MODULAR COIL DESIGN DEVELOPMENTS FOR THE NATIONAL COMPACT STELLARATOR EXPERIMENT (NCSX)

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Abstract

The National Compact Stellarator Experiment (NCSX) is a quasi-axisymmetric facility that combines the high beta and good confinement features of an advanced tokamak with the low current, disruption-free characteristics of a stellarator. The project is based on a three field-period plasma configuration with an average major radius of 1.4 m, a minor radius of 0.3 m, and a toroidal magnetic field on axis of up to 2 T. The modular coils are one set in a complex assembly of four coil systems that surround the highly shaped plasma. There are six each of three coil types in the assembly for a total of 18 modular coils. The coils are constructed by winding copper cable onto a cast stainless steel winding form that has been machined to high accuracy, so that the current center of the winding pack is within ±1.5 mm of its theoretical position. The modular coils operate at a temperature of 80 K and are subjected to rapid heating and stress during a pulse. At this time, the project has completed construction of several prototype components which validate the fabrication and inspection processes that are planned for the production coils. In addition, some advanced techniques for error-field compensation and assembly simulation using computer-aided design (CAD) have been developed.

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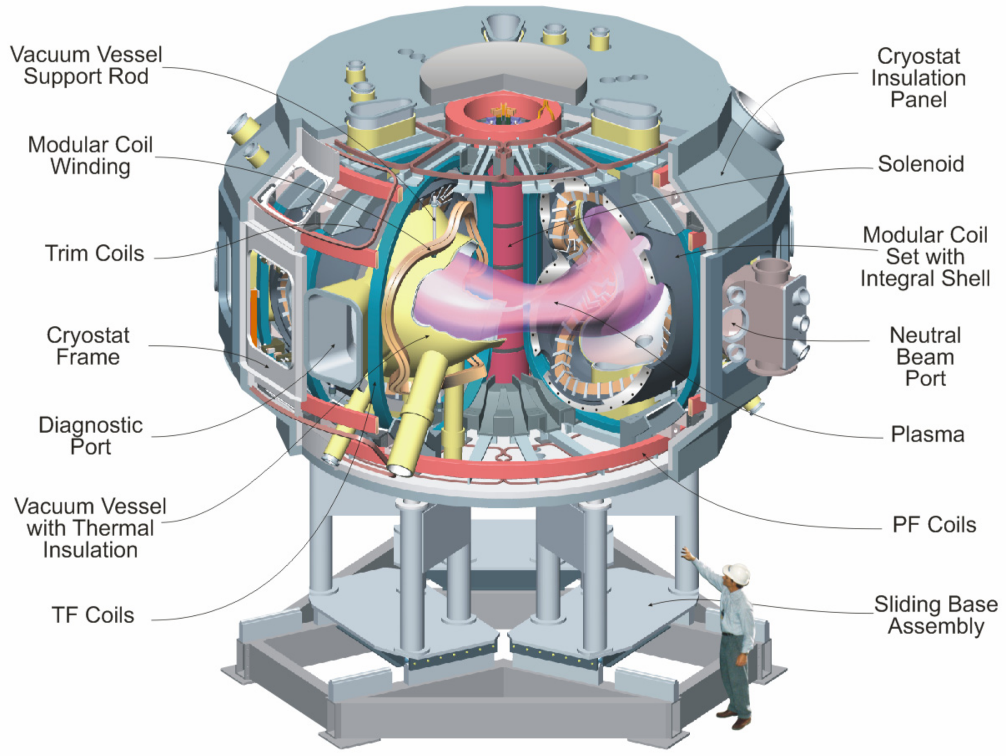
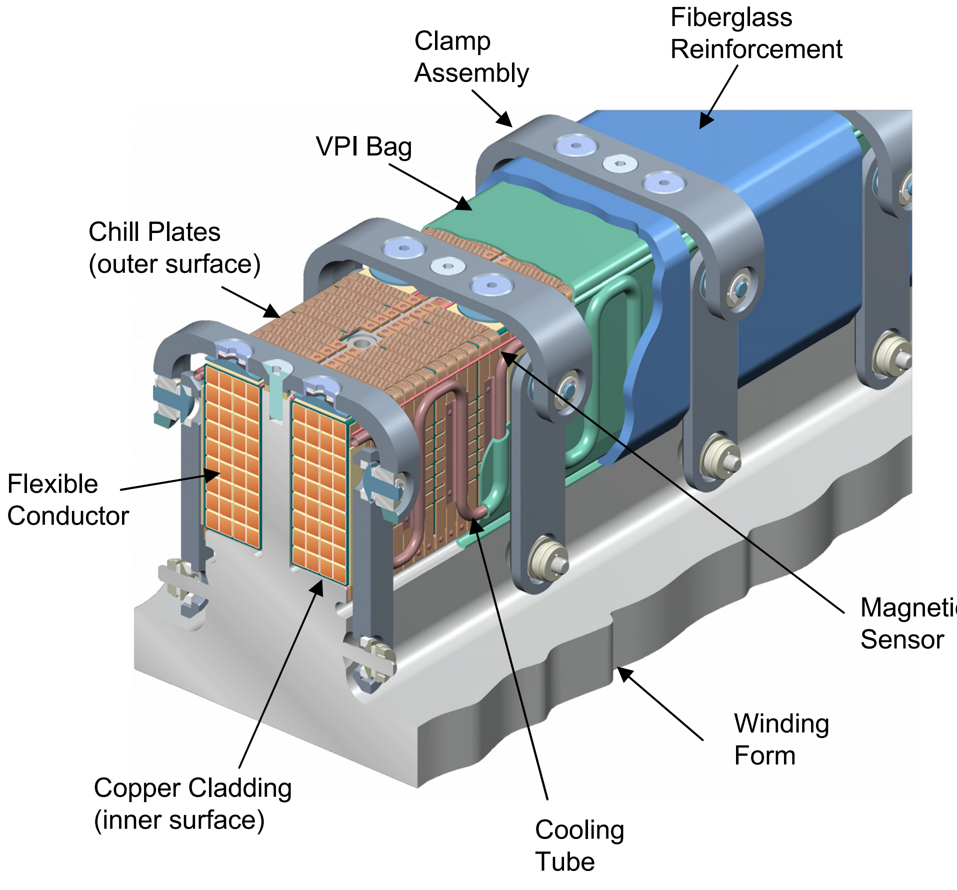


NCSX STELLARATOR CORE



WINDING PACK ASSEMBLY

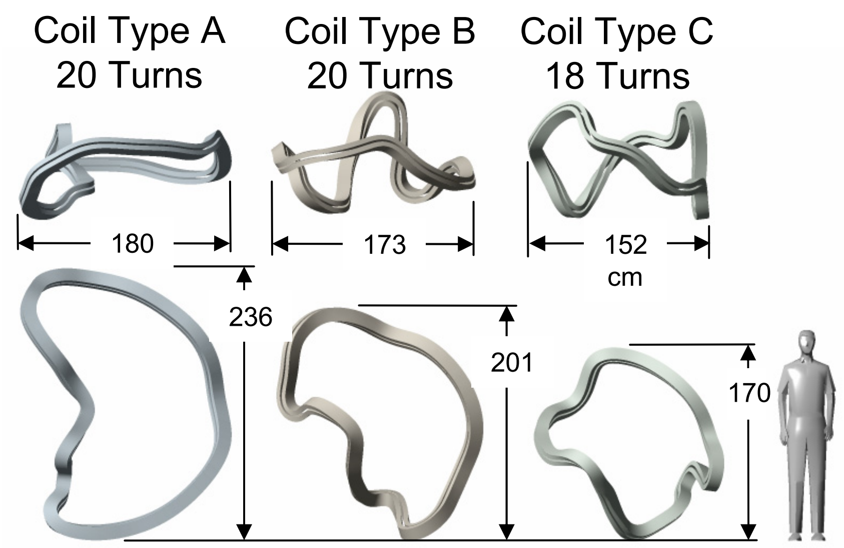
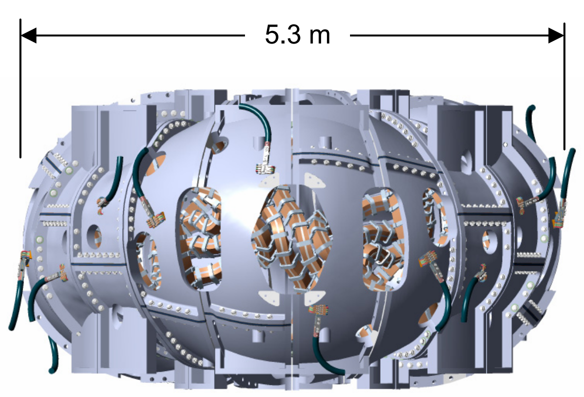


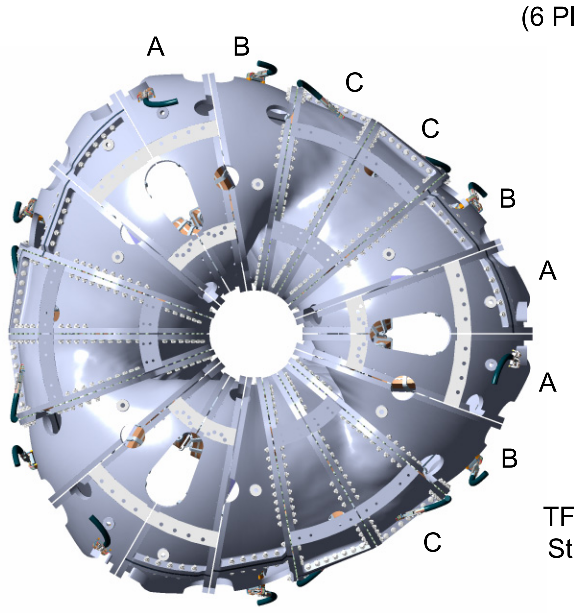
Table 1 Modular Coil Parameters

No. of coils	18 (3 x 6)
Winding length	6.6 to 7.4 m per turn
Number of turns /coil	36, 40
Gross cross section	2 x 40 mm x 120 mm
Current per coil*	Up to 828 kA-turns
Max. current density in Cu*	~ 14 kA/cm²
Temperature operating range	From 85 to 125 K

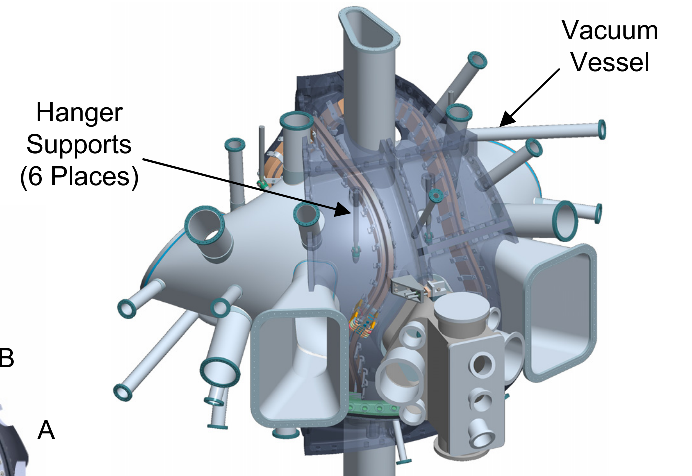
* at nominal 1.7 T operating conditions



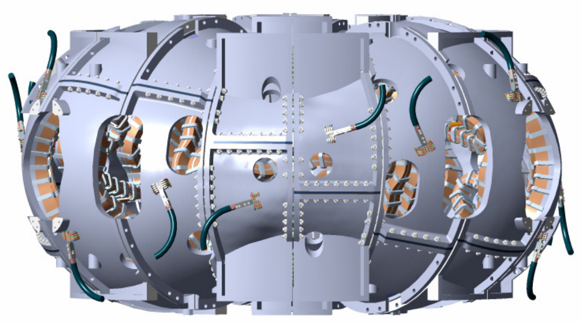
ELEVATION AT 0-DEG



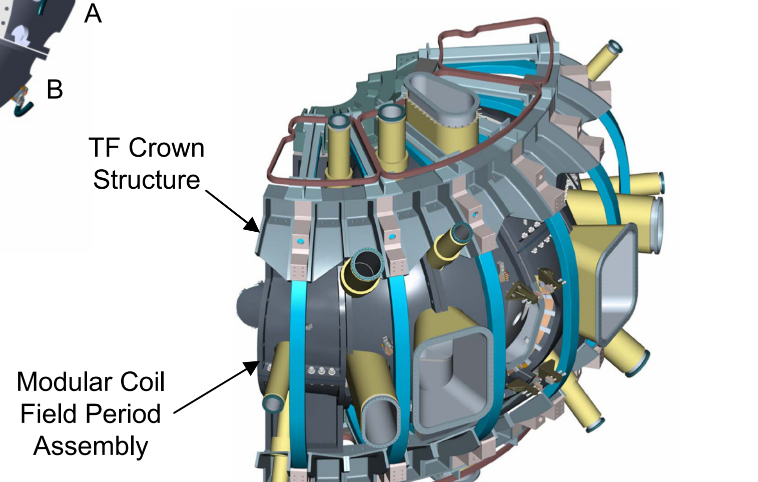
MODULAR COIL ASSEMBLY



VESSEL INTERFACE

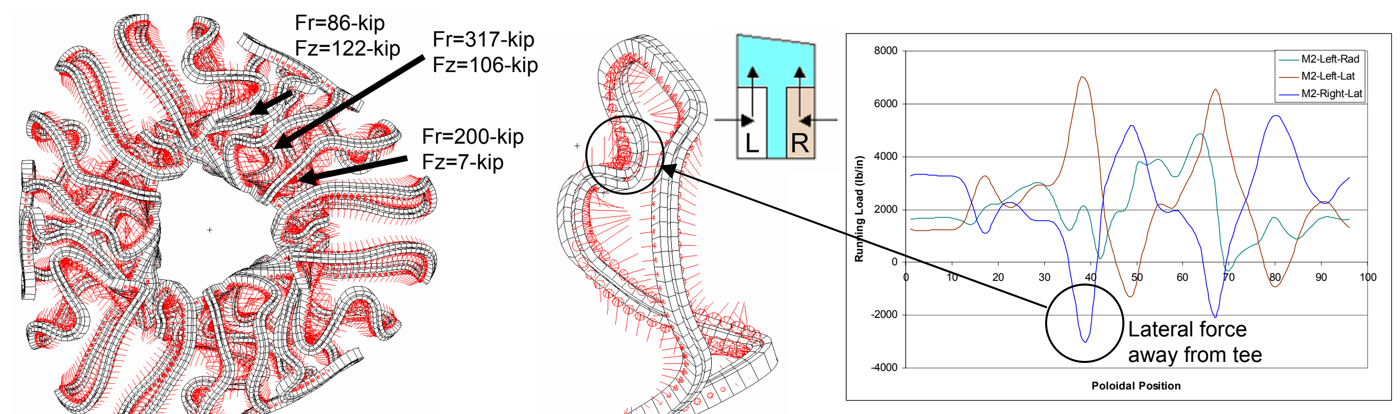


ELEVATION AT 60-DEG

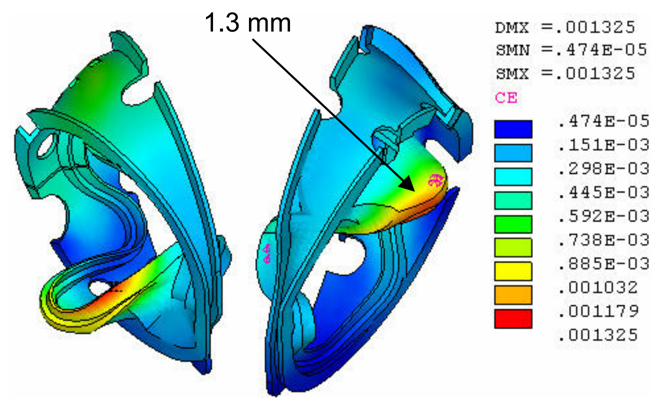


TF COIL INTERFACE

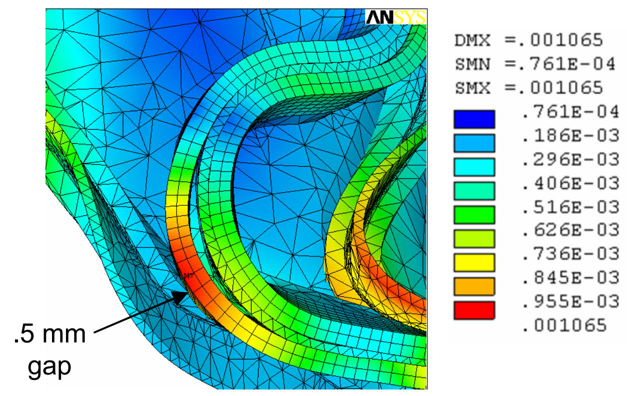
Operating Loads (Electromagnetic, Thermal)
- Magnetic flux density at windings up to 4.7 T
- Heating to 130 K during pulse
- Cooling by conduction to 85 K in ~15 min
- Eddy currents reduced by segmentation
- Coil EM load up to 1.4-MN radial, .5-MN vert
- Maximum running load is 1.2 MN/m
- EM force is mostly toward structure
- Clamps provide winding preload



EM LOADS AT 2T OPERATING SCENARIO



MODULAR COIL DISPLACEMENT



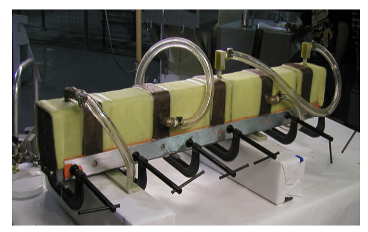
WINDINGS SEPARATION GAP

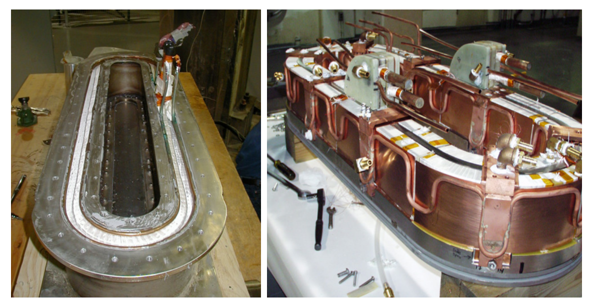
Coil Deflection and Stress
- Windings track shell deflection in most places
- Local deflection depends on shape, initial strain
- Clamps help maintain contact in most regions
- Max stress in structure ~200 MPa (FS>2 at 80 K)
- Max stress in windings ~80 MPa

Manufacturing Development

Conductor – OFHC Copper
- 34-gauge Wire (0.0063 in. diameter)
- 0.342 in. x 0.383 in. (bare) +/- 0.008 in.
- 0.004 in. thick nylon serve
- 12x5/54/34 cable, 3240 strands

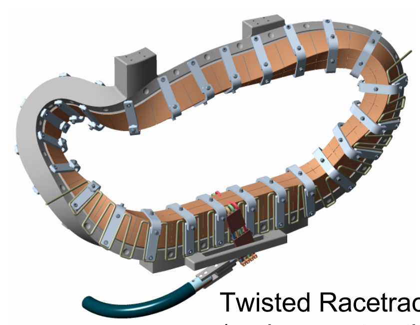
Straight Tee Section
- First use of "bag mold" for VPI process
- CTD-101K resin



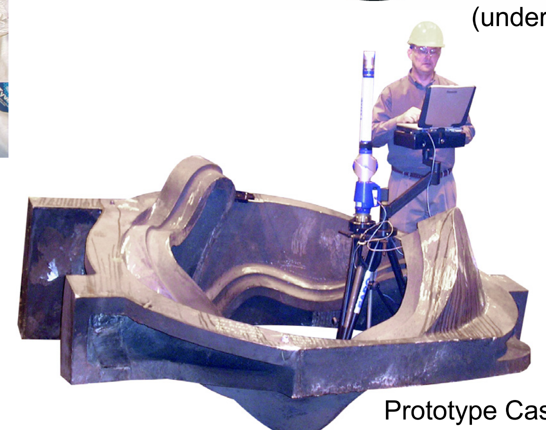


Racetrack Coils
- First winding experience and use of copper cladding / chill plates

Three-Dimensional Winding Fixture

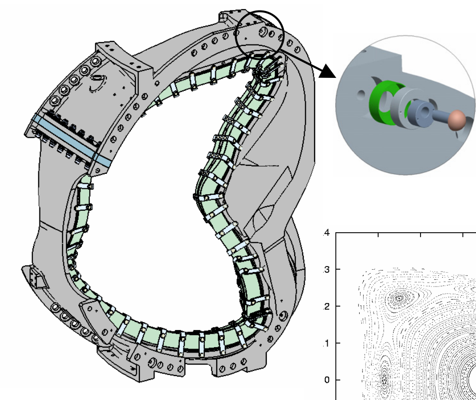


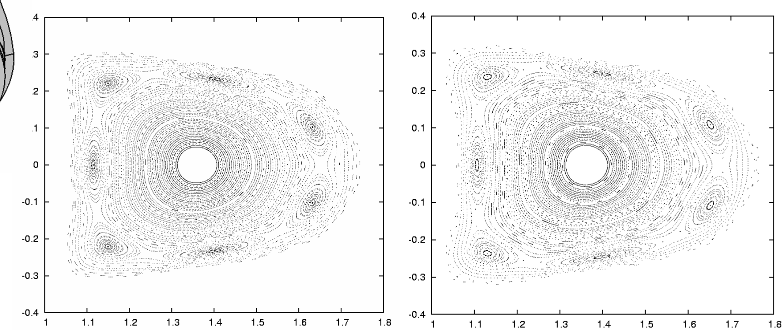
Twisted Racetrack Coil (under construction)



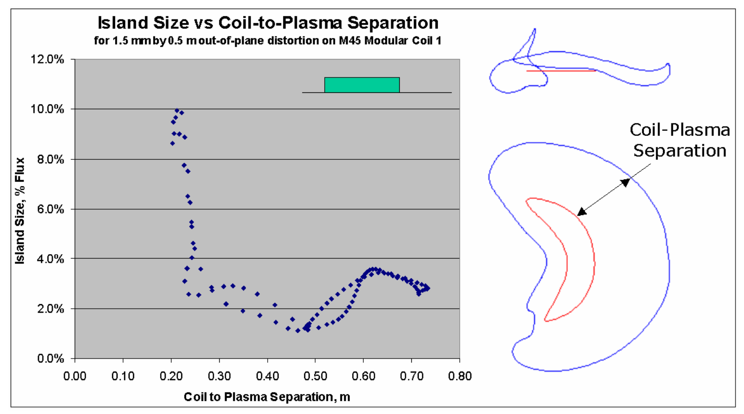
Prototype Casting (Energy Industries of Ohio)

Magnetic Field Errors
- FEA deflected shape was analyzed for typical scenario, vacuum field plot did not change
- Fabrication errors in winding center evaluated, errors < 30 cm from plasma were significant but in other areas could be ignored
- Shape of as-built coil derived from magnetic measurements to aid in precise assembly
- Assembly features allow independent positioning





Vacuum Field for Undeformed Coil — Deformed Coil at 2T Scenario



Effect of Fabrication Error on Field Configuration

Conclusion

Engineering and physics optimization has helped the NCSX modular coil design to systematically progress from physics targets to filamentary models to prototype components. At this time, the winding forms are ready for procurement, and the windings and assembly designs are nearly complete. It is anticipated that coil production will begin in January, 2005 and continue for approximately 18 months.

Field Period Assembly
- Three coil sector installed over vessel segment
- Assembly fixture motion defined by kinematics code that analyzes component clearance