORT AND ALIGNMENT SYSTEMS FOR THE APS-U STORAGE RING*

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Abstract

As part of the Advanced Photon Source Upgrade project (APS-U), the storage ring will be upgraded to a multibend achromat (MBA) lattice [1]. This upgrade will provide dramatically enhanced hard x-ray brightness and coherent flux to beamline experiments in comparison to the present machine. The accelerator physics requirements for the upgrade impose very stringent alignment, assembly and installation tolerances and tight vibrational tolerances on the magnet support and alignment system designs. The short installation duration dictates a need for transporting groups of fully assembled magnet modules into the storage ring enclosure while preserving magnet-to-magnet alignment. The current magnet support and alignment systems preliminary design status for the APS-U storage ring will be presented along with an overview of the R&D program required to validate design performance. Magnet module transportation and installation logistics will also be discussed.

INTRODUCTION

The existing APS storage ring will be completely removed and replaced with an MBA lattice as part of the APS-U. The APS-U storage ring will consist of forty repeating arc sectors, each containing nine magnet modules as shown in Figure 1. Each arc sector contains five concrete plinths used to build up groups of magnets that can be installed as a module. The largest magnet module located in the center of the arc sector is the curved Focusing-Defocusing (FODO) module. On either side of the FODO module are straight Multiplet modules followed by Quad Doublet modules. Supported on bridges between the concrete plinths are longitudinal gradient dipole magnets (L-Bend), a total of four per arc sector. The concrete plinths effectively "raise the floor" to help reduce geometric amplification of ground vibrations. The magnet groups on each concrete plinth are mounted to a girder that is supported by a three-point semi-kinematic six degree of freedom (DOF) support and alignment system. The planned installation duration is very short, allowing only one year for removal, installation, testing, commissioning and return to beamline operations. Installing pre-assembled magnet modules will reduce installation time and the three-point semi-kinematic six DOF support and alignment systems will reduce the time and effort required for alignment.

Derived from the APS-U accelerator physics requirements, the survey and alignment assembly and installation tolerances are shown in Table 1. The requirement is that each magnet module girder be aligned to within 100 μm RMS of a neighboring girder at the start of commissioning. The APS-U physics requirements also impose tight vibration tolerances on the magnet support and alignment system designs as shown in Table 2. For instance, a 9 nm RMS vibration tolerance on the vertical magnet-to magnet motion must be satisfied for proper operation. Measurements of the floor vibration spectrum in the APS storage ring indicate that the ground motion will be less than 1 nm above 50 Hz. Therefore, a first mode frequency greater than 50 Hz is chosen as a design goal for the installed magnet modules since it will ensure that vibration tolerances will be met.

Table 1: Survey and Alignment Assembly and Installation Tolerances at Start of Commissioning .

Girder misalignment	100 μm
Elements within girder	30 μm
Initial BPM offset errors	500 μm
Dipole fractional strength error	$1 \cdot 10^{-3}$
Quadrupole fractional strength error	$1 \cdot 10^{-3}$
Dipole tilt	$4 \cdot 10^{-4}$ rad
Quadrupole tilt	$4 \cdot 10^{-4}$ rad
Sextupole tilt	$4 \cdot 10^{-4}$ rad

Table 2: Summary of Vibrational Tolerances

	X (rms) 1-100 Hz	Y (rms) 1-100 Hz	X (rms) 0.1-1000 Hz	Y (rms) 0.1-1000 Hz
u_{girder}	32 nm	40 nm	320 nm	400 nm
u_{quad}	13 nm	9 nm	130 nm	90 nm

In order to validate design performance, a comprehensive R&D program has been established that addresses major risks. Numerous vibration tests are being conducted on prototype modules that will provide substructure stiffness information and allow finite element model validation [2]. Temperature change-driven misalignment tests are planned that will provide insight into how the alignment of a magnet module reacts to local temperature fluctuations. Since fully assembled magnet modules will be transported and installed into the storage ring, transport tests are being conducted to ensure that magnet alignment is retained through this process. Tests are also being conducted that will inform installation planning and logistics.

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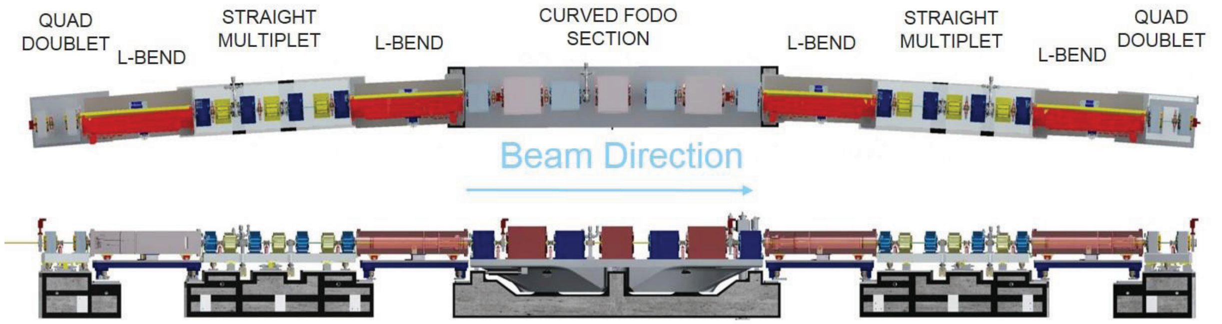

Figure 1: APS-U storage ring arc sector layout.

PRELIMINARY DESIGN

The magnet support and alignment systems design for the APS-U storage ring reflects preliminary design. Future results obtained through R&D and from finite element modelling will further inform the designs and allow for design maturation.

Concrete Plinths

Granite was originally considered for the plinths; however, through an R&D collaboration it was demonstrated that a hybrid steel and concrete plinth design provides excellent dimensional stability at less than half the cost of granite. The concrete plinths use a continuous welded steel frame with internal rebar and large headed anchor studs welded to all channels and plates in order to help minimize shrinkage and distortion. A proprietary low-moisture, low-shrinkage concrete mix was specially developed for the plinths. Several prototype concrete plinths were fabricated and dimensional stability measurements were made over time to monitor shrinkage and distortion. Less than 20 µm of shrinkage was measured during the first two months. For production, after six months of curing each concrete plinth will be painted to seal the concrete in order to prevent dust generation inside of the storage ring.

Girders

All of the magnet support structures, referred to as girders, will be geometrically optimized and fabricated from cast iron. GTAM topology optimization software is used to maximize the first mode frequency response while minimizing strain energy (static deflection) along the beam path through the magnets [3]. Starting with a seed geometry, an objective function and the constraints, the software determines where mass is needed and where it is not. Several initial thicknesses of the girder are chosen for seed geometries and a parametric study is performed to see how the first mode frequency and static deflection vary as a function of girder thickness. The chosen ideal structure may then need to be modified based upon input from the foundry in order to transform the ideal structure into a manufacturable casting design. Figure 2 illustrates this process for the prototype FODO module girder casting [4]. After casting, the girder is heat treated in order to strain relieve the structure prior to machining.

Using ductile cast iron for girders has many advantages over using thick steel plate. Ductile cast iron is more cost effective, can be machined to tighter tolerances, and exhibits higher specific damping capacity. Casting the girders allows material to be used only where it is needed and allows for the fabrication of complicated optimized geometries.

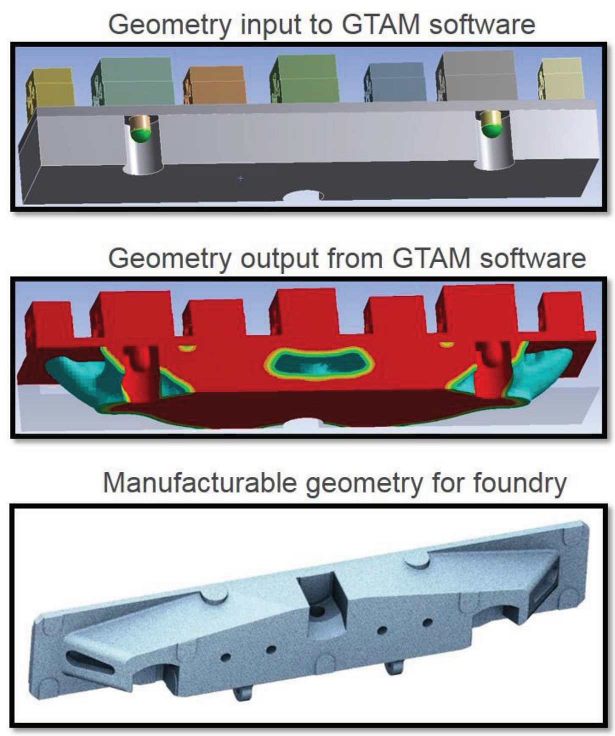

Figure 2: Optimization process for the FODO section girder casting.

Support & Alignment Systems

Each magnet module in the APS-U accelerator is aligned using a three-point semi-kinematic six DOF support and alignment system. Figure 3 shows a typical concrete plinth with the support and alignment systems installed. On the top of the concrete plinth are the components that comprise the support and alignment system for the girder. Three commercially available wedge jacks are used for the vertical supports, and these contain spherical bearings and slip plates to decouple translation and rotation from the vertical motion. The two lateral pushers provide lateral and yaw constraint and alignment, and the longitudinal pusher provides longitudinal constraint and alignment.

In addition, all concrete plinths use a temporary six DOF alignment system, referred to as support outriggers, to align the plinth prior to grouting to the storage ring floor. There are a total of three support outriggers, two on one side of the concrete plinth and one on the other side, and each provides vertical, lateral and longitudinal adjustment. Plinths are moved into location using an air caster system, rough aligned using the support outriggers, grouted in place, and once the grout has cured the support outriggers are removed.

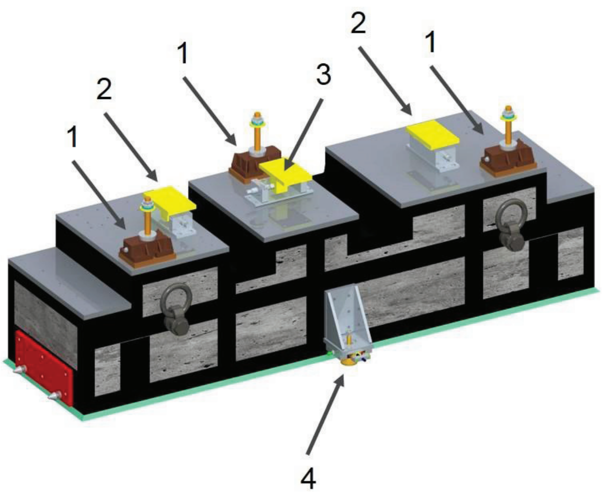

Figure 3: Typical concrete plinth support & alignment systems - (1) three-point vertical wedge jack supports, (2) lateral pushers, (3) longitudinal pusher, (4) support outriggers (3 total).

Magnet Modules

The largest magnet module in the APS-U storage ring is the FODO module with a length of nearly 6.5 m and a total weight around 29,000 kg. Due to space constraints in the storage ring, the FODO module has been designed so that all adjustments can be made on the aisle-side. A prototype FODO module has been procured and extensive R&D on the module is planned. A rendering of what the FODO module will look like in our testing area is provided in Figure 4.

The straight Multiplet module is the next largest magnet module with a length of nearly 3.6 m and a total weight around 11,800 kg. Extensive tests have already been conducted on a demonstration Multiplet module (DMM) we have in our testing area. The smallest magnet module containing a concrete plinth is the Quad Doublet module with a length of only 1.5 m and a total weight around 4,500 kg.

There are a total of 160 L-Bend magnets in the APS-U storage ring, four per arc sector installed on support bridges between the concrete plinths. The L-Bend magnet support bridge contains a manual translation stage that allows removal of the magnet from the vacuum chamber during bake out. Each L-Bend module is around 2 m long and weighs 2,900 kg. Prototypes of the Quad Doublet module and the L-Bend module will be procured and extensive R&D on these modules is planned.

Figure 4: Rendering of the prototype FODO module in the testing area.

CONCLUSION

For the APS-U project, the entire storage ring will be removed and replaced with an MBA lattice consisting of forty repeating arc sectors. There are four types of magnet modules and each arc sector contains nine magnet modules. Due to the short installation duration, pre-assembled magnet modules will be installed in the storage ring and six DOF support and alignment systems will be used to reduce alignment time and effort. Though currently in the early stages of preliminary design, extensive R&D is being conducted on several prototype magnet modules, and results obtained through testing and finite element modelling will further inform the designs.

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