

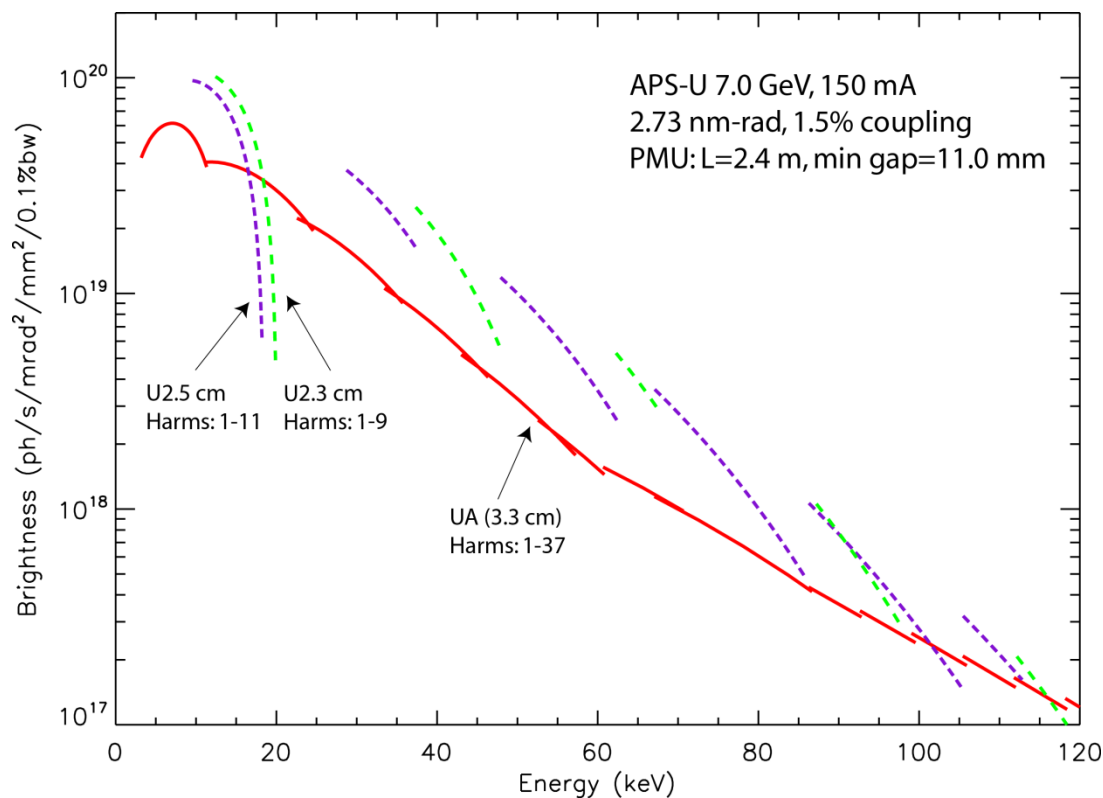
A Revolver Undulator for Sector 35 (DCS): Two Undulators in One!

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Revolver Undulators- What do they do?

- Revolver undulators are “two undulators in the space of one,” allowing higher X-ray brightness over a broader energy range than a planar undulator with a single magnetic period. **A revolver undulator will be used in lieu of multiple in-line undulators for DCS.**



The revolver undulator being built for Sector 35/DCS will use 3.0- and 2.7-cm period magnet structures.

Tuning curves for three undulator periods: 3.3-cm (red), 2.5-cm (purple) and 2.3-cm (green). A revolver undulator combining 2.3- and 2.5-cm periods was being considered for Sector 1 as part of the original APS-U. That combination offers an essentially continuous tuning range from 30 – 115 keV and higher brightness at most energies than a single undulator designed to cover that energy range.

Two Undulators in One? How is That Accomplished?

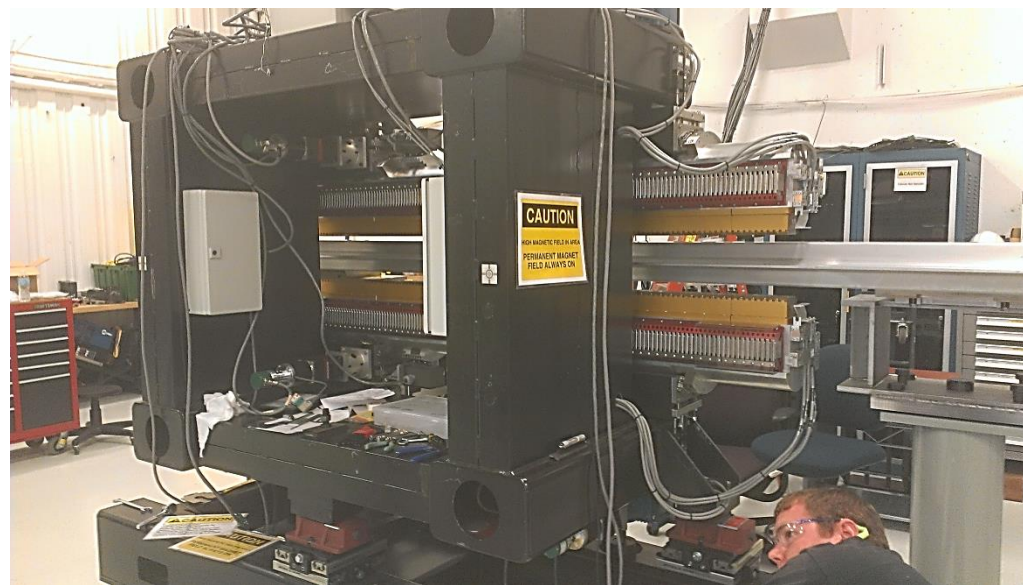
- Where conventional undulators use magnet structures of a single period on each “strongback,” our revolver undulators use two magnet structures of different periods on a revolving strongback.
- Those magnet structures are mounted at 90° to each other; the revolving strongback allows precise rotation between the two structures when the undulator gap is sufficiently open.



Revolver Undulator History at the APS

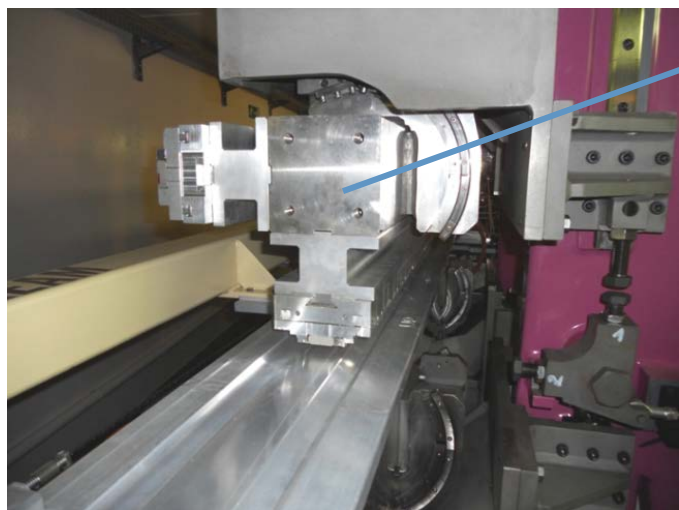
- Revolver undulators were envisioned to be a significant part of the original APS-U; 5 revolver undulators were in the APS-U baseline, with possibly more in contingent scope. Another was planned for DCS; only that one is still underway.
- Single-jaw prototypes were designed and tested as part of an LDRD; one prototype was further developed into a full revolver undulator with two revolver jaws and two different magnet structures.
- Final mechanical and controls design (for “production” revolver undulators) was to have been part of APS-U, but was removed with the switch to the MBA lattice. The work has proceeded, but there has been schedule impact.

The prototype revolver undulator (3.3/2.7-cm periods) undergoing testing while installed over an ID vacuum chamber.



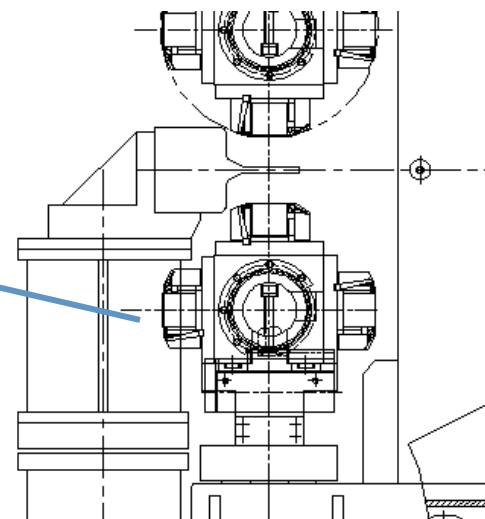
Revolver Undulator Design Challenges

- Revolver undulators are mature technologies at other light sources. ESRF has had revolver undulators in operation for well over a decade.
- Revolver undulators were not envisioned when the design direction was set for IDs and ID vacuum chambers at the APS, so incorporating revolvers presented some challenges unique to the APS. APS undulators are longer than most ESRF undulators (2.4m vs. 1.6 m), our gap separation mechanism uses 4 independent gap drive motors (vs. 1), and our undulators are allowed to taper the gap with up to a 5 mm difference end-to-end.



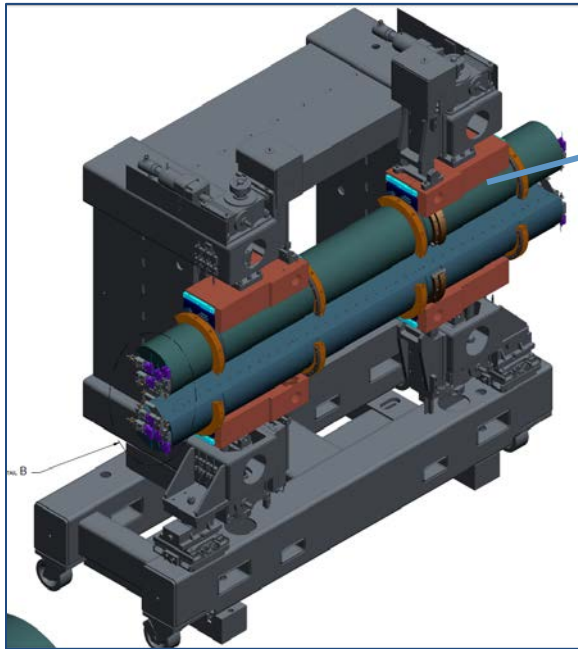
Upper jaw of revolver undulator at ESRF. The ID vacuum chamber was designed to accept revolver undulators.

End view of an early APS revolver undulator design and the existing ID vacuum chamber and support. The support needed to be redesigned to accommodate the unused lower magnetic structure in the outboard position.



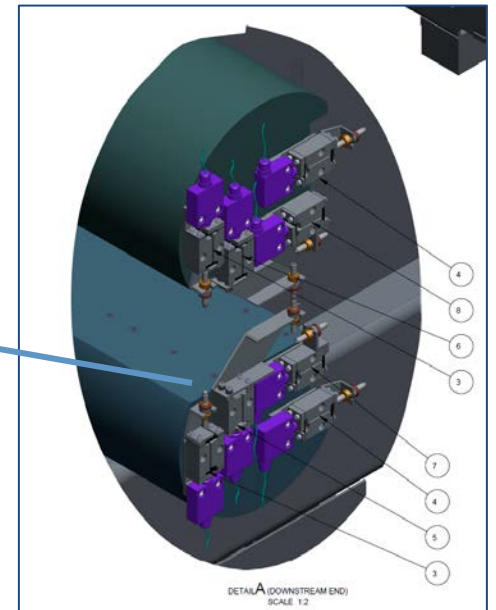
Revolver Undulator Design Challenges

- Many of these challenges were addressed with an APS-specific revolver undulator development program (LDRD-funded), where single-jaw prototypes were designed, built and tested. That project culminated in a design being selected and parts procured for a two-jaw prototype.
- Further design refinements of the revolver undulator, and design of ID vacuum chamber stands to accommodate the revolver, were done as part of APS-U.



Modifications to the strongbacks and their supports, based on the single-jaw prototype testing, were straightforward.

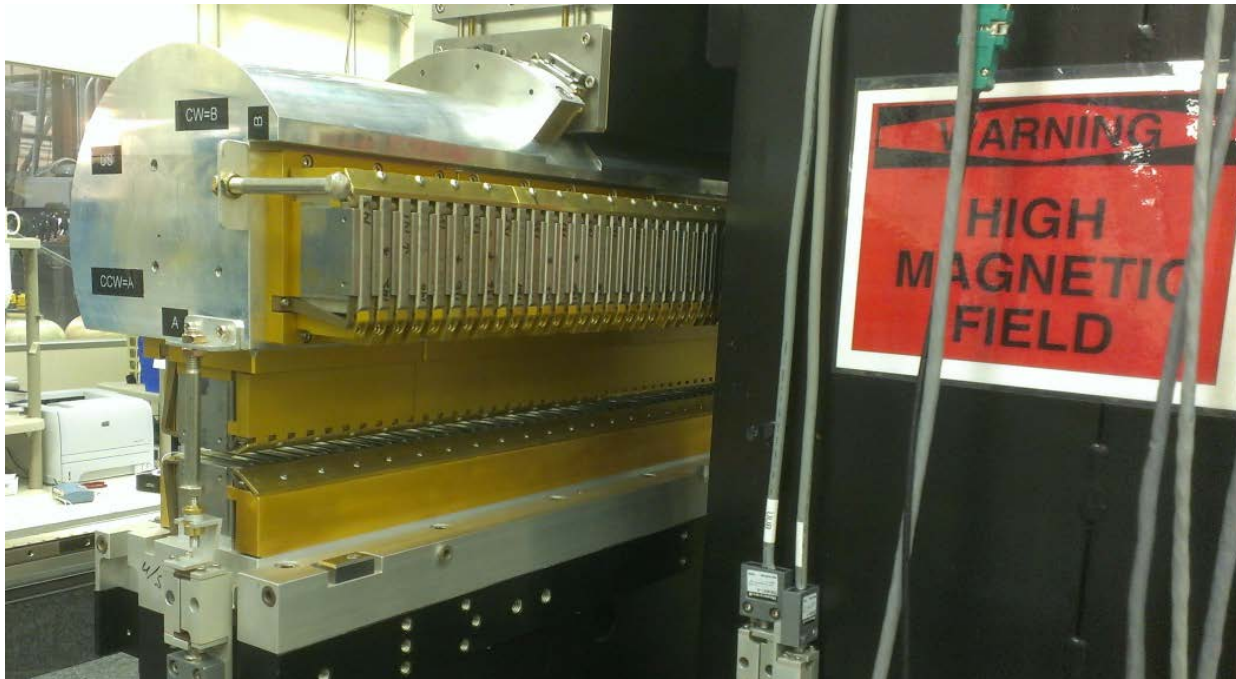
Design of a minimum-gap limit switch arrangement, as well as IDVC stands that were revolver-compatible, were rather involved. The full overtravel range of the revolver axes, the different heights of the magnet structures and the large forces required of the IDVC stands had to be addressed.





Revolver Undulators, Single-Jaw Prototype Measurement and Testing

- The single-jaw prototype was magnetically measured with excellent results (after some tweaks); the A position field reproducibility is 2-3 Gauss at a gap of 10.5 mm with phase errors of 3.6-4.0 degrees, similar to a non-revolver undulator. It also completed a 500 cycle test, simulating 2 years of operation.



Close-up of the single-jaw prototype in the “A” position, with the gap closed. The magnetic structure in the “B” position is rotated back towards the undulator frame.



Revolver Undulators, Dynamic Compression Sector (DCS) Status & Plans

- The prototype revolver undulator (3.3/2.7-cm periods) is being prepared for installation in Sector 35 in the upcoming shutdown. This is an integral activity in the DCS schedule and was presented as a schedule contingency at the DCS CD-2 review.
- The sector cannot currently accommodate the full-length ID vacuum chamber (IDVC) that was intended for installation. To avoid having to modify the currently-installed IDVC to accept the revolver-compatible stands, we experimented (successfully) with removing the center IDVC stand. The area the revolver will occupy is entirely between the two stands.
- The first “production” revolver undulator (3.0/2.7-cm periods) will be built early in 2015 and installed in Sector 35 in the April/May Shutdown (and the prototype revolver undulator will be removed). All the parts for the production undulator are in-house except for the “strongbacks,” which are expected in December, 2014.



DCS Revolver Undulator



Revolver Undulator Engineering Highlights, Controls

- The control system is designed to make the switch between magnet structures transparent to the user, while maintaining strict protection of the undulator and the ID vacuum chamber.
- The gap and revolver drives are interlocked. The gap must be open to enable the revolver drives; the revolver drives must both be in one of the two desired positions to enable the gap drives.
- The controls employ redundancy in these interlocks, similar to that used in the gap separation controls, with **software and encoder feedback as the first line of defense**.
- **Gate array logic using limit switches is the next line of defense**, which allows recovery from hitting a limit switch by inhibiting further motion in that direction, but allowing motion in the opposite direction.
- Finally, a **hard-wired interlock provides the last line of defense**, as it completely disables motor power.

IDControl.adl

ID Gap Control
Building 314 ID
Undulator_APS27#4_2.7cm
Software Version: 4.21R

Avg Current	169.997	17.153
Tpr	-0.006	0.000

Avg Desired	170.000	17.153
Tpr	0.000	0.000

Gap (mm) Energy (keV)

Start Stop

Access Mode : System Manager
System Manager

Harmonic Select (1-7): 1

Gap Deadband (micron): 0

BL. Comm. Limit (mm): 11.000

Magnet Select: U3.3cm
U2.7cm

Total Power: 0

Status Messages:
Device At Destination

Rotation Complete

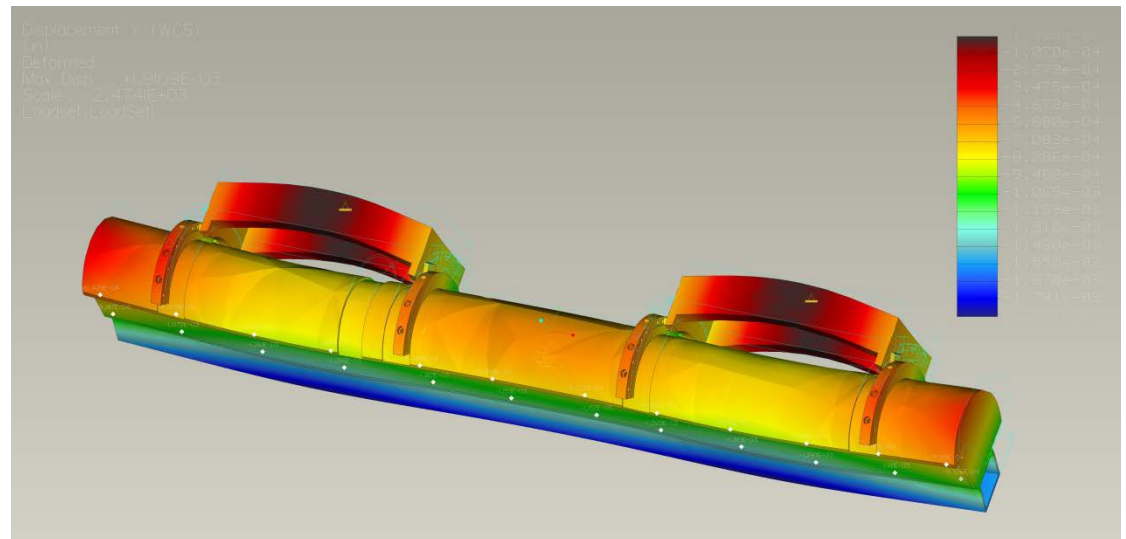
Time Left: 7200 seconds

ID Info: !

Revolver Undulator Engineering Highlights, Mechanical

- The revolver undulator uses the existing APS undulator gap separation mechanism, accommodates all APS-designed undulator magnet structures, preserves gap tapering capability and is compatible with existing ID vacuum chambers.
- The components unique to the revolver were designed for minimal *differential* pole gap deflection, by supporting the strongback in four places and optimizing the strongback supports and the guide rail spacing to complement the strongback.
- The design features low-friction, commercially-available curved bearings/rails for revolver guidance, and a wormgear drive system that cannot be backdriven, so is failsafe when unpowered.
- The wormgear is a “duplex” design, allowing backlash adjustment without changing the wormshaft/wormwheel center distance.

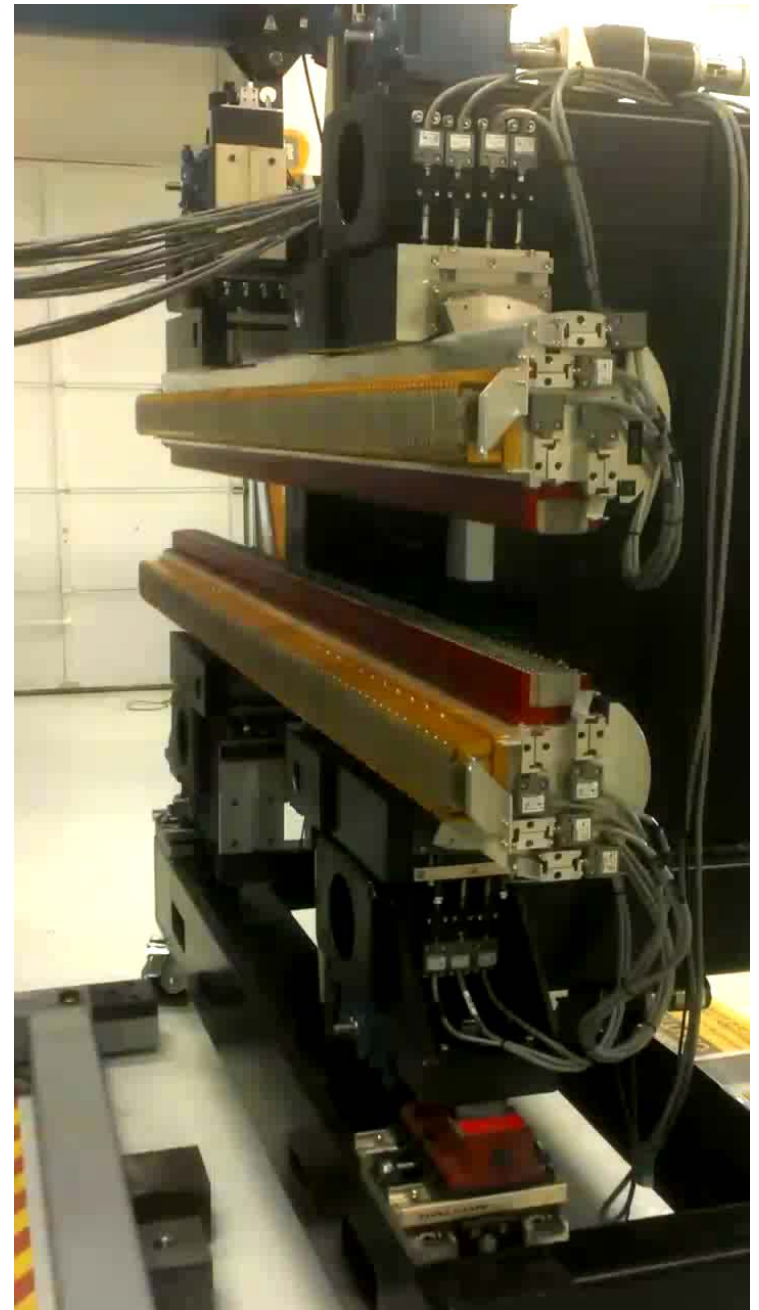
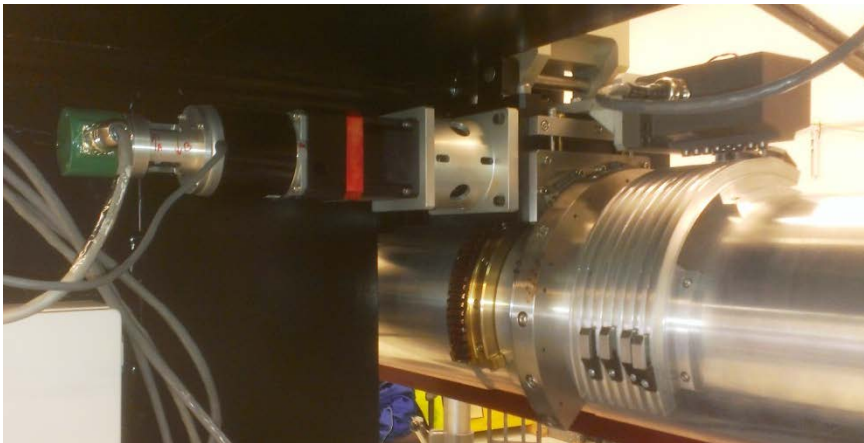
Early design deflection analysis (highly exaggerated) showing uniform deflection (green area) across the magnet mounting face (<10 micron variation under loading of 5000 pounds (larger than force from 3.3-cm period undulator at 10.5 mm gap)).



Revolver Undulator, Revolving!

Video of the 3.3-/2.7-cm period prototype revolver undulator.

- At a gap of 170 mm (for either magnet position), the revolver drives are enabled.
- The video shows the jaws revolving from the 2.7-cm period magnet structure (red) to the 3.3-cm period magnet structure (gold).

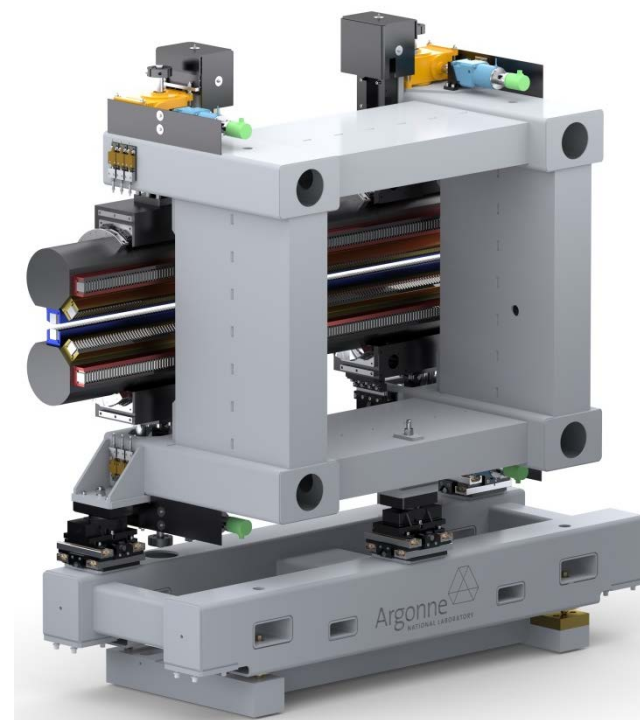
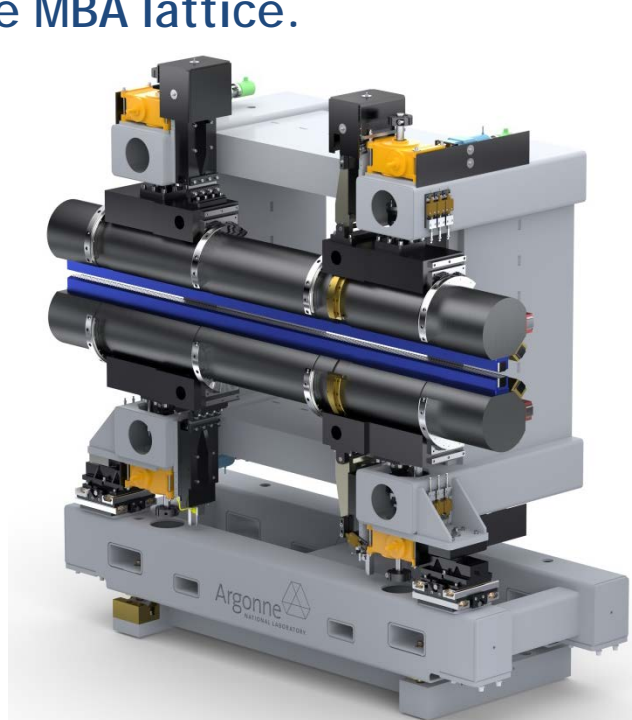


DCS Revolver Undulator



Revolver Undulator Future Plans- Three Undulators in One?

- A design study was done to explore extending the capabilities of this revolver undulator to three magnet structures, oriented at 45° to each other.
- This would exploit the smaller “good field” region required by the MBA lattice by using narrower magnets and poles. It would also exploit the smaller IDVC of the MBA lattice; this scheme would not be feasible with the current IDVC.
- There are also control and magnetic tuning questions to be addressed, but a “three-headed” revolver looks like a very viable, cost-effective option for use with the MBA lattice.



DCS Revolver Undulator





Revolver Undulator Program, Acknowledgements

Individuals:

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