Electromagnetic Linear Structural Analysis of the National Compact Stellarator Experiment (NCSX) Modular Coil System

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A detailed electromagnetic-structural ANSYS analysis of the NCSX Modular Coil (MC) system is presented. The simplified (linear) model is used to provide some insights into the essential behavior of the modular coil. In the actual device, the winding packs are Vacuum Pressure Impregnated (VPI'd) in-place and restrained by 50+ clamps per coil. In general, JxB Lorentz forces press the WP onto the structure which makes the linear ("glued") approach justifiable. The benefit, of course, is relatively fast computer run-times and a modeling tool which is able to perform numerous design studies. However, there are regions where the EM forces point away from the structure and locally invalidate the "glued" approximation.

The results of a variety of design studies are presented, such as the structural stiffness and worst case running loads at the poloidal breaks, non-ideal coil center displacements from thermal contractions and structural loads, smeared winding pack and winding form stresses, and the effects of supporting the convoluted MC "wings" with the neighboring shell. Critical results are illustrated with contour plots, and where possible, compared to the requirements of the NCSX structural design criteria. The analysis provides the following results:

- Poloidal Breaks are exposed to a tensile running load of 4 k-lb/in to 9 k-lb/in from EM loads.
- The stiffness of the MC shells to opening displacements at the poloidal breaks is 22 k-lb/in to 57 k-lb/in, depending on the shell type ("A", "B" or "C").
- The maximum principal strain in the conductor is determined to be ~0.1%. With the WP in weak compression, or a near zero stress state at the end of the pulse, a zero to 0.1% and back to zero cyclic strain test for 130,000 cycles represents the worst in-service loading.
- The maximum stress in the stainless steel winding forms is determined to be ~190 MPa. Although a design-basis fatigue curve for the SS casting material is work in progress, the stress range is ~1/3rd the yield stress of annealed 316LN, which would indicate near endurance limit behavior.
- Cool-down displacements and MC WF deformations from EM loads are calculated and lead to non-ideal coil positions, off by as much as 1.5 mm. Displacements at each element centroid are provided as input to field error calculations by others.
- The effects of MC module Type C-C mechanical continuity in the inaccessible inboard region at final assembly are studied and show that only toroidal continuity provides any benefit. In-plane restraints (i.e., shear keys) provide essentially no benefit, and therefore eliminate the need for such details.
- Providing support at the extremes of the MCWF "wings" is critical to minimizing the bending stresses in the WP.
- The wing supports must be capable of carrying about 0.6 MN (135 k-lb) in compression with minimal deflection in order to be effective.