Engineering Update and PDR Plans

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PAC-6

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What has happened since the CDR?

NCSX

- Incorporated design improvements
- Continued to resolve outstanding issues
- Developed plans for a June PDR
- Initiated manufacturing development and R&D activities

Design improvements and outstanding issues

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Added poloidal break in MC structure

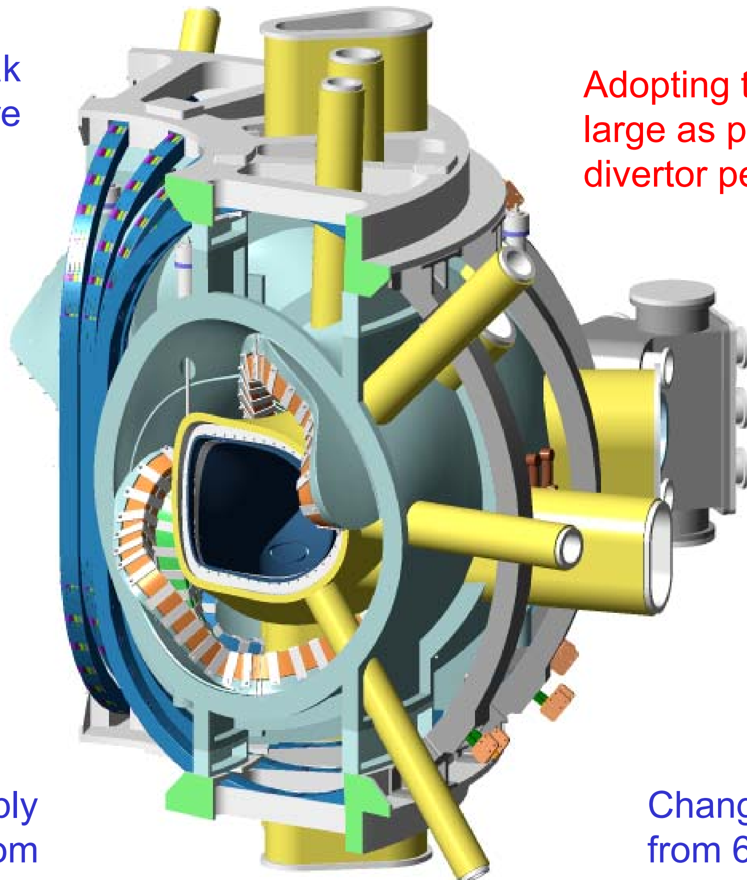
Simplified MC cooling

Adopted 2x2 conductor pack in MC to minimize keystoning

Simplified VV port attachment

VV assembly joint tilted to avoid assembly interference

Changed field period assembly process for MC from "1 at a time" to "3 at a time"



Adopting the new MC set, making VV as large as possible for improved divertor performance and flexibility

Developing option of bucking TF coils off CS coils rather than off separate structure

Evaluating reducing the number of PF coils from 6 to 5

Changed order of MC production from 6(A-B-C) to 6A-6B-6C

Poloidal break added to MC structure

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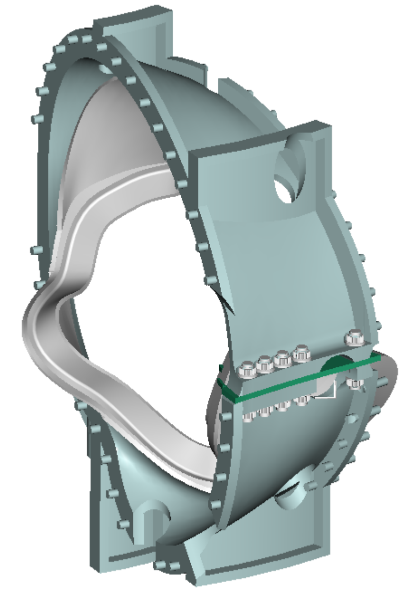
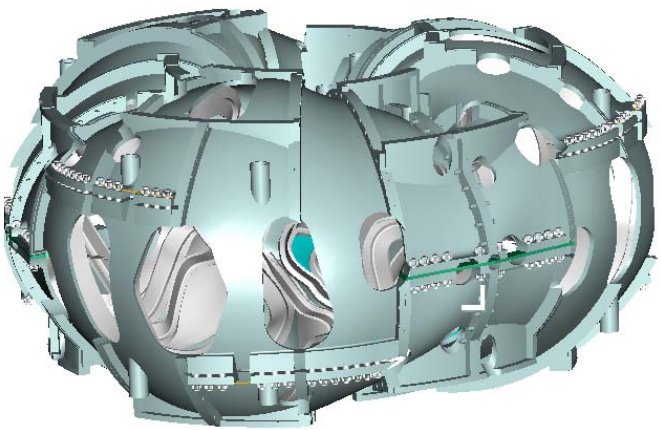
- Time constant w/o poloidal break was too long
  - 70ms with 3 toroidal breaks
  - Plasma current ramp time is 60ms
  - Requirements is < 20ms
- Adding a single poloidal break and 15 toroidal breaks (none at field assembly joint) drops the longest time constant to 18 ms

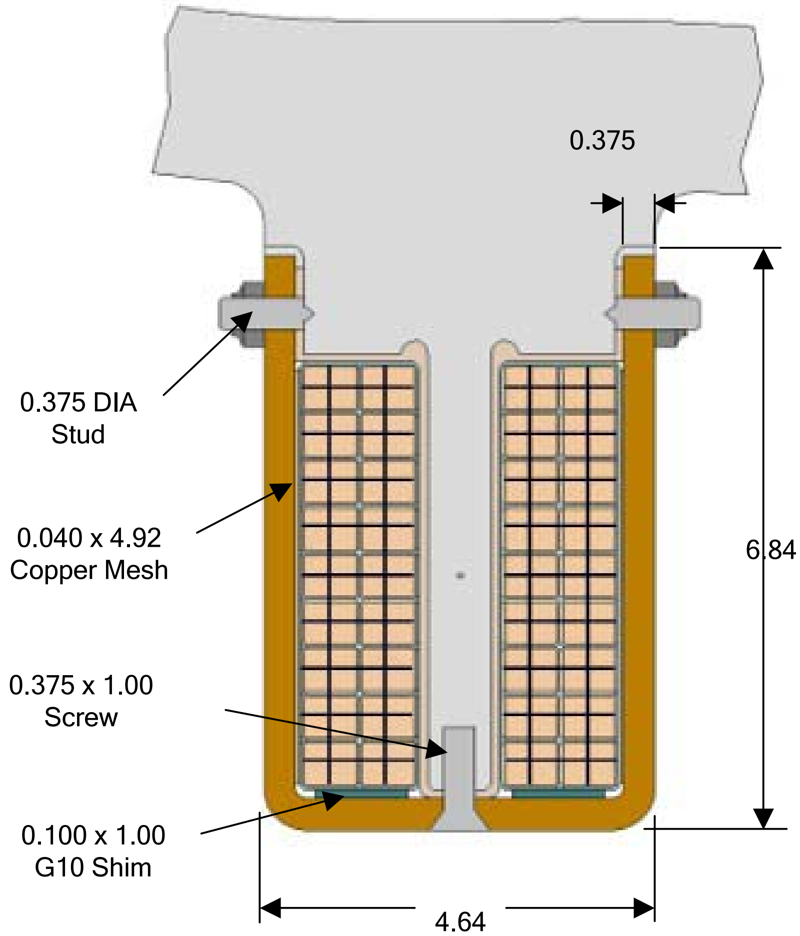




Simplified MC cooling scheme adopted

NCSX

- CDR concept of applying loose copper strips to tee section compromises positional accuracy of winding surface
- Loose copper strips replaced by copper cladding
  - Applied to tee section over an electrical insulator
  - Contacts clamps at attachment points
- Cooling tubes are attached to copper clamps
- Copper mesh outside ground wrap conduct heat to clamp on outside of winding pack
- Adequate cooldown is achieved



Adopted 2x2 conductor pack to minimize keystoning

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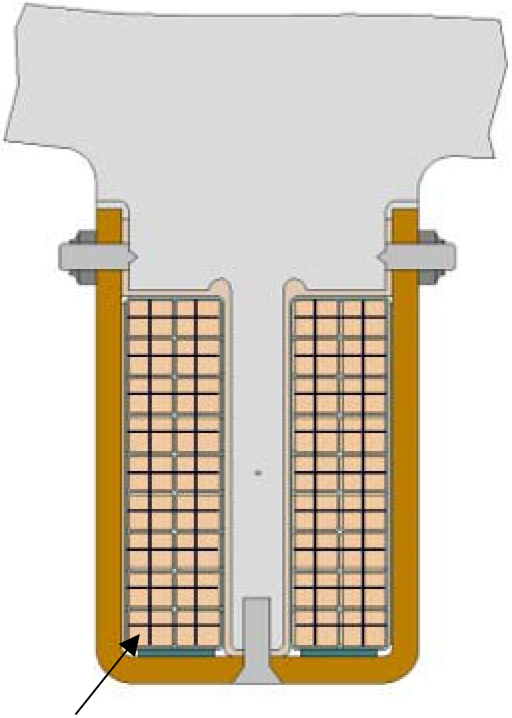
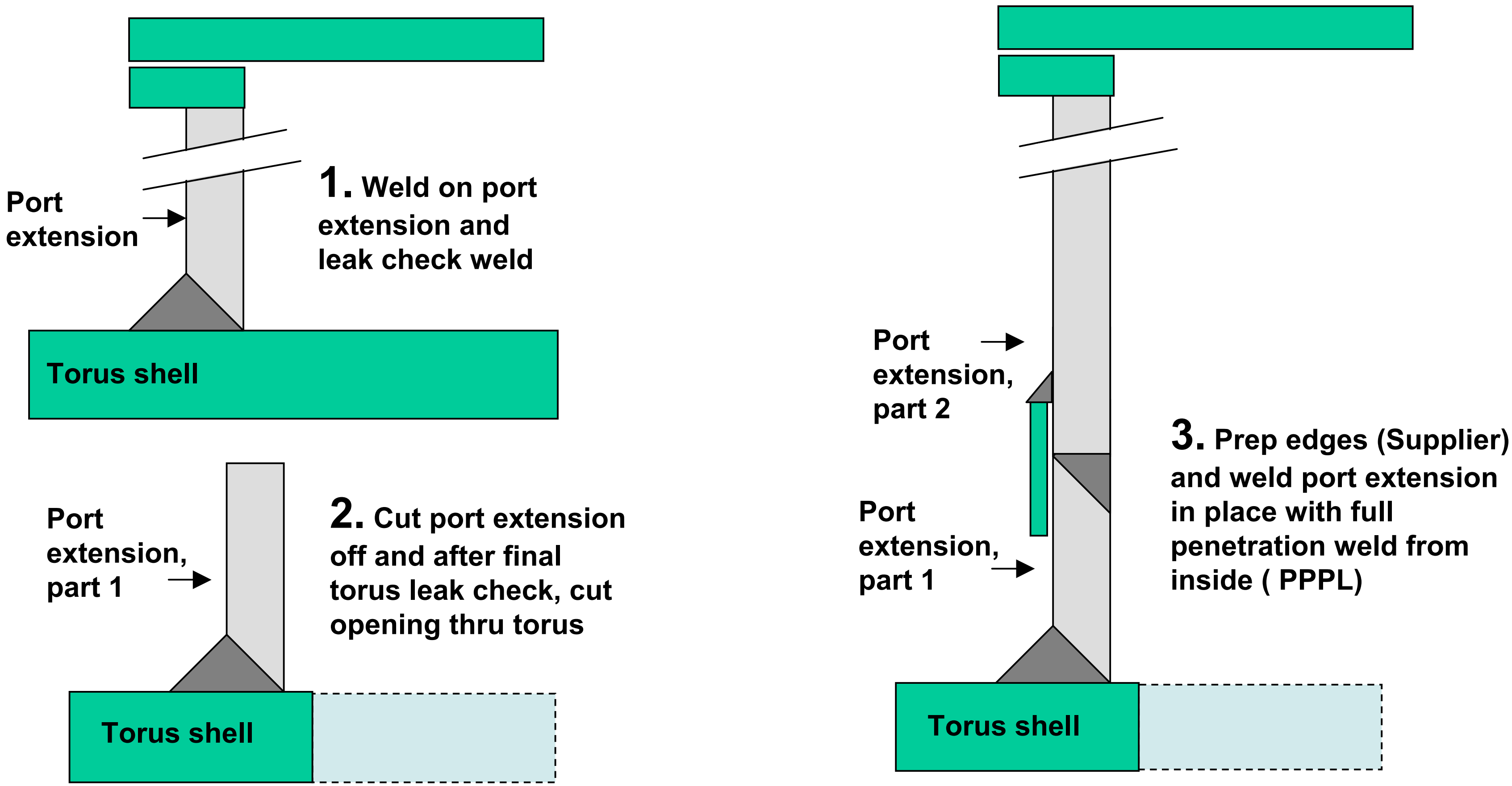
- CDR concept of using a single conductor per turn would result in substantial keystoning in regions of tight curvature
- 2x2 conductor array per turn should greatly reduce keystoning
- Goal is to avoid compensation in the geometry of the winding surface or the use of mechanical force to squash winding pack into shape
- Keystoning tests are planned for early CY03

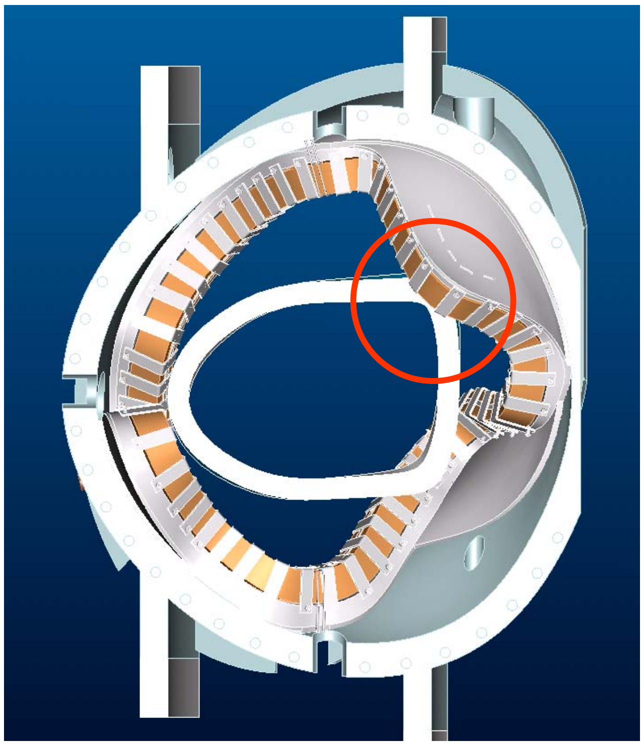


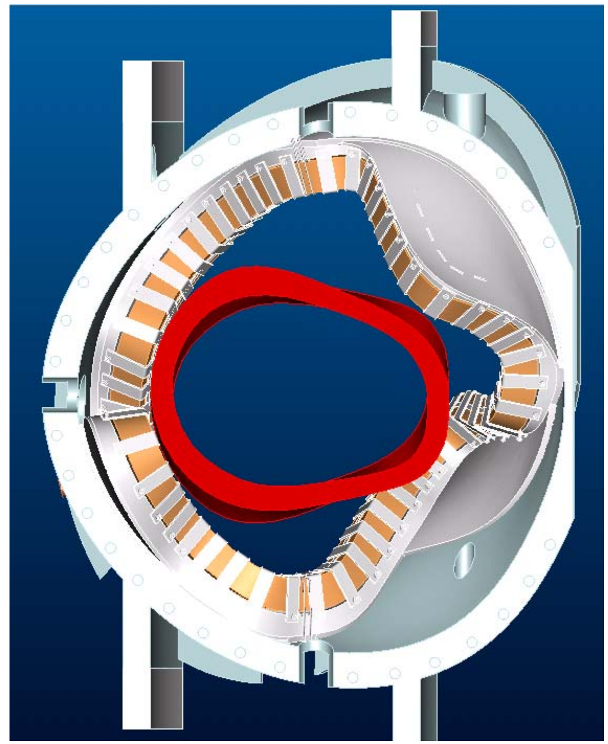
Use 0.25x0.313-in, 32-ga conductor
4 cables per turn

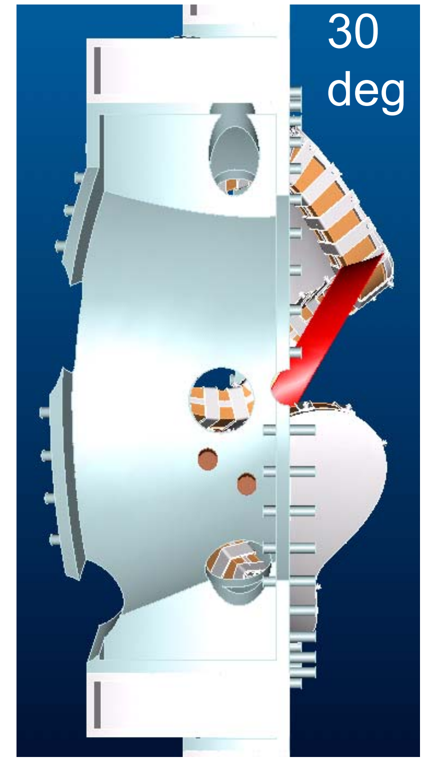
Simplified VV port attachment adopted to facilitate leak checking and reduce cost



Assembly interference resolved by tilting assembly joint





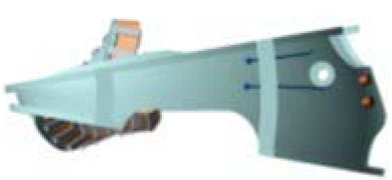


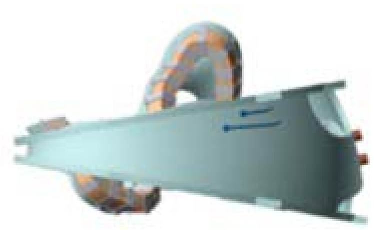
Vertical assembly flange showing interference with mod coil during assembly operation

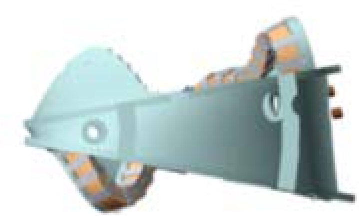
Problem solved by tilting assembly flanges 30 deg off vertical.

Changed field period assembly process for modular coils

- CDR plan was to slip the modular coils one at a time over the VV
- Appears beneficial (in SLA model) to pre-assemble 3 modular coils and slip them as a unit over the VV
  - Avoids simultaneously mating the modular coils to their neighbors while avoiding collisions with the VV
  - Provides more schedule flexibility w/o impacting first plasma. Modular coils no longer have to be mated in a strict A-B-C order. The first VV segment would not be required until the first A-B-C modular coil assembly is completed.

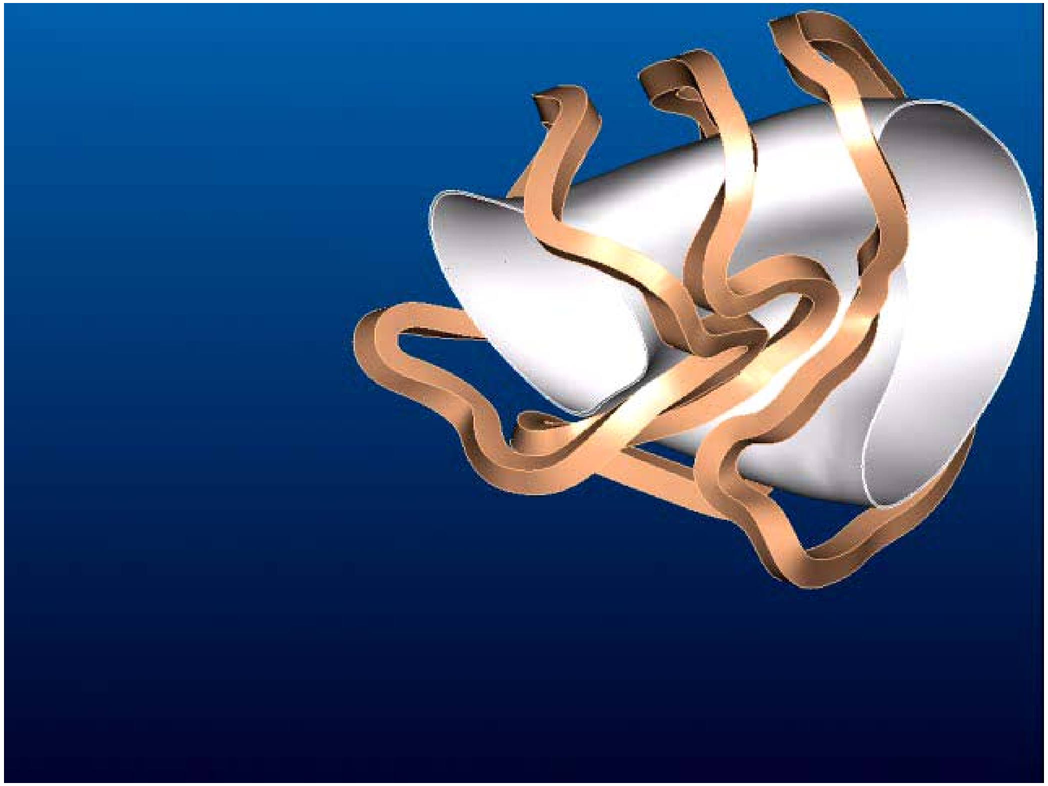






Modular coils assembled 3 at a time

- Requires careful programming of MC trajectory
- Limits size of VV



Algorithm developed to optimize MC trajectory

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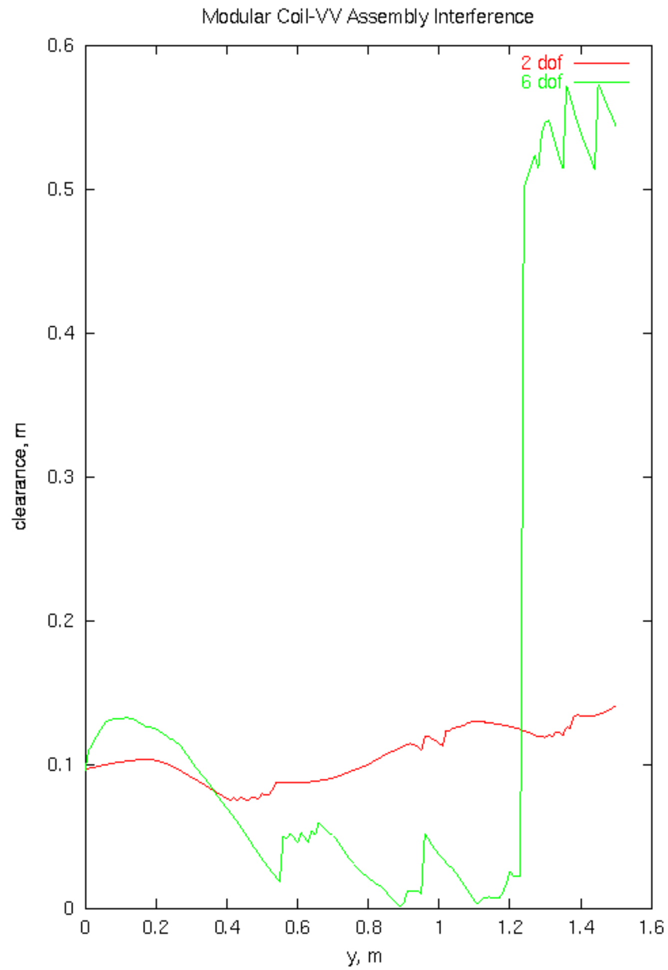
- Chooses trajectory to maximize MC-VV separation
- Runs well in trial with 2 degrees of freedom
- More work needed to accommodate 6 DOF



Relaxed the order of MC production

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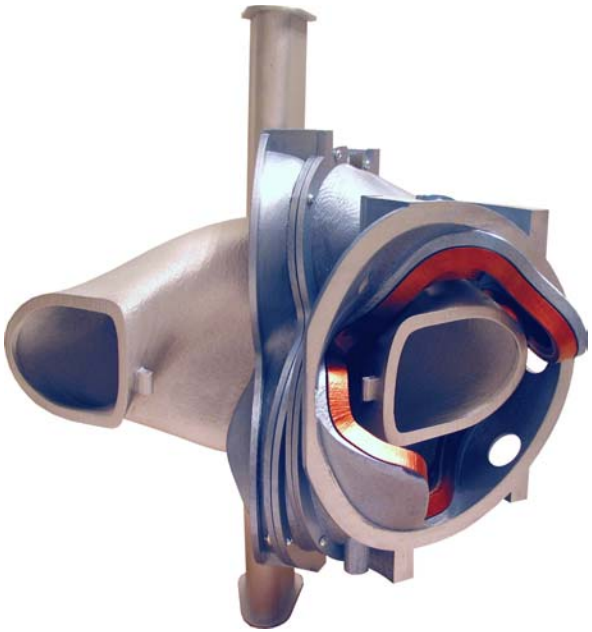
- Suggestion made at CDR by D. Anderson (UW) to produce all modular coils of the same type in sequence (6A-6B-6C), rather than always changing the coil type being produced (6[A-B-C])
- Appears advantageous for casting/machining the winding forms and winding the coils
- Pre-assembling the modular coils three-at-a-time gives quite a bit of flexibility in what order the coils can be received



Developing option of bucking TF coils off CS coils

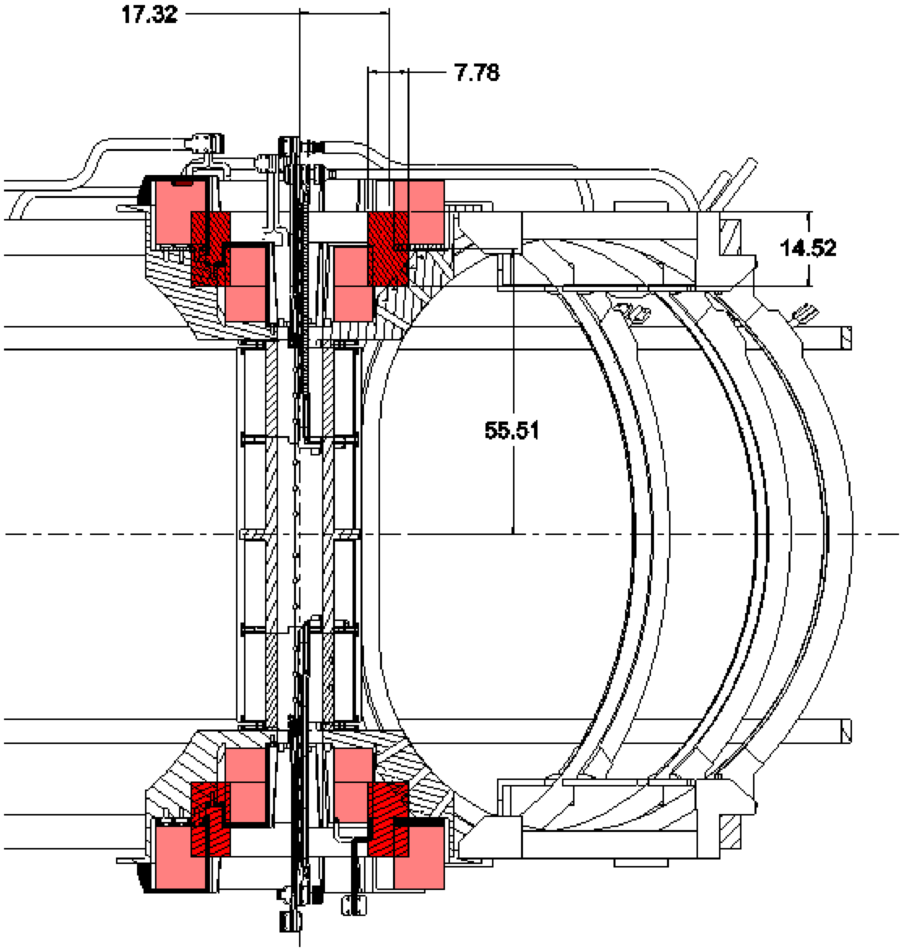
NCSX

- At CDR, two options appeared viable
  - Buck TF coils off a separate structure w/ vertical plates and horizontal disks – the CDR design
  - Buck TF coils off CS coils
- The second option offers significant advantages and is being developed for the PDR
  - Increased OD for CS coils, more V-s, less power required
  - Simpler CS structure should translate into lower cost

Evaluating reducing the number of PF coils from 6 to 5

NCSX

- Evaluating whether adequate performance and flexibility would be provided by combining PF3 and PF4
  - New coil would be located in between PF 3 and PF4
  - Same cross-section as PF3
- Benefits
  - Reduce cost (fewer coils and circuits, eliminate crown structure)
  - Simplify assembly and maintenance (solenoid can be inserted and removed with PF3 in place)



The major outstanding issue is incorporating the new MC design and expanding the VV

- Physics has identified a new MC set with increased coil-to-plasma spacing for improved divertor performance
- Key engineering metrics have been incorporated into the optimization (max coil current, min bend radius, min coil-to-coil spacing) and have been preserved or improved in the new MC set – we do not anticipate any problems engineering the new MC set
- Engineering will expand the VV as far as assembly constraints allow to the realize improved divertor performance

Plans developed for a June PDR

NCSX

- Requirements for the PDR have been defined
- Work plans leading to a June PDR for the Modular Coils (WBS 14) and Vacuum Vessel (WBS 12) have been coordinated, incorporated in the project control system, and are being tracked
  - Plans implement CDR recommendations
- The conceptual design and cost and schedule estimates for all other WBS elements will be updated at that time
- Updating the conceptual design with the new MC set and expanded VV is the pacing item for the PDR

Requirements for the PDR

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- Performance requirements have been defined
- A design has been developed that fully meets those requirements
- All feasibility issues have been resolved
- Interfaces with other systems have been fully defined
- Plans for assembly, installation, and test are established
- Models and drawings have been developed, reviewed, and released at the Preliminary Design level

Key activities leading to the PDR

- Reconstruct conceptual design of stellarator core
  - Incorporate the new MC set and expanded VV
  - Resolve all outstanding configuration issues
- Develop system requirements for the MC and VV
- Complete analyses required to show that these systems fully meets their system requirements
- Work out interfaces with other systems
  - VV-Diagnostic interfaces are particularly important (port geometry, envelopes for in-vessel diagnostics, port allocations)
- Document plans for assembly, installation, and test
- Update cost and schedule estimates incorporating vendor input

Manufacturing development and R&D activities have been initiated

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- 4 vendors (2 for the MC and 2 for the VV) will be brought on board for mfg development and prototype fabrication
  - RFPs have been issued
  - Proposals due in December (MC) and January (VV)
  - The vendors for the production units will be selected from among those participating in this next phase
- Modular coil in-house winding R&D has already been started at PPPL

VV manufacturing development and prototype fabrication

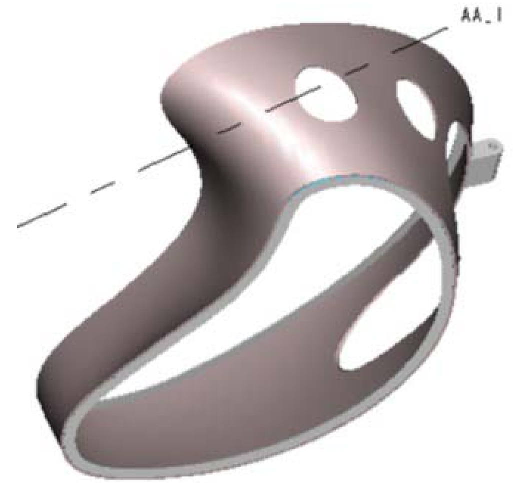
NCSX

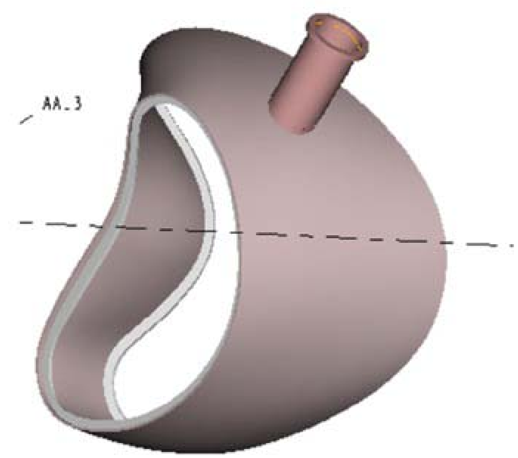
- Manufacturing development activities will be conducted by 2 subcontractors to support the VV PDR.
  - Manufacturing methods for fabricating the VV will be identified.
  - Recommendations for improving the VV design and performing additional mfg development activities will be solicited.
  - Preliminary Manufacturing, Inspection, and Test (MIT) and Quality Assurance (QA) Plans will be developed and used as the basis for budgetary cost and schedule estimates.
- The subcontractors will fabricate a full scale 20º prototype VV segment.
- The subcontractors will submit a final MIT/QA plan and a fixed price cost and schedule proposal for the production units

20º prototype vacuum vessel segment

NCSX

- Purpose is to develop the methods and demonstrate the capability to form, weld, and assemble a VV prototype with acceptable quality, low distortion during welding and heat treatment, satisfactory tolerances, low permeability, and UHV compatibility
- Full scale 20º prototype includes one port and sections with high curvature
- Segment design will be reviewed with vendors to determine if the 20º segment alone is adequate for this purpose

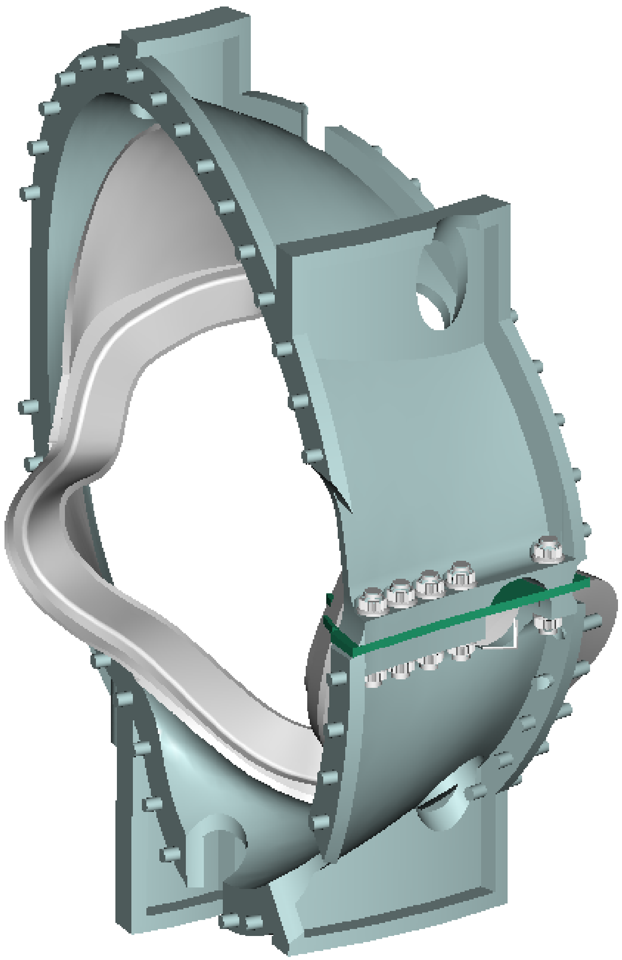




MC winding form manufacturing development and prototype fabrication

NCSX

- Deliverables are similar to those for the vacuum vessel
- Manufacturing development activities will be conducted by 2 subcontractors to support the Modular Coil PDR
- The subcontractors will fabricate a full scale prototype modular coil winding form (later used for winding R&D)
- The subcontractors will submit a final MIT/QA plan and a fixed price cost and schedule proposal for the production units



In-house winding R&D

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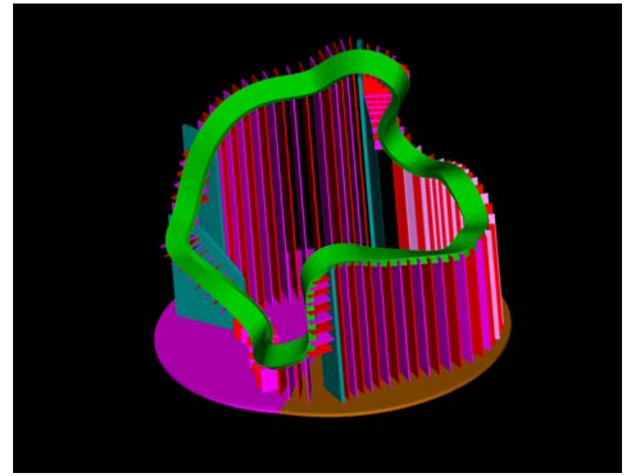
- Winding R&D at PPPL has been initiated in FY03
- Key elements
  - Perform keystoning tests
  - Develop VPI process
  - Determine winding material properties and allowables
  - Develop molding process
  - VPI molded test samples in small oven (pre-PDR) and autoclave (post-PDR)
  - Wind, mold, and VPI full scale prototype coil (post-PDR)

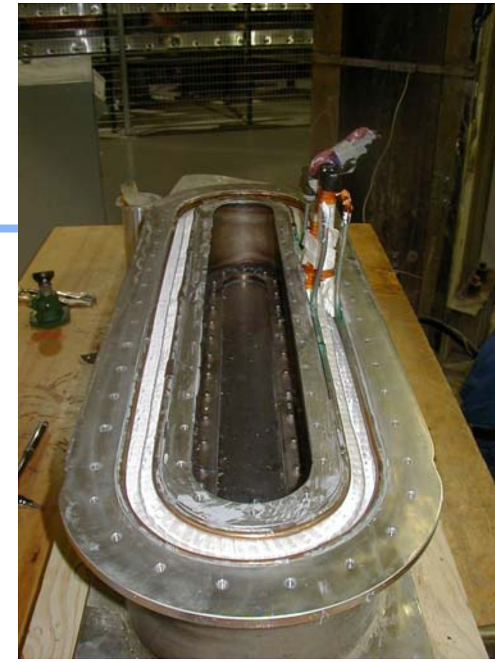
Keystoning tests

- Winding form being designed
- Nine insulated turns using four (4) conductors per turn will be wound onto form
- “Faro” mechanical measuring arm will be used to measure tolerance build as a result of conductor keystoning



Develop VPI process

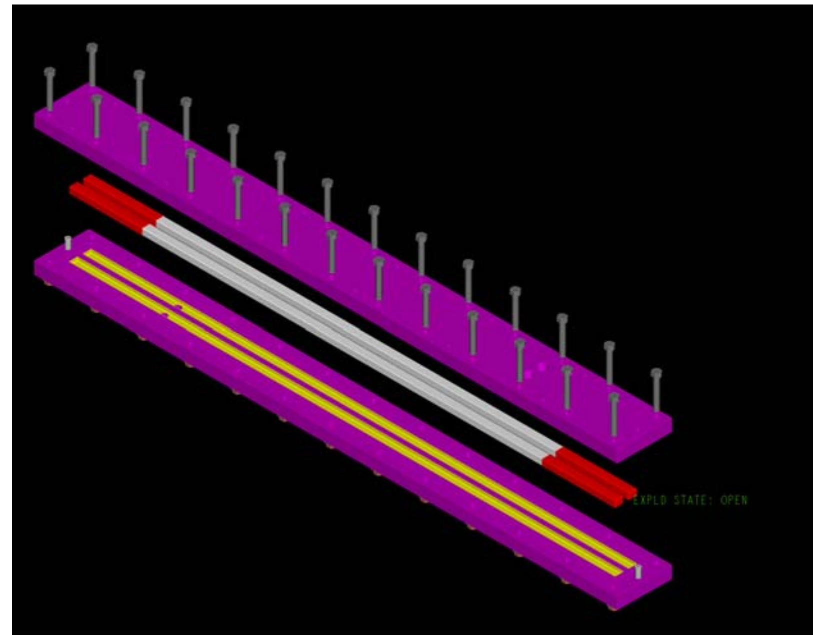
- CTD 101K selected as the resin system for impregnating modular coils
- Epoxy characterization underway (cure cycle, viscosity, etc.)
- Existing small vacuum oven and viscometers will be used
- VPI of 1st tensile specimens and UT coil will be done in December
- R&D is being conducted in TFTR Basement



Material tests to determine properties and allowables

NCSX

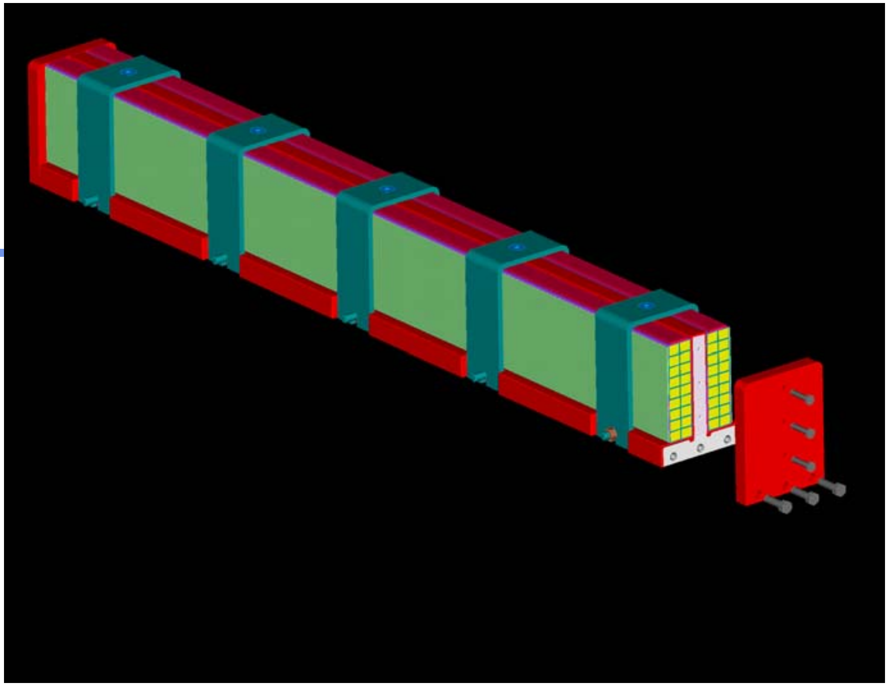
- SOW has been drafted identifying all necessary tests
- Mold has designed and fabricated for 1st tensile specimens
- VPI of 1st tensile specimens expected this week
- Properties needed for thermal and structural analyses

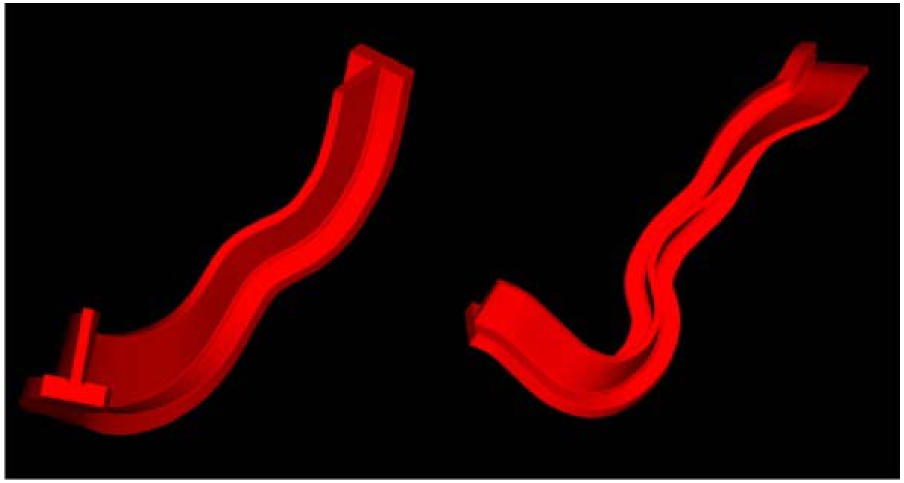


Develop molding process

NCSX

- Wet wrap of winding pack is planned to form pressure boundary for VPI
- Molding process will first be tested on straight samples, VPI in small oven
- Molding process tested on actual coil sections next
- Larger sections and a full scale prototype will be molded after the PDR, VPI in autoclave





Summary

NCSX

- Substantial design improvements have been made since the CDR, no new “showstoppers” have been identified
- Plans have been put in place for a June MC (WBS 14) and VV (WBS 12) PDR and project-wide Cost & Schedule Review
  - Incorporating the new MC design and expanded VV are the pacing items
- Critical path manufacturing development and winding R&D activities are moving along well