Coil Development for the Quasi-Poloidal Stellarator Project

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The Quasi-Poloidal Stellarator (QPS), currently in the R&D and prototyping stage, is a low-aspect-ratio ($R/a \geq 2.3$), compact stellarator experiment with a non-axisymmetric, near-poloidally-symmetric magnetic field. The QPS design parameters are $\langle R \rangle = 0.95$ m, $\langle a \rangle = 0.3$-0.4 m, B = 1 T, and a 1.5-s pulse length with 3-5 MW of ECH and ICRF heating power. The most challenging component to design and fabricate is the set of 20 nonplanar modular coils located inside the QPS vacuum tank. There are five distinct coil winding shapes, but only three types of winding forms are needed because each supports two distinct windings and both windings on the most complex coil form are the same shape. The stainless steel winding forms are machined to the required high tolerance and stranded copper cable conductor is wound on the winding forms to the highly precise shape required (to an accuracy of less than 1 mm). The windings are enclosed in a welded, stainless steel cover with stiffeners for compatibility with the QPS vacuum requirements, and the cans are then vacuum pressure impregnated with cynate ester resin to form the finished coil winding pack. Computer modeling and experimental measurements of the welding process indicate that distortion and thermal stress should be acceptable. A prototype coil using the most complex of the three winding forms is being fabricated. The coil winding form has been cast and is being machined to the required tolerance prior to winding with conductor. The machined modular coil forms will be shipped to the winding facility mounted on carts, which provide a work platform for preparing, winding, welding, and potting of the coils. The carts allow rotating the coils for optimum positioning during winding and fabrication. An overhead fixture allows supporting the spools of conductor and feeding the conductor in the correct orientation, groupings, and tensioning.

An R&D program is underway that includes extensive conductor characterization and testing, vacuum canning studies, and fabrication of a full scale-prototype modular coil. One of the most critical issues is the cooling of the winding pack because of space constraints, variable conductor behavior, coolant effectiveness, complex electrical circuits, impregnation issues, vacuum can conductance, possibility of welding/brazing damage, and the extremely complex conductor leads interface and connection. Two possible conductor cooling concepts are being evaluated: (1) an internally cooled conductor having a copper tube filled with a Pb-Bi filler imbedded in the conductor cable to avoid crimping during winding, and (2) an externally cooled winding pack using copper cladding inboard and copper chill plates outboard of the pack. The internally cooled conductor concept is attractive due to a much more effective, active cooling of the conductor than the copper cladding/chill plates allow, resulting in up to a factor of 5 faster cooldown between shots. Issues being studied are the effect of the increased conductor stiffness on winding the coil, evacuating the filler material in the coolant tube after the initial potting step, and separating the cooling tube from the conductor at the electrical connection interface. Four-turn test coils are being tested for mechanical properties (cyclic loading for fatigue properties), thermal properties (conductivity), and tensile properties (stiffness and strength).

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