

# Progress in the Construction of NCSX

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for the NCSX Team

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Suppliers and Collaborators*

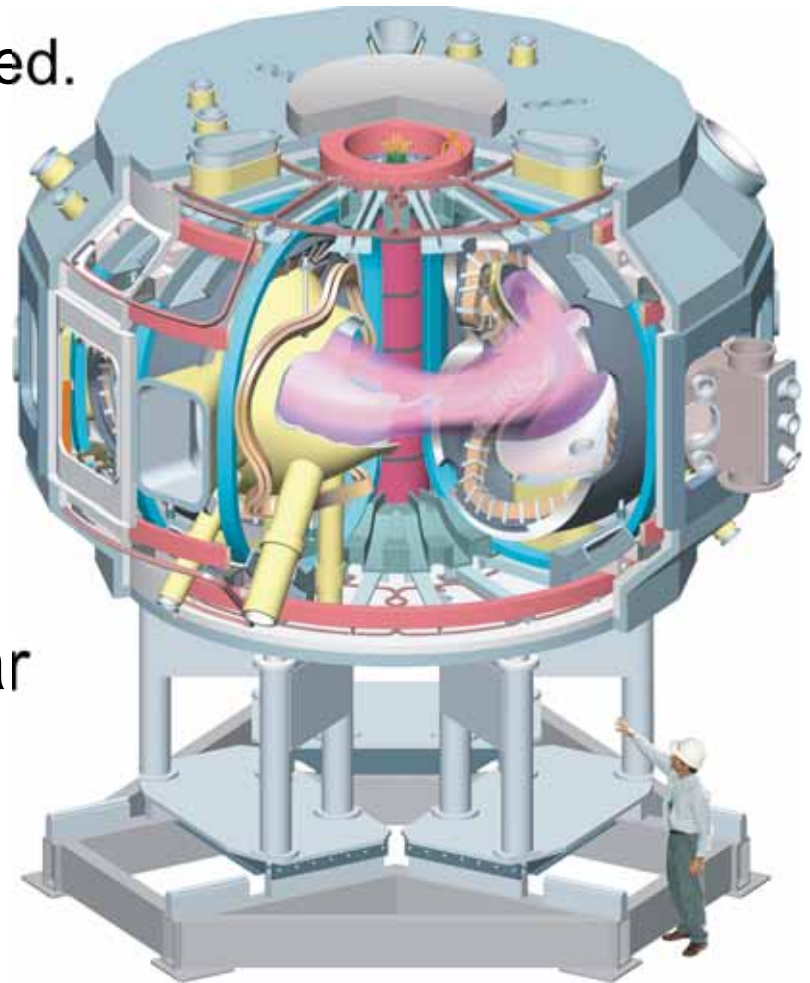
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# NCSX construction is 65% complete

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- NCSX component challenges were met.
  - Complex 3D geometries realized.
  - Field errors are minimized.
- Manufacturing solutions were developed— components are now in production.
- Vacuum vessel and 5 modular coils (of 18) are completed.
- On schedule for First Plasma in July, 2009.



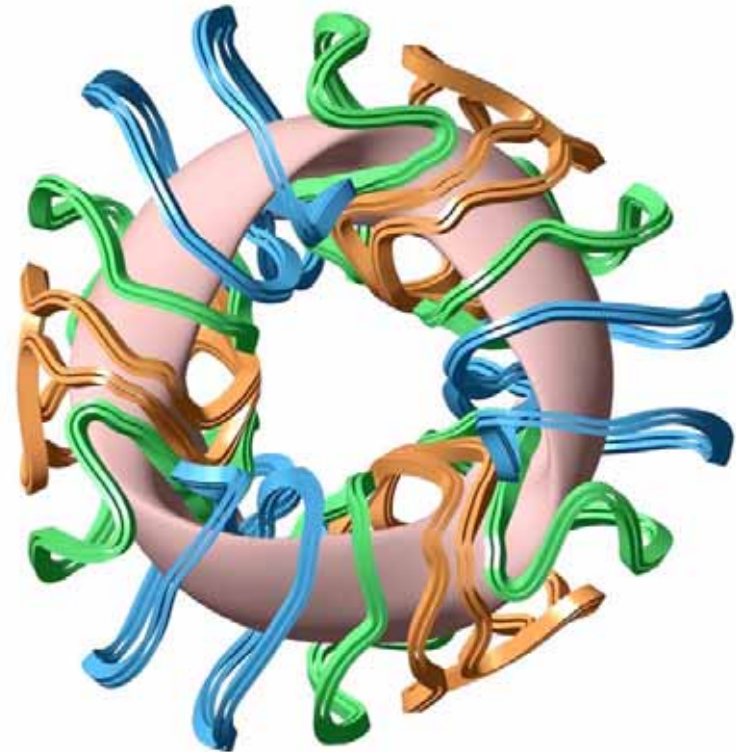
# NCSX Optimized Configuration to Test High $\beta$ , Quasi-axisymmetric Stellarator

## Plasma Properties at $\beta = 4\%$

- Quasi-axisymmetric. Low ripple.
  - Tokamak-like particle and flow behavior.
- Stable, good magnetic surfaces.
- Low  $R/\langle a \rangle$  (4.4)
- Reverse shear  $q$ -profile.
- 25% of transform from bootstrap.
- Constrained by engineering feasibility metrics.

## Mission: Test MFE Potential

- Steady state without current drive.
- High- $\beta$ , disruption-free operation.
- Compact, tokamak-like performance.



- 3-period plasma.
- 18 modular coils (3 shapes).
- TF, PF, & helical trim coils (not shown).
- $R = 1.4$  m.
- $B = 1.2 - 2.0$  T, pulse 0.5 - 2.0 s

# Field Error Minimization is Critical

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## Design and Manufacturing Strategy

- Dimensional accuracy ( $\pm 1.5$  mm on completed magnet system).
  - $\pm 0.5$  mm allocated to coils.
- Low magnetic permeability.
- Low eddy currents.
- Enforce stellarator symmetry.

**Requirements are being met within project cost and schedule constraints.**

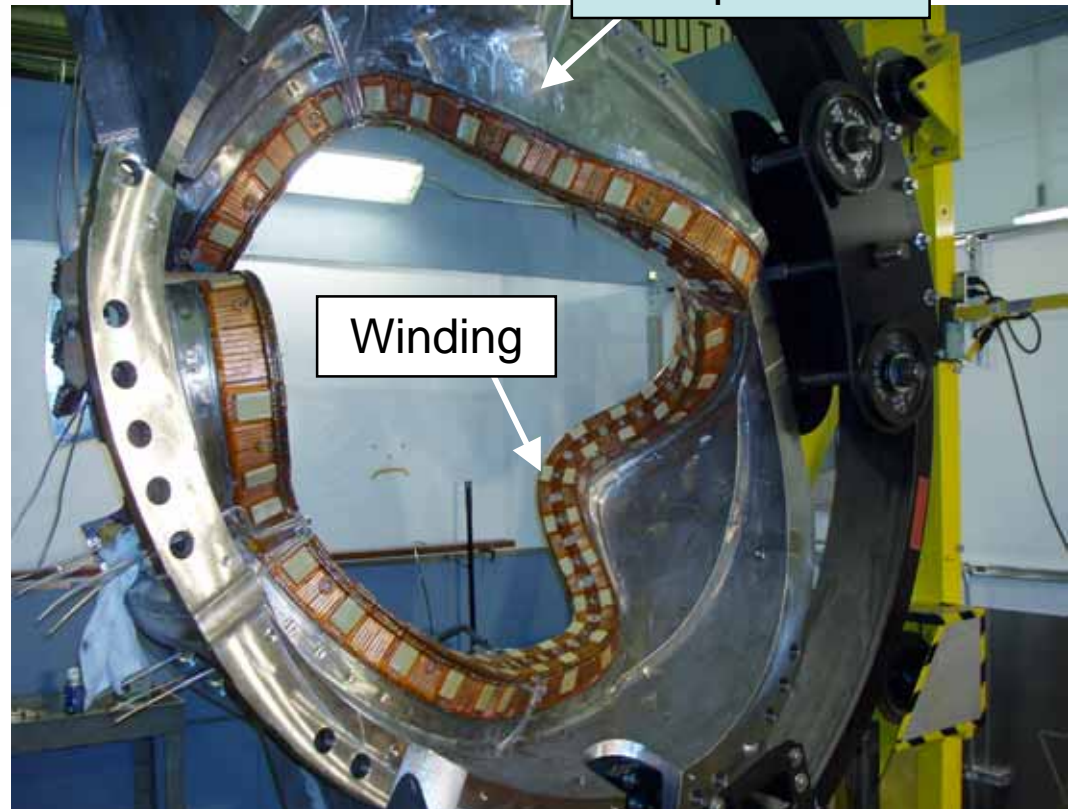
# Coil Design Reduces Field Error Risks



Modular Coil System

Modular coil winding form (MCWF) one per coil.

- Robust structural shell minimizes deflections.
- Toroidal and poloidal breaks inhibit eddy currents.
- Winding form stays with the coil as a permanent structure.
- Lead / crossover arrangement minimizes field errors.



Winding



# Winding Forms Are Manufactured to $\pm 0.25$ mm Tolerance on Critical Surfaces

- Custom casting alloy (close to 316LN st. steel)
  - Low permeability ( $\mu < 1.02\mu_0$ )
  - Air quenchable (minimizes distortion risk).
- Optimized casting mold.
  - Hard wood pattern for part reproducibility.
  - Flow-solidification simulations used to design molten metal feed system.
- Machined on a series of multi-axis milling machines.



“Tee”-shaped winding surface

**All 18 Have Been Cast  
8 Have Completed Machining  
and Shipped to PPPL**

# Winding Process Controls Current Center Position

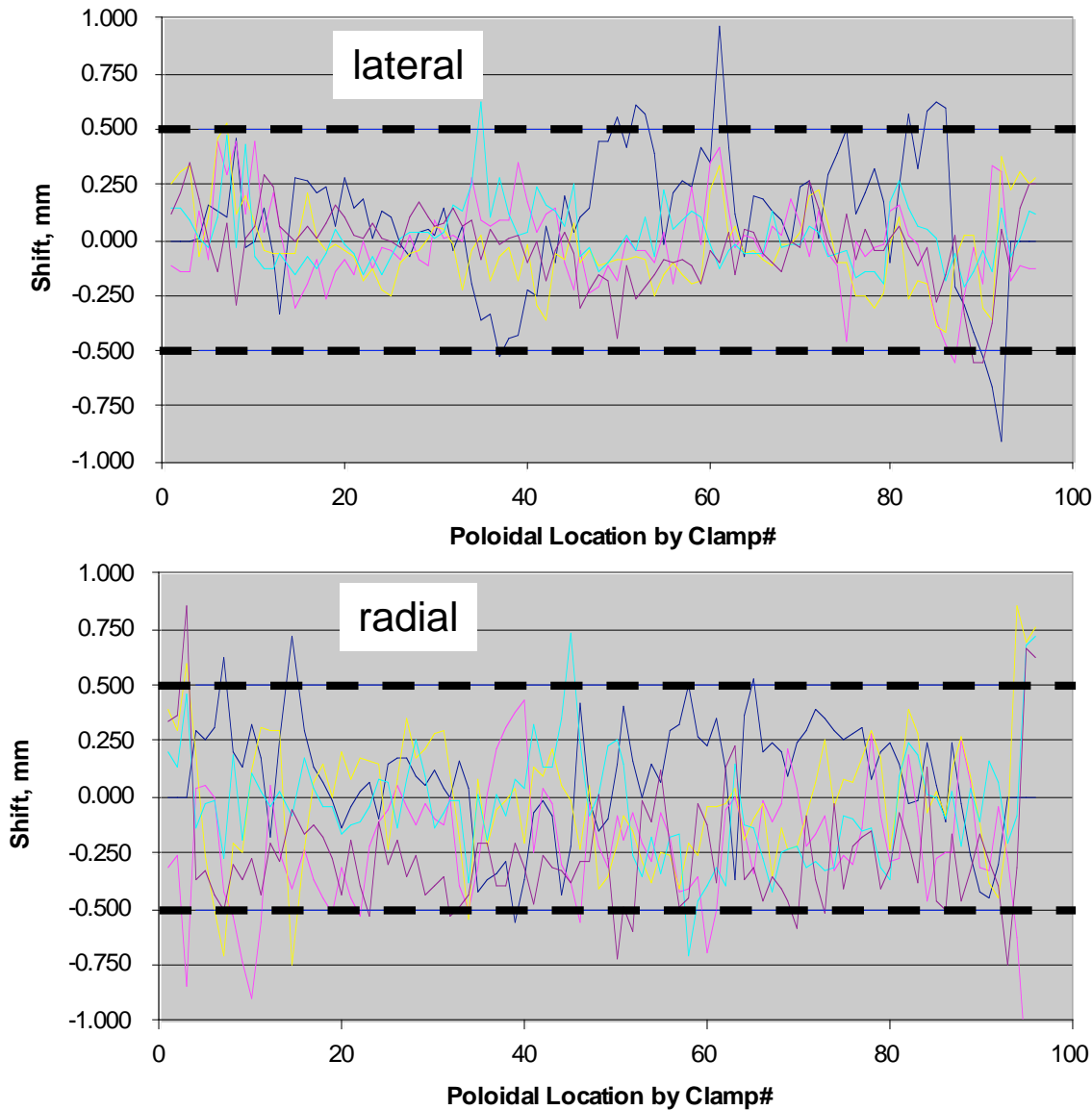


- Conductor is flexible copper “rope”.
  - Follows “Tee” winding surface.
  - Small (9x10 mm) conductor, wound 4-in-hand, maintains shape in bends.

- Winding pack dimensions are adjusted with clamps.
  - Compensates for winding form errors.
  - Bundle secured with fabric strips after adjustment.
  - Complete assembly is epoxy-impregnated by VPI.

# Coil Construction Achieves $\pm 0.5$ mm Accuracy

## Current Center Position Error (5 Coils)

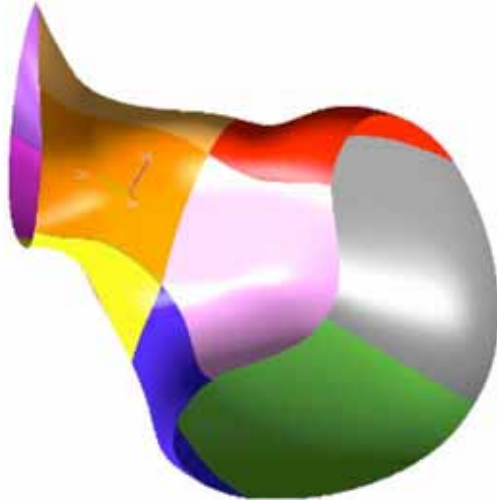


**5 Coils Have Been Completed**

- First coil was successfully cooled down and tested at full current.



# Large-Panel Vacuum Vessel Construction Achieved $\pm 5$ mm Accuracy



**Material: inconel**  
Low  $\mu$  ( $< 1.02\mu_0$ ),  
Low eddy currents

**Segmentation Plan**  
(10 per Half Period)  
Minimizes Welding  
& Distortion Risk



**Panels Pressed at Room Temp.**  
Assembled & welded on skeletal fixtures



**All 3 Field Period Sectors Completed!**

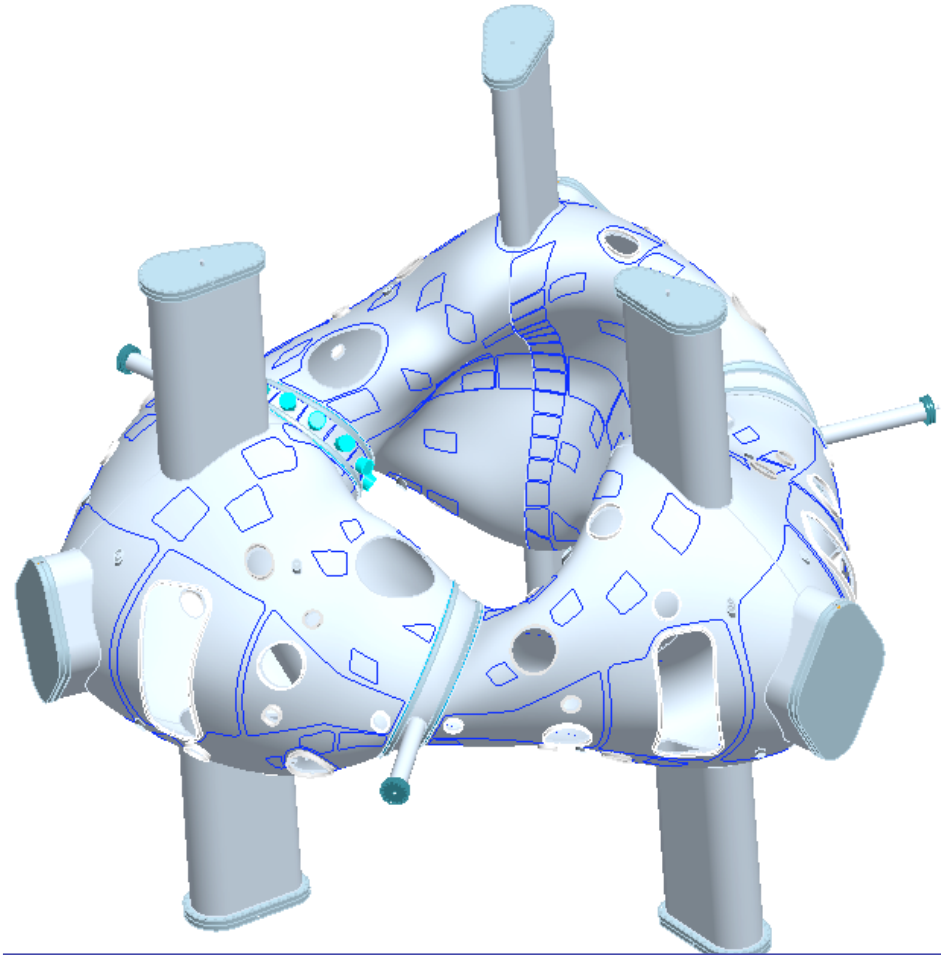
# Ex-Vessel Flux Loops for Reconstruction

## Requirements

- Measure stellarator-symmetric (SS) equilibrium fields for reconstruction ( $n = 3, 6, \dots$ ).
  - Also non-SS field errors and instabilities.

## Method

- Free-boundary VMEC equilibrium data base.
  - 2,500 cases
- VV locations ranked for reconstruction effectiveness using SVD algorithms.



- 227 loops / 151 distinct locations/shapes.
- Custom installation templates made for each shape ( $\pm 0.13$  mm).

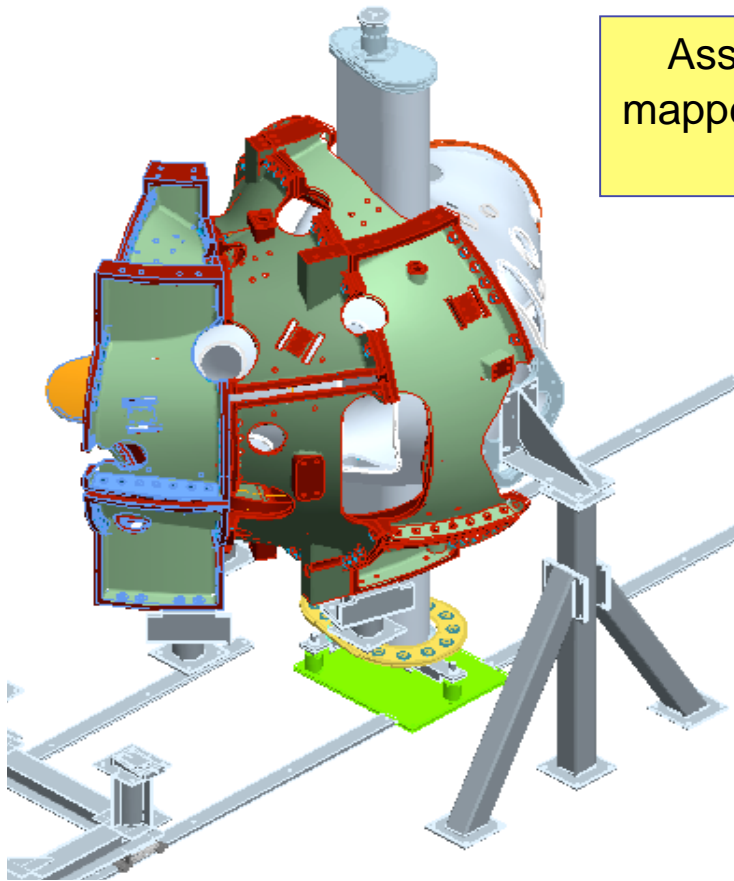
# Flux Loop Mounting Points Mapped to VV Surface

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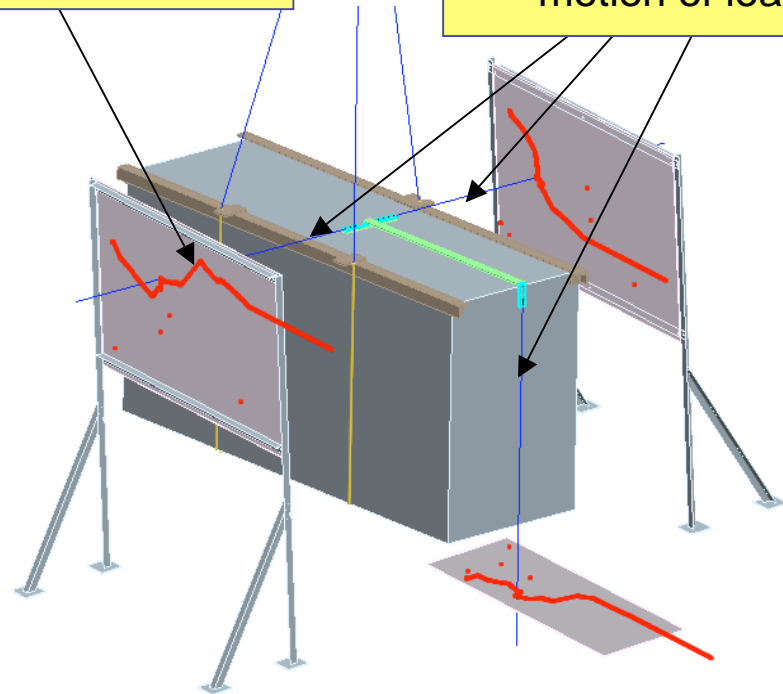
Mounting locations are transferred from CAD model to vessel using laser scanner.

# Next Step: Build Field-Period Subassemblies



Assembly trajectory mapped to 2D traces via CAD model

3 laser beams track traces to guide motion of load



**Modular Coil triplets will be installed over vacuum vessel.**

- Coils are moved along assembly trajectory suspended from crane.

Low-cost trajectory-following technique was successfully demonstrated.



# Thanks to our Suppliers and Collaborators

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- Major Tool & Machine, Inc. -*vacuum vessel, modular coils*
- Energy Industries of Ohio, Inc. -*modular coils*
- C. A. Lawton Co. -*modular coils*
- MetalTek International, Carondelet Div. -*modular coils*
- New England Wire Technologies, Inc. -*modular coils*
- Everson Tesla, Inc. -*TF coils*
- Tesla, Ltd. (UK) -*TF coils*
- Österby Gjutery (Sweden) -*TF coils*
- A. Boozer, Columbia Univ. -*magnetic diagnostic design.*

# NCSX is on Schedule for July, 2009 First Plasma

