NEG-COATED COPPER VACUUM CHAMBERS FOR THE APS-UPGRADE STORAGE RING VACUUM SYSTEM

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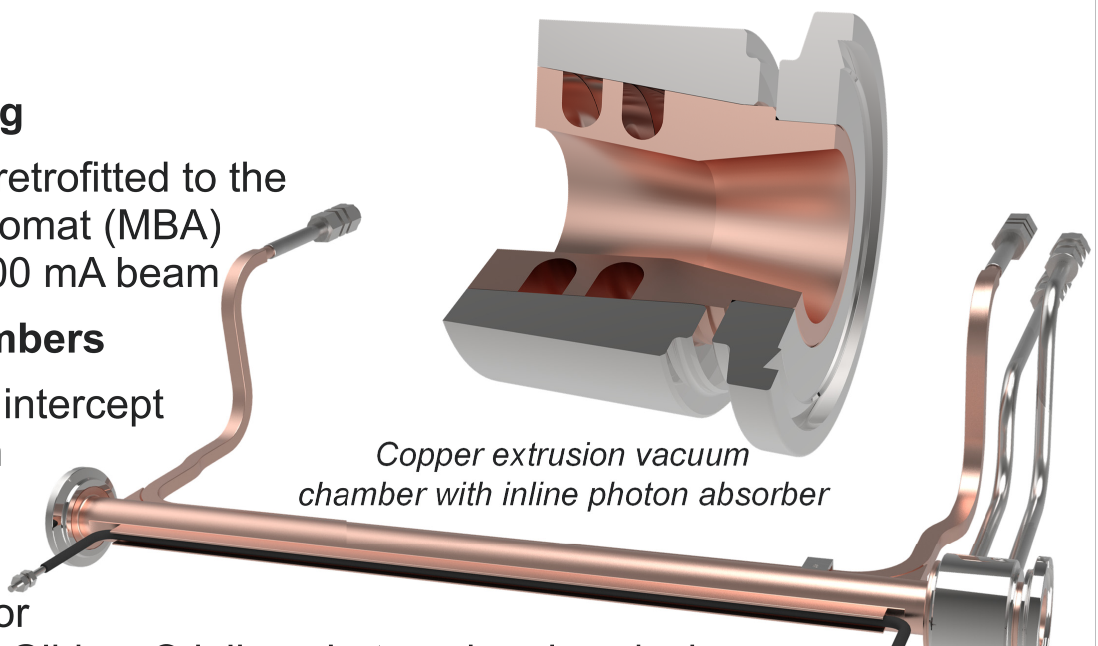
OVERVIEW

APS-Upgrade (APS-U) Storage Ring

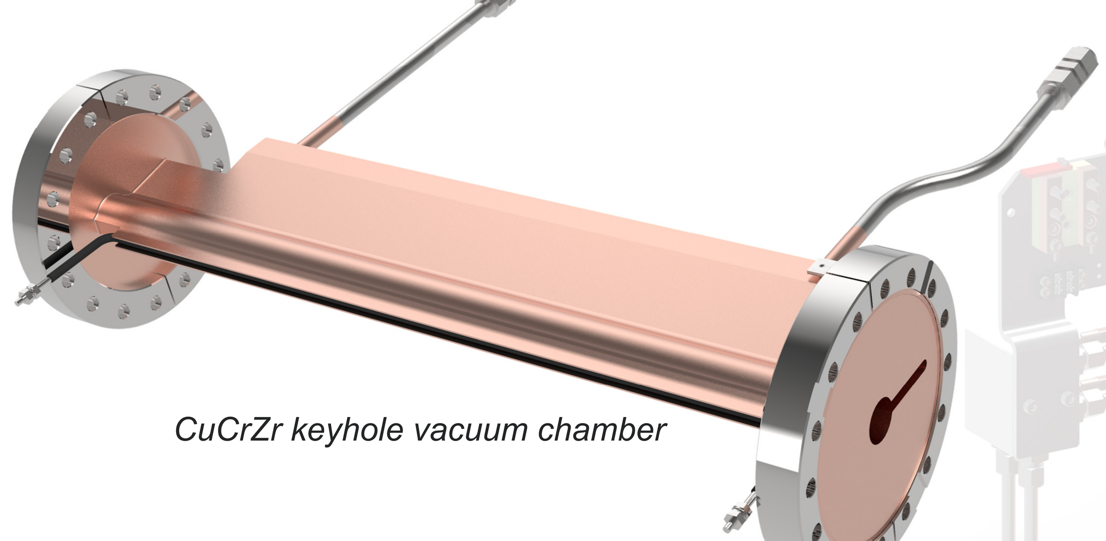
- 40 sectors, 1.1 km circumference, retrofitted to the current APS with a multi-bend achromat (MBA) lattice that will produce a 6 GeV, 200 mA beam

NEG-Coated Copper Vacuum Chambers

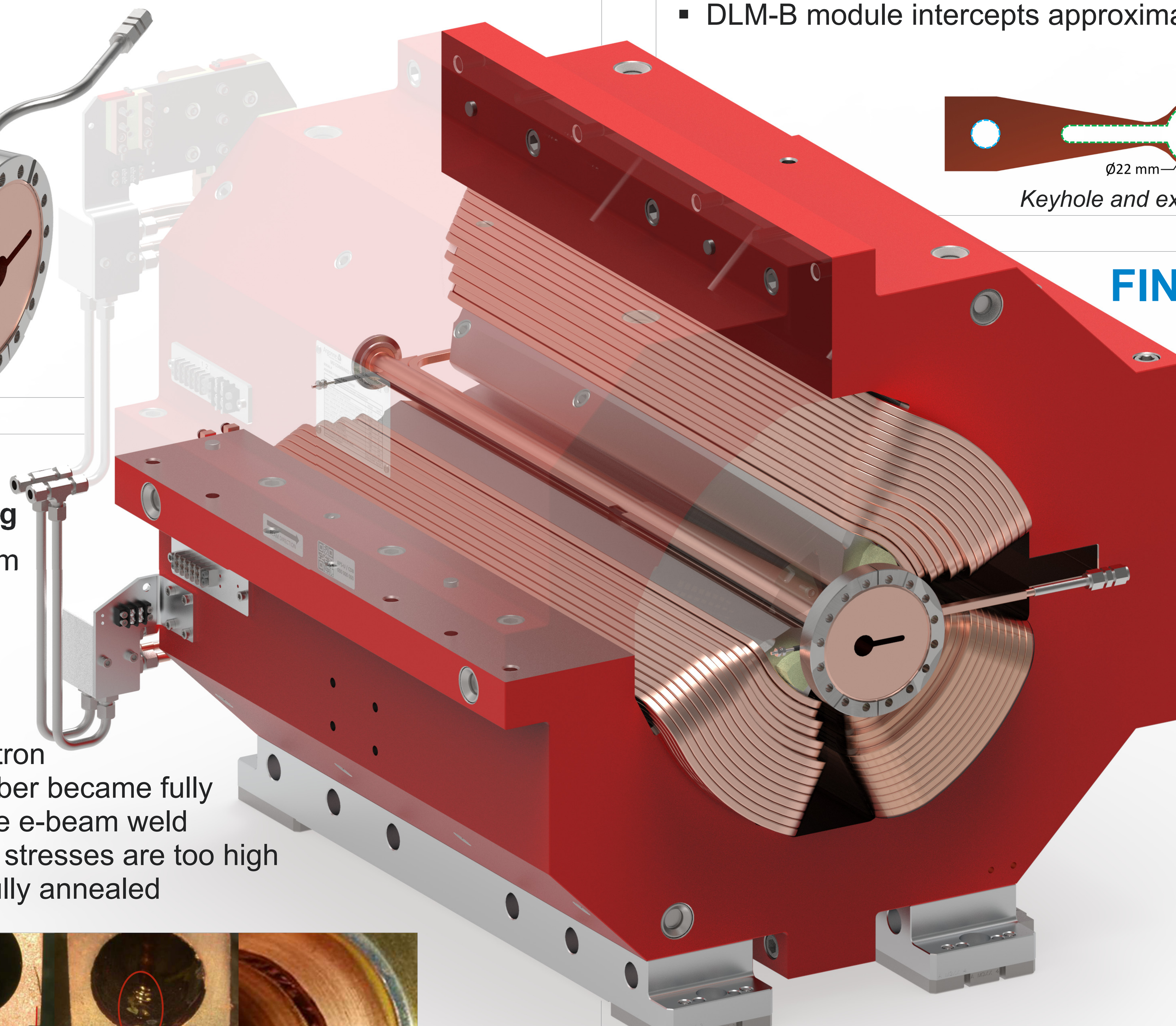
- Strategically placed in regions that intercept high-intensity synchrotron radiation – i.e. FODO and DLM-B modules
- Seven distinctive copper alloy vacuum chamber designs per sector
  - 5x OFS copper extrusion with a Glidcop® inline photon absorber design
  - 1x CuCrZr keyhole photon extraction design
  - 1x OFS copper extrusion and CuCrZr keyhole-transition hybrid design
- Vary from 0.3 m to 1.7 m in length
- Ø22 mm vacuum aperture



Copper extrusion vacuum chamber with inline photon absorber



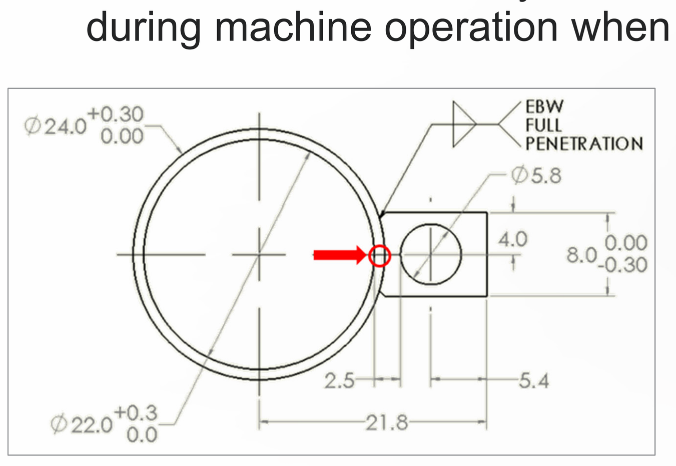
CuCrZr keyhole vacuum chamber



PROTOTYPING

Initial Phase – Electron-Beam (E-Beam) Welding

- Water cooling channel e-beam welded to vacuum chamber housing
- First attempt: damaged vacuum chamber walls
- Second attempt: new weld joint geometry and manual correction during e-beam weld process
  - Metallurgical evaluation showed the synchrotron radiation-struck surface of the vacuum chamber became fully annealed due to the heat-affected zone of the e-beam weld
  - Thermal-structural analyses showed thermal stresses are too high during machine operation when material is fully annealed

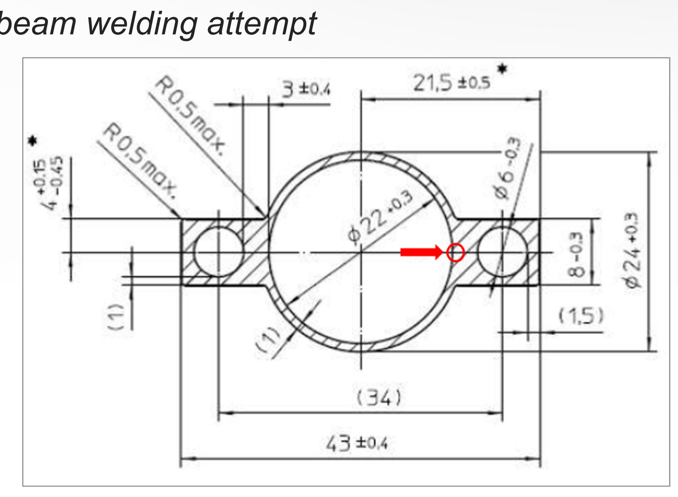


E-beam welded vacuum chamber cross-section with radiation-struck wall circled in red

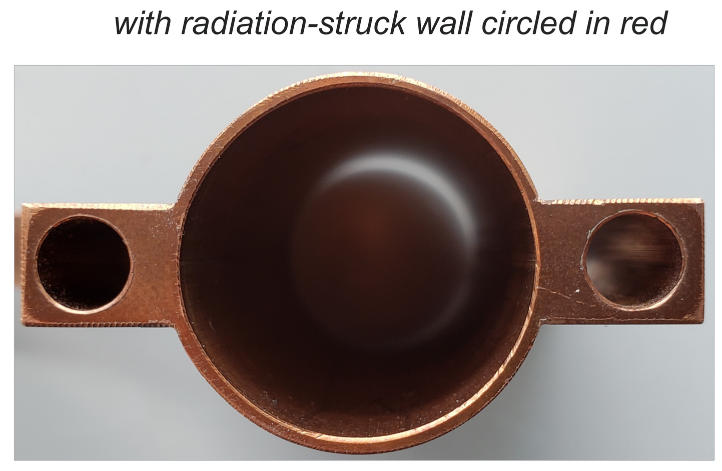
Damage to vacuum chamber and water channel walls from first e-beam welding attempt

Secondary Phase – Triple-Hollow Copper Extrusions

- Two-step fabrication process
  - Copper extruded to approximate required dimensions
  - Extrusions cold-drawn to final dimensions in a work-hardened condition
- In-depth validation of extrusions
  - Dimensional inspection: very accurate and consistent across 3 m extrusions
  - Material strength: well above prescribed requirements and vendor's ratings
  - Metallurgical investigation: no signs of material defects that may eventually lead to material failure or vacuum leak development
  - Surface roughness: consistently well below APS-U requirement of 1.5 µm RMS



Extruded vacuum chamber cross-section with radiation-struck wall circled in red

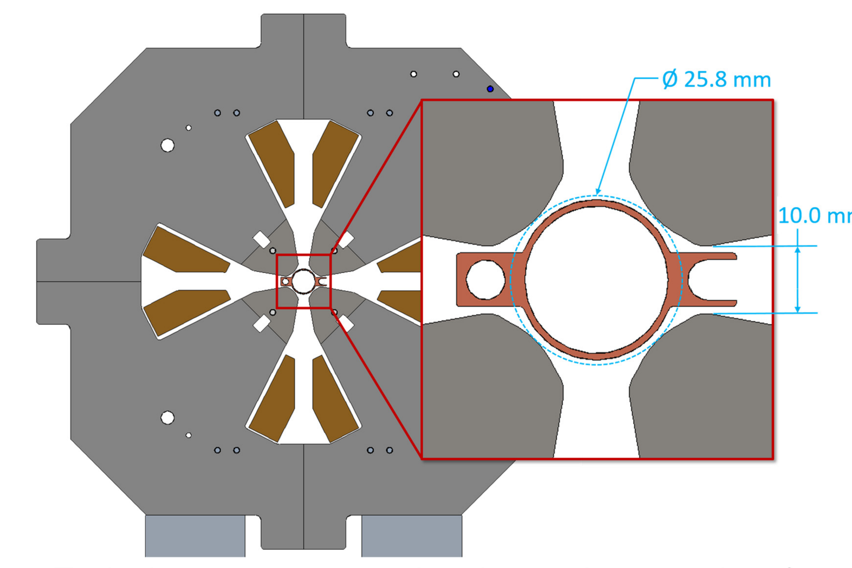


OFS copper extrusion

DESIGN CONSTRAINTS

Interfaces

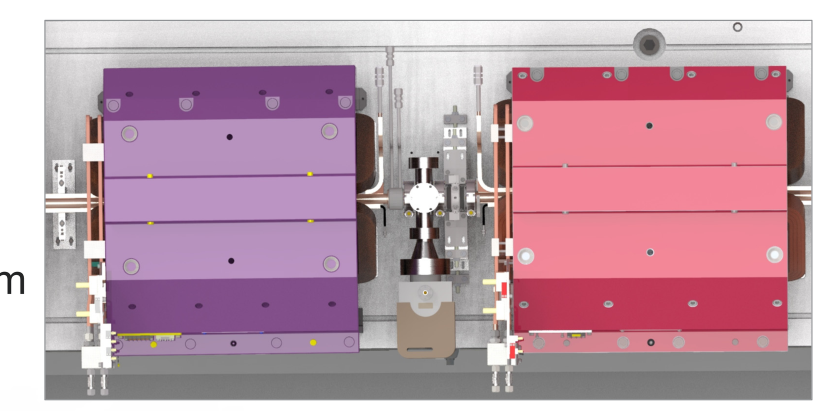
- Quadrupole and sextupole magnets
  - Typically less than 1 mm between pole tips and vacuum chamber surfaces
  - Three vacuum chamber designs are curved to follow the shape of magnet pole tips
- Plinths and vacuum system supports
- Electrical and water systems
- Neighboring vacuum equipment



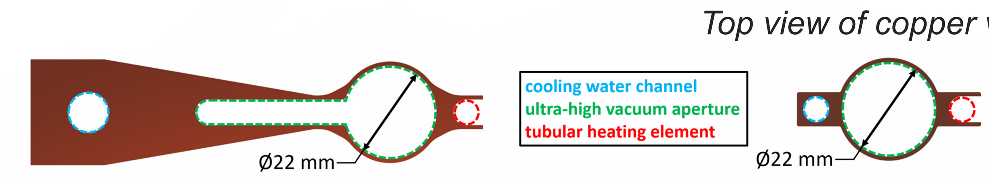
Typical copper vacuum chamber and magnet interface

Ray Tracing

- 0.2 kW to 2.6 kW of power depending on vacuum chamber design and location
  - CuCrZr keyhole vacuum chamber does not intercept any direct synchrotron radiation
- FODO module intercepts approximately 1,000 W/m
- DLM-B module intercepts approximately 600 W/m



Top view of copper vacuum chamber interfaces

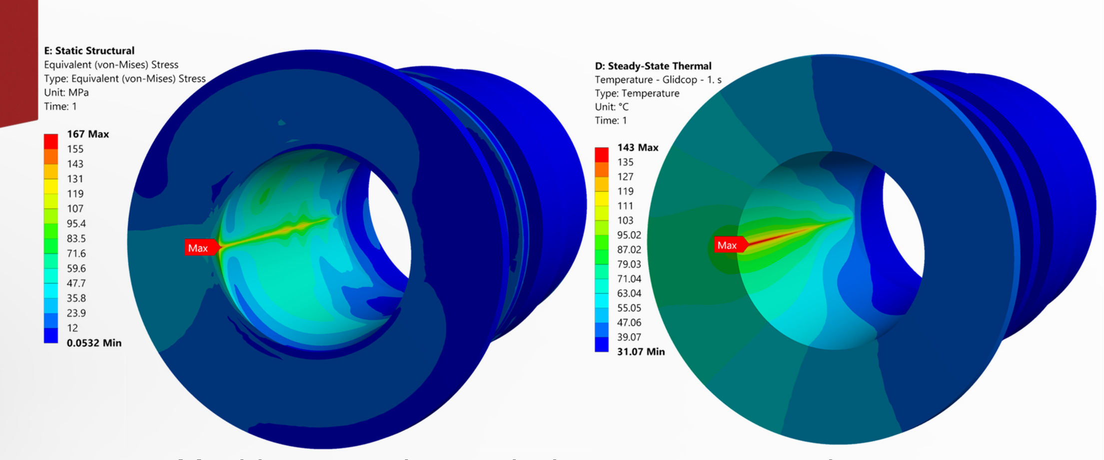


Keyhole and extrusion vacuum chamber apertures

FINAL DESIGN AND FABRICATION

Analysis

- Extensive thermal-structural analyses completed throughout each phase of design
  - Machine operation: high stresses from vacuum forces, hydrostatic pressure, and beam interception
  - Bake-out: buckling of vacuum chamber walls and potential annealing of material



Machine operation analysis: temperature and stress results for hottest inline photon absorber (A:VC16)

Manufacturing Processes Utilized

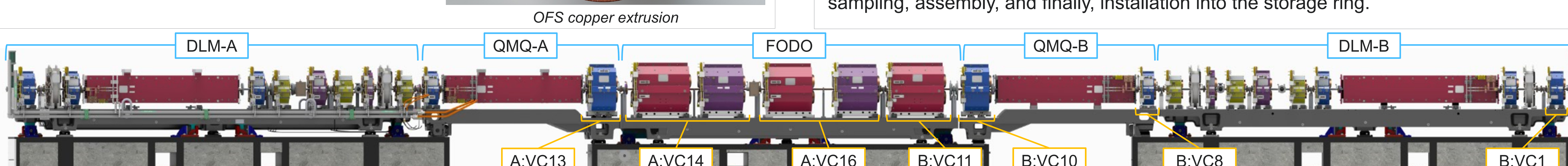
- Machining: conventional (mill, lathe, among others) & EDM
- Bending: of cooling water channels and three vacuum chamber designs
- Joining: e-beam welding, furnace brazing, and torch brazing

NEG Coating

- Implemented on each of the seven copper vacuum designs
- Employed across approximately 40% of the storage ring vacuum system
  - Including all Ø22 mm aperture vacuum chambers with the exception of copper-coated stainless steel keyhole vacuum chambers
  - Similar NEG coating scheme to that of MAX IV
- Copper vacuum chambers to be activated at 180°C to capture maximum NEG performance and minimize risk of overheating magnets across narrow installation gaps

CONCLUSION

After a complex copper vacuum chamber development process involving three distinctive phases of design, prototyping, analysis, and rigorous internal and external design reviews, the copper vacuum chamber have recently gone through a formal bidding process. The procurement process is currently underway, with future steps including fabrication, testing, QA sampling, assembly, and finally, installation into the storage ring.



*Courtesy of Josh Downey

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