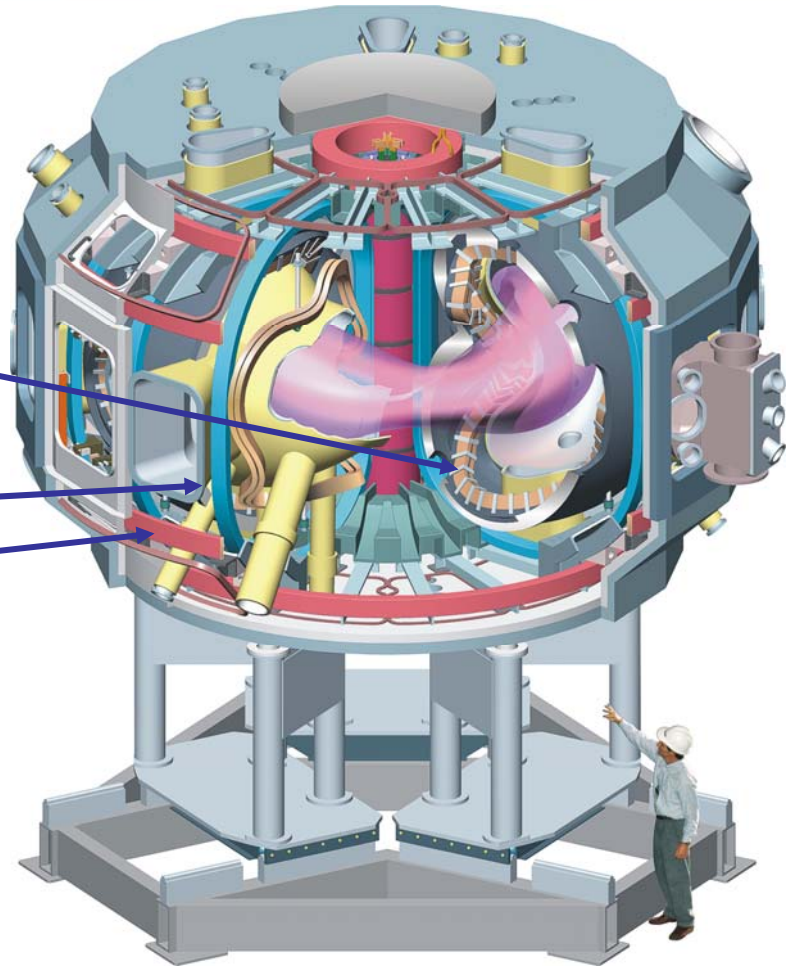
National Compact Stellarator Experiment (NCSX) Dimensional Control Concerns and Issues

NCSX Overview

NCSX
National Compact Stellarator Experiment

- NCSX is the centerpiece of the U.S. effort to develop the physics of the compact stellarator.
- Quasi Symmetric
- 18 Modular Coils
  - 6 each of type A, B, and C
  - Modular coils are connected by bolted joints with shims.
- 18 Toroidal Field Coils
- 6 pairs of Poloidal Field Coils
- Trim coils
- Major Radius 1.4m
- Aspect Ratio 4.4
- Magnetic Field 1.2T – 1.7T



Current Status

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- The 3 vacuum vessel segments are completed.
- All 18 modular coil castings have been completed.
- 14 of the 18 modular coils have been wound.
- Machine assembly operations are just getting started.

What are our metrology issues and concerns?

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This is PPPL's first use of Faro/Romer arms, laser trackers, and VeriSurf software.

- Issues:
  - Steep learning curve.
  - Working near the spec limits of the instrumentation.
  - Development of efficient metrology procedures capable of meeting Project dimensional requirements AND budget/schedule goals.
  - The components being aligned are not rigid bodies.
  - The building where final assembly will be performed may have deflections which are significant, considering our dimensional goals.
- Concerns:
  - Stacking of tolerances during leapfrogging operations.
  - Instability of the measurement instrumentation has been an intermittent problem.
  - Accuracy, time and schedule. At present, we plan to use laser trackers for assembly operations.
    - Are our proposed techniques sound and the most efficient?
    - Can photogrammetry improve the accuracy of the final assembly?
    - Can photogrammetry reduce time?

There are Three Types of Modular Coil

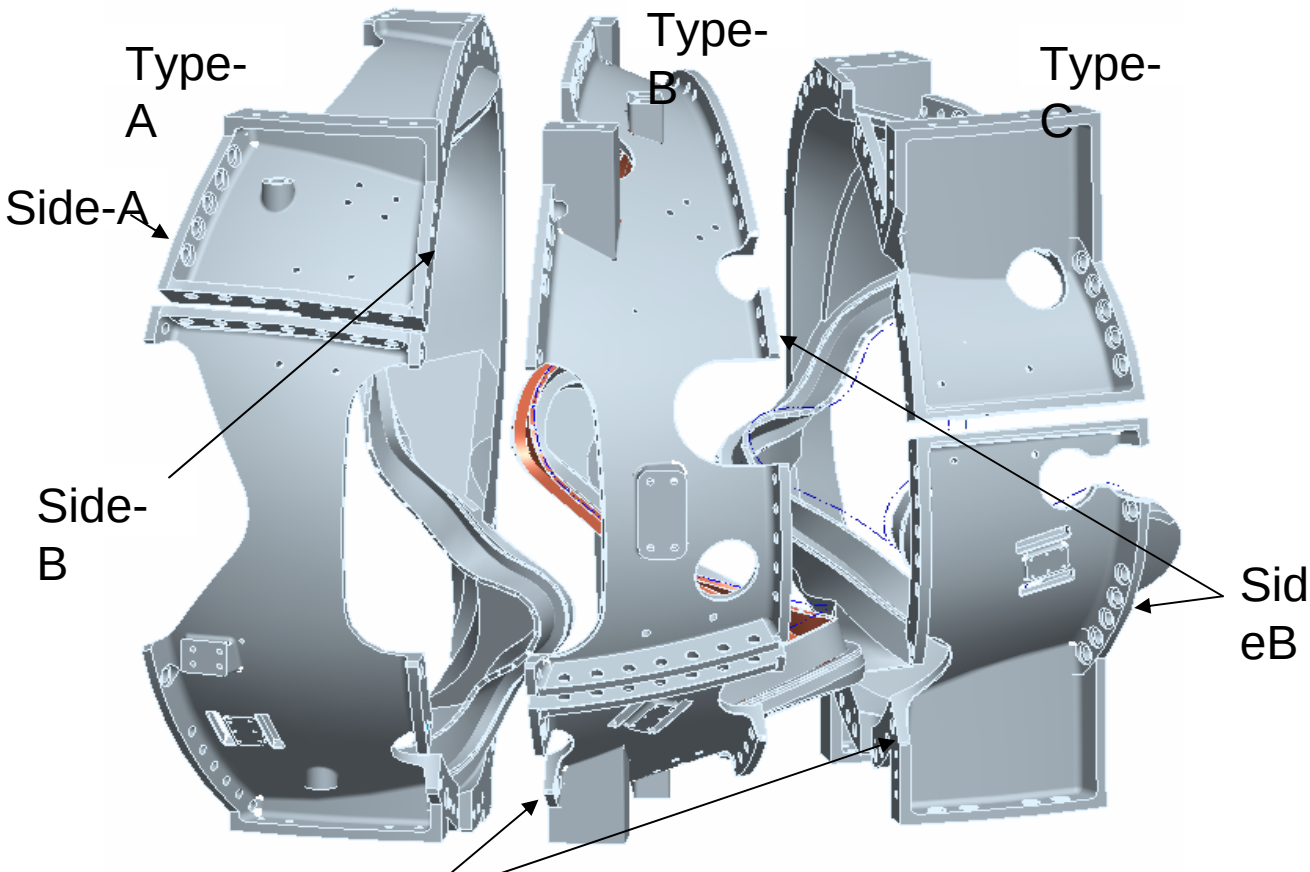

Figure 2. MCHP Component Winding Forms

Coil Tolerance Specifications

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- These coil tolerances pertain to the location of the current centers of the installed coils relative to the ideal [theoretical] position.
  - Modular Coils +/- 1.5mm [.060in]
  - PF Coils +/- 3.0mm [.120in]
  - TF Coils +/- 3.0mm [.120in]
  - Trim Coils +/- 3.0mm [.120in]
- The modular coils are the most critical.
- An allocation of the modular coil tolerance for each major assembly step has been defined.

Tolerances are Allocated to Each Modular Coil Assembly Step

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- Vendor machining and in-house winding +/- 0.5mm [.020in]
  - Manufacturing deviations in the winding forms are compensated for during winding.
  - Realignment offers a chance for improved performance.
- Half Period [3-pack] Assembly [B-A, C-B] +/- 0.25mm [.010in]
  - We expect this to be the most difficult requirement.
  - Flange to flange alignment determines overall alignment.
  - A-A alignment performed prior to half period assembly.
- Full period assembly over vacuum vessel
  - HPA + FPA tolerance = 0.5mm [.020in].
  - A-A alignment will bring us close to this goal.
- 3 period assembly in test cell +/- 0.5mm [.020in]
  - C-C alignment

The Assembly Tolerances are at the Limits of our Measurement Technology

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- The position of the coil throughout assembly is defined by a set of fiducial monuments.
  - The winding geometry is measured in a coordinate system referenced to these monuments.
- A mechanical measuring arm is used for the coil winding process.
- A laser tracker is used for subsequent assembly tasks.
- Measurement software works with the measurement arm, laser tracker and CAD models to expedite measurement of each winding form.

Half Period Assembly

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- The 0.25mm [.010in] tolerance for half period assembly is possibly the most stringent requirement in the assembly sequence.
  - Modular coils are ~2m [79in] “diameter”.
  - Modular coils are not rigid bodies.
- Precise assembly is necessary for proper load sharing between shims, as well as for dimensional control.
- An integrated metrology and assembly sequence has been prepared.
  - Laser metrology will play a key role in assembling the modular coils within the tolerance goal.
  - Fujipaper is used to monitor shim compression.
  - Stiff fixtures are required for assembly.
- Results of initial trials are encouraging.

Assembly Sequence…

- The first coil is placed on the assembly fixture, “B” side up.
- The laser tracker is aligned to the monuments on the coil.
- The “B” (upper) flange is scanned.
- Using the “B” flange measurements and the “A” flange from the mating coil, a set of shim thicknesses is calculated

Assembly Sequence…

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- Fit up trials were performed which indicated to demonstrate feasibility of the proposed processes.
  - Three of the shims are placed on top of the first coil.
  - The second coil is lowered into position.
  - The monuments on the bottom coil are re-measured, and the coil is jacked where necessary to restore its shape.

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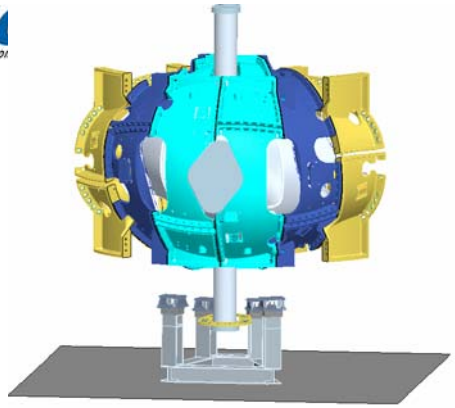
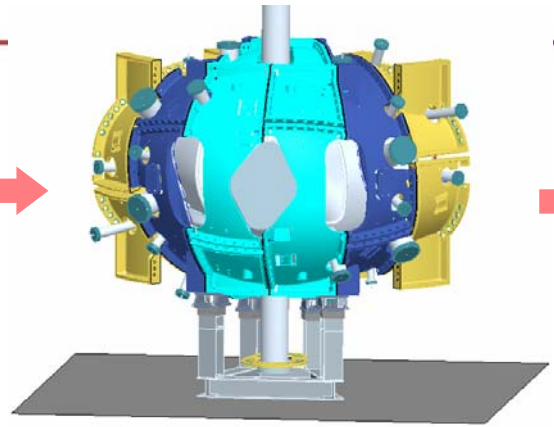
Assembly Sequence…

- The steps for mating the first two coils in a half period are repeated, on a different fixture, when the third coil is joined.
- The new fixture is tilted 40deg instead of 20deg, so that the mating surface will be horizontal.
- Because the top flange of the second [middle] coil is measured in its as-assembled condition, the accumulation of errors is minimized.
- A complete field period is assembled by bolting two half periods together at the interface between two “A” coils.
- Pre-fitting two mating type A coils prior to half period assembly will maximize the likelihood of successful full period assembly with a minimum of iterations.
- A trial of the A-A fitup will demonstrate the feasibility of our assembly sequence.

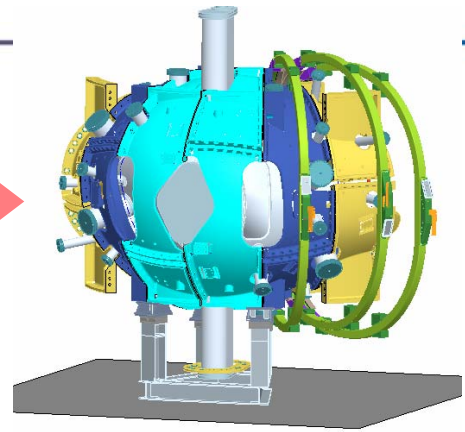
The field period is completed in Station 5



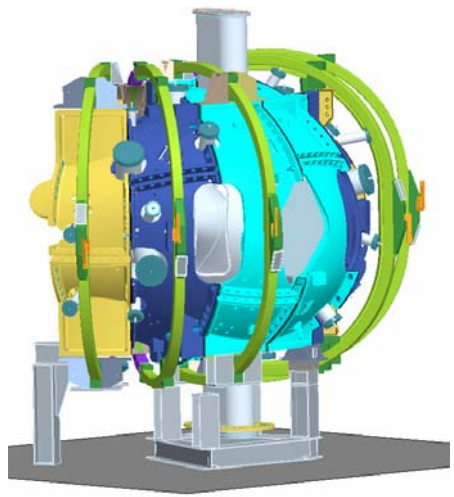
FPA on support stand



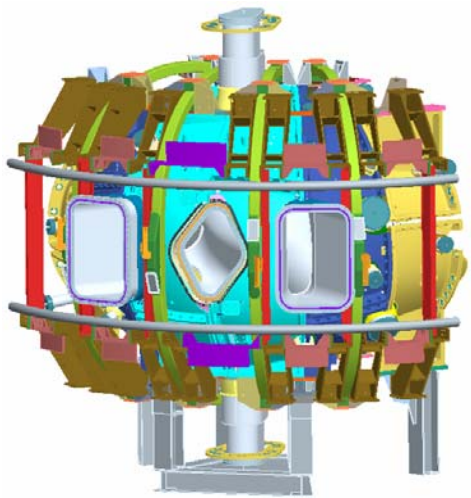
VV ports installed



TF temporarily positioned



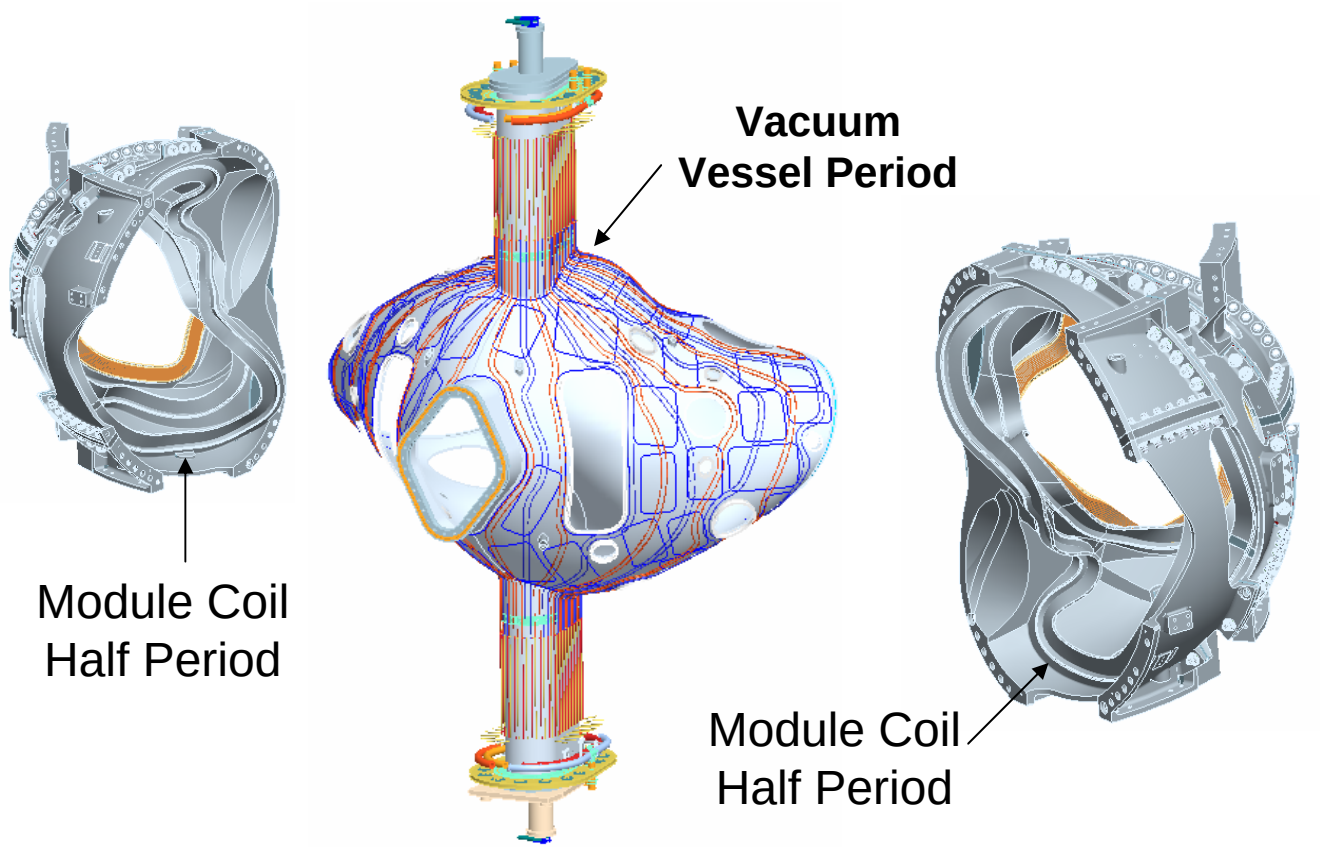
TF final fit-up



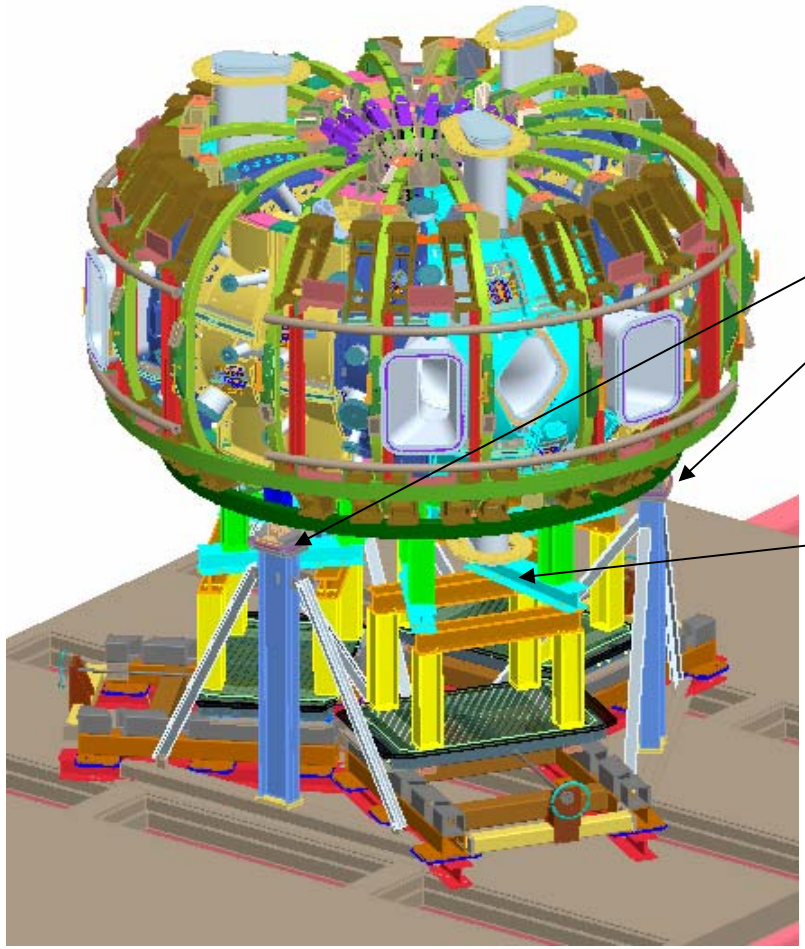
Completed period assembly

MCHP installed over the VV occurs at Station 3

The design intent for Station 3 is pass two MCHP assemblies over the VV and accurately position mating flange. The tolerance for the assembled period is ± 0.020”.



The NCSX device is completed in Station 6



Permanent machine supports

Temporary FPA supports