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

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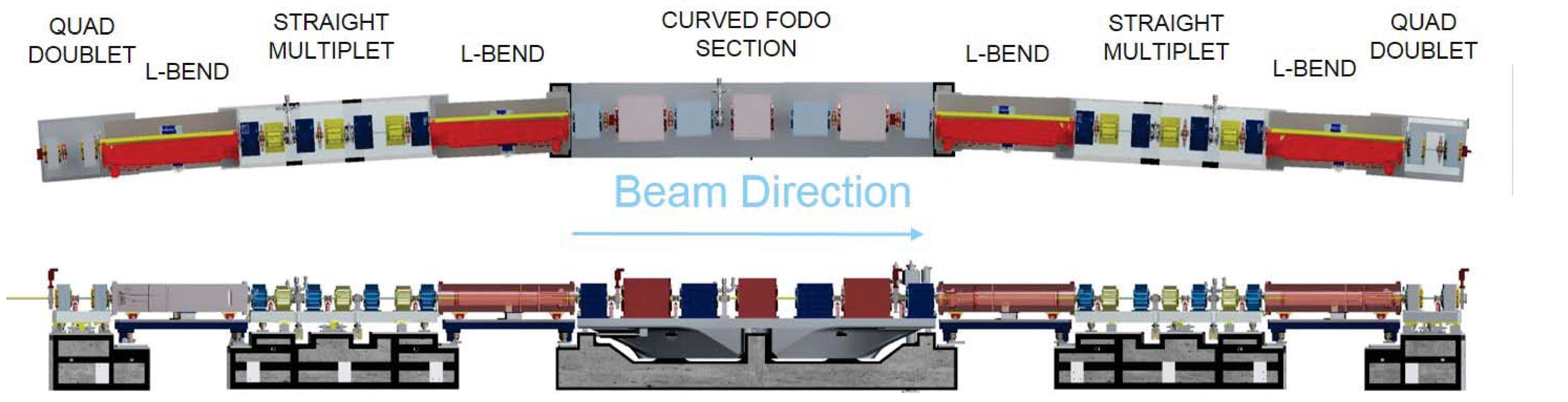
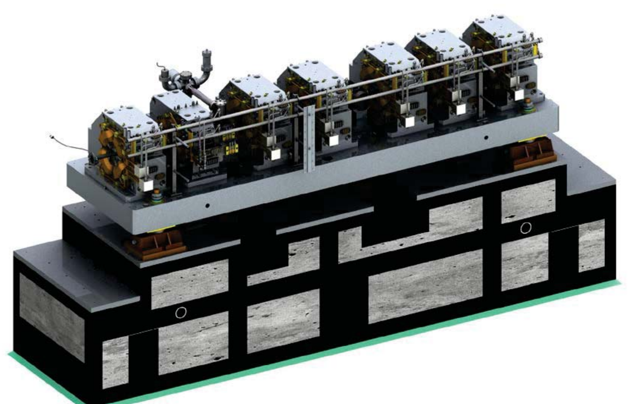
ABSTRACT

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 presented along with an overview of the R&D program required to validate design performance.

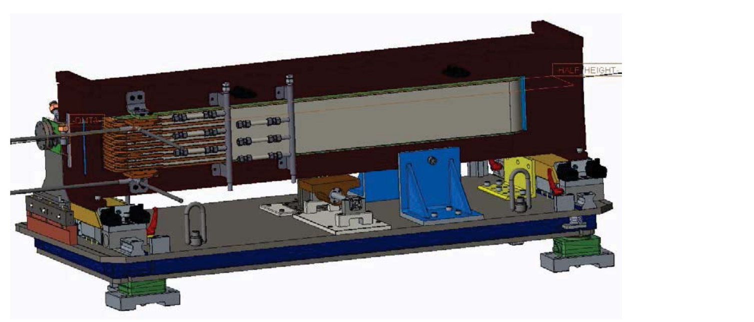
MAGNET MODULES

The APS-U storage ring will consist of forty repeating arc sectors, each containing nine magnet modules. 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.

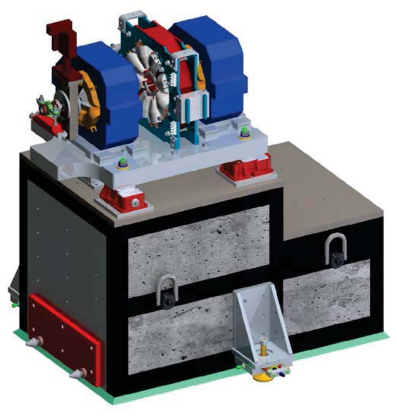




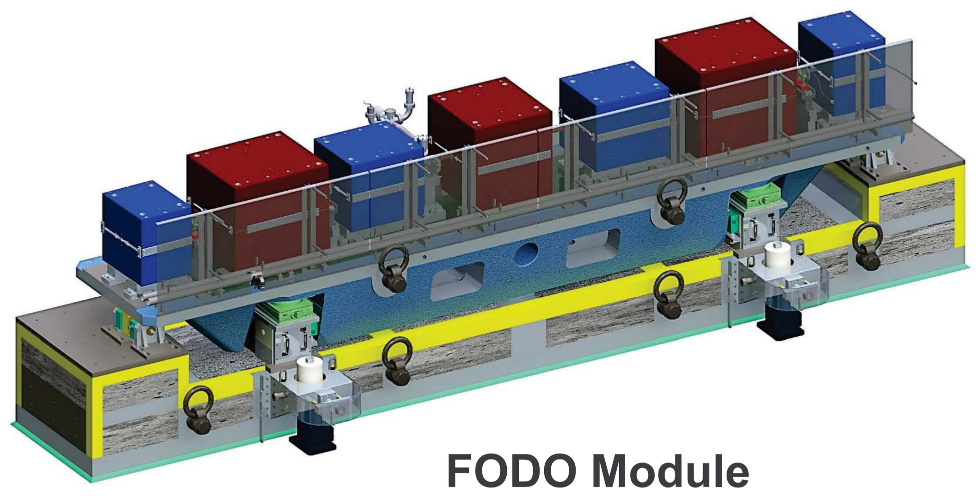
Multiplet Module



L-Bend Module



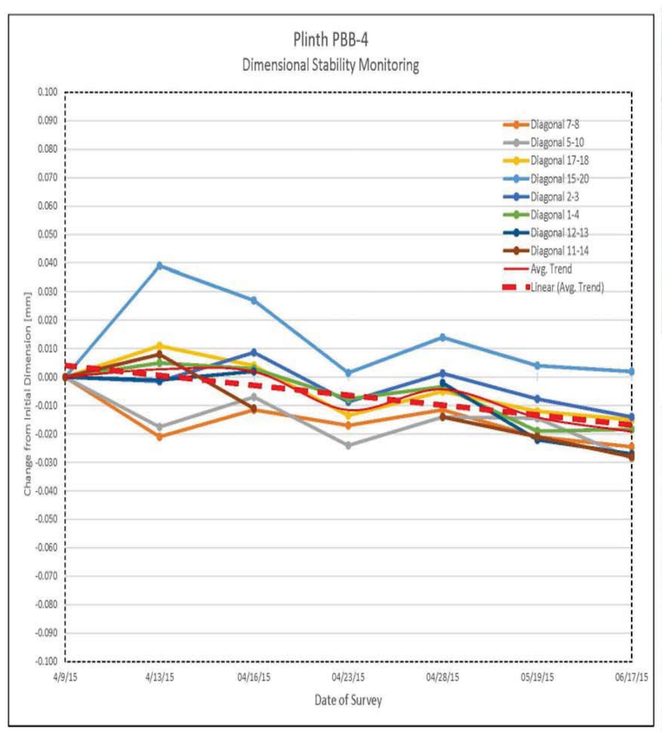
Quad Doublet Module



FODO Module

CONCRETE PLINTHS

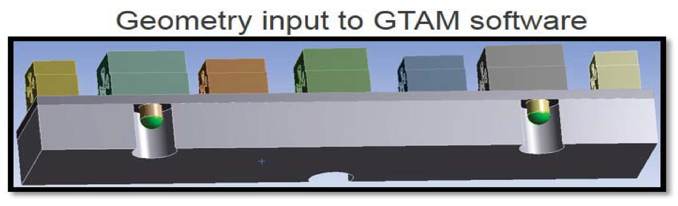
The concrete plinths use a continuous welded steel frame with internal rebar and large headed anchor studs welded to all channels and plates in order to help minimize shrinkage and distortion. A proprietary low-moisture, low-shrinkage concrete mix was specially developed for the plinths. Several prototype 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.



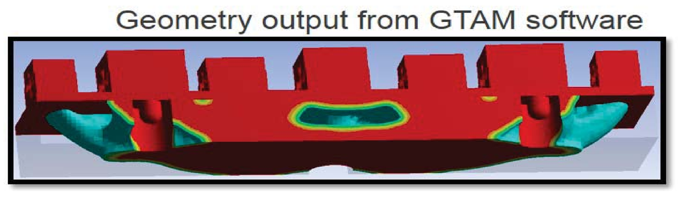
GIRDERS

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. This process is illustrated 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.

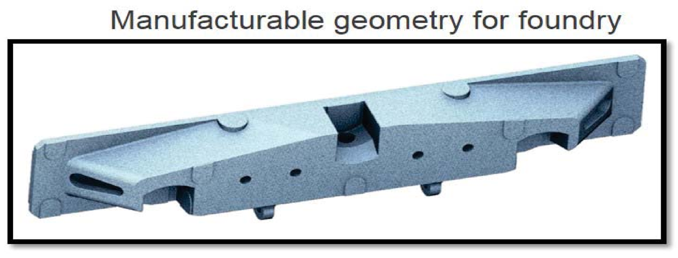
Geometry input to GTAM software



Geometry output from GTAM software



Manufacturable geometry for foundry



TOLERANCES

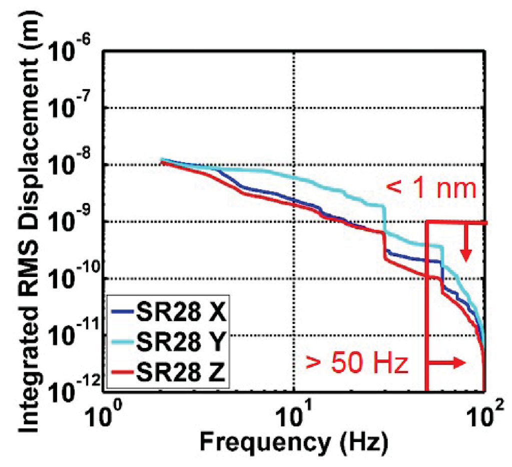
Derived from the APS-U accelerator physics requirements, the survey and alignment assembly and installation tolerances require that each magnet module girder be aligned to within 100 μm RMS of a neighboring girder at the start of commissioning. The APS-U physics requirements also impose tight vibration tolerances on the magnet support and alignment system designs. 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.

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

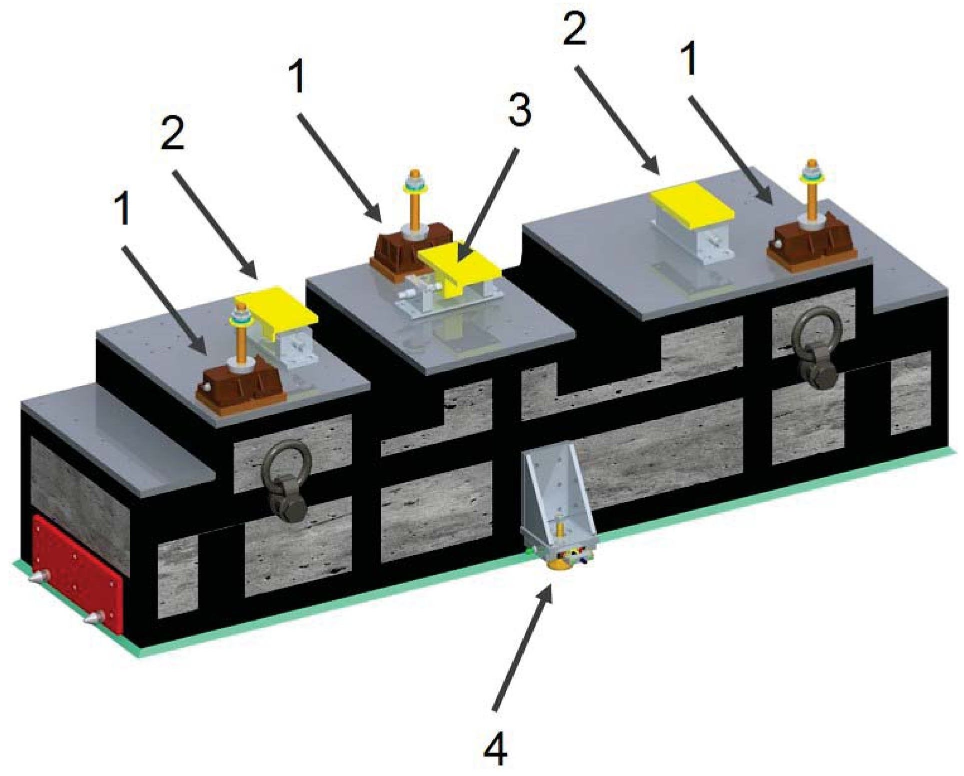
Summary of vibrational tolerances

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



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. On the top of each 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. 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 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.



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

R&D PROGRAM

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.

REFERENCES

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[2] 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.
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[4] 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.

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