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Status of the Quasi-Poloidal Stellarator

J. F. Lyon[1], J. H. Harris[1], R.D. Benson[2], M.J. Cole[1], P.J. Fogarty[2], K.D. Freudenberg[1], P. L. Goranson[2], G. L. Lovett[2], A. Lumsdaine[2], M. Madukhar[2], B. E. Nelson[1], T.E. Shannon[2], A. Brooks[3], P.J. Heitzenroeder[3], G. H. Neilson[3]

[1]*Fusion Energy Division, Oak Ridge National Laboratory, Oak Ridge TN, USA*

[2]*Magnet Design Laboratory, University of Tennessee-Knoxville, Knoxville TN, USA*

[3]*Princeton Plasma Physics Laboratory, Princeton NJ, USA*

The Quasi-Poloidal Stellarator (QPS) is a very low aspect ratio ($\langle R\rangle/\langle a\rangle \geq 2.3$) stellarator experiment intended to test the novel confinement properties of quasi-poloidal symmetry. Chief among these are poloidal flow and poloidal flow shear which are a factor of ~10 larger than in any other toroidal confinement system, reduced neoclassical transport, and reduced growth rates for trapped-particle and ion-temperature-gradient instabilities. The combination of these favorable characteristics leads to a compact, low-plasma-current, enhanced-confinement configuration, which is very attractive as a fusion reactor [1], with an overall physical envelope similar to that of a conventional tokamak, but without disruptions or the requirement for steady-state current drive and its associated high recirculating power.

Figure 1 shows the special capacity of the QPS configuration to promote the development of large flows in the poloidal direction [2] due to reduced poloidal viscosity. The calculations are performed for model electron-cyclotron (ECH) and ion-cyclotron heating (ICH) plasmas in scaled configurations corresponding to present and future stellarators. The

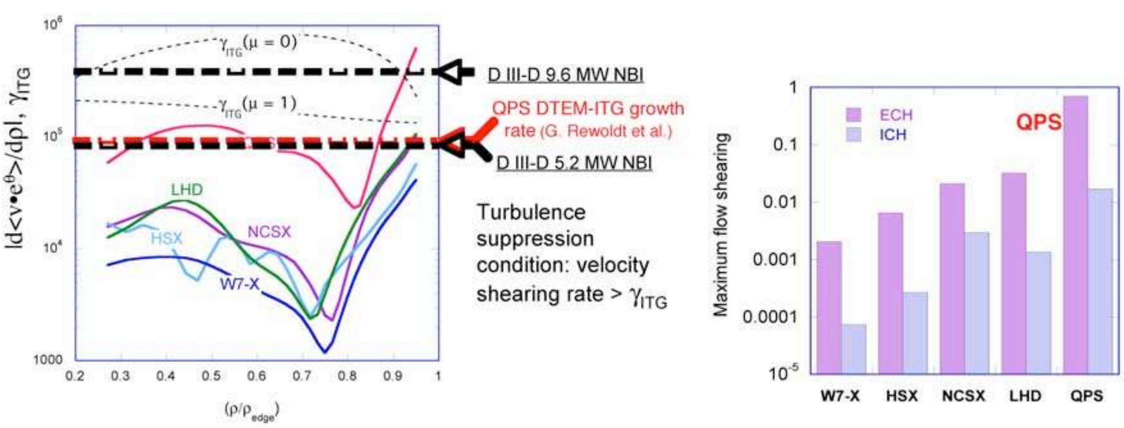

Fig. 1. Flow generation in QPS.

E x B flow shear resulting from the ambipolar electric field is compared to the ion temperature gradient (ITG) mode growth rate. The shearing in QPS is found to be nearly an order of magnitude larger than that for the other configurations over most of the plasma minor radius, and comparable to that measured for DIII-D with > 5MW of unidirectional neutral beam injection. This suggests that it may be possible to access improved confinement modes in QPS configurations even without external momentum input, which would be valuable in both near-term experiments and reactors.

QPS will be constructed at Oak Ridge National Laboratory as a moderate size ($\langle R \rangle$= 0.95 m, $\langle a \rangle$ = 0.3-0.4 m, B = 1 T, a 1.5-s flat-top pulse length, and 3-5 MW of ECH and ICH power) research device with a highly flexible magnetic configuration, which is obtained by varying the relative currents in each of the modular stellarator coils, the toroidal field coils, and the poloidal field coils. The QPS design is driven by both the complex 3-D design requirements and the need to reduce construction cost and risk.

In the fabrication concept being developed (Fig. 2), complex, highly accurate (tolerances ≈ 1 mm) stainless-steel modular coil winding forms are cast and machined; internally-cooled cable conductor is wound directly onto the modular coil winding forms; a vacuum-tight cover is welded over each coil pack; the coils are vacuum pressure impregnated using a cyanate-ester resin; and the completed coils are installed in an external vacuum vessel. Because of the high degree of innovation required to fabricate QPS, the design team is carrying out an extensive program of R&D and prototyping of all the components and processes required.

Ten modular coil forms (of three types) are required (Fig. 3). The largest (~3.5 tonnes) and most complex of the winding forms has been cast for prototype development using

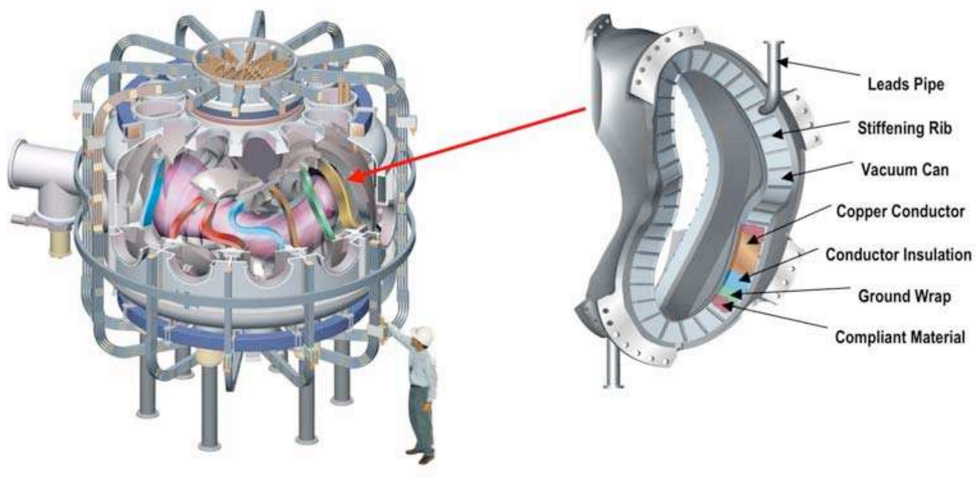

Fig. 2. Construction concept for QPS compact stellarator device.

a patternless process (machined sand molds) and a high-temperature pour, and is being precision machined.

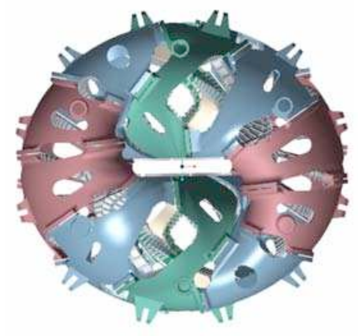

Fig. 3. QPS modular coil forms.

The coils will be wound with a purpose-developed stranded, flexible copper conductor (11.4 mm square-cross section) with an internal cooling tube (Fig. 4). The use of this conductor allows for a simplified winding technique using low-force clamps, and eliminates the need for external cooling plates.

Once the coils are wound, a thin (0.75-mm wall-thickness) stainless-steel can is constructed around the coil on two sides and welded to the coil form to complete the vacuum enclosure. A model can has been tested with internal pressurization, and the deflection of the can wall at the maximum expected pressure of 1 atm remains acceptable.

The coil and can assembly is then potted using a high-temperature cyanate-ester resin (CTD-403). CTD-403 was originally developed because of its robustness to high neutron fluxes, but is also useful for conventional coils because of its higher temperature capability (about 150C compared to <100C for typical epoxies), very low water absorption, low cure shrinkage, very low viscosity of the uncured resin, and indefinite pot life at room temperature.

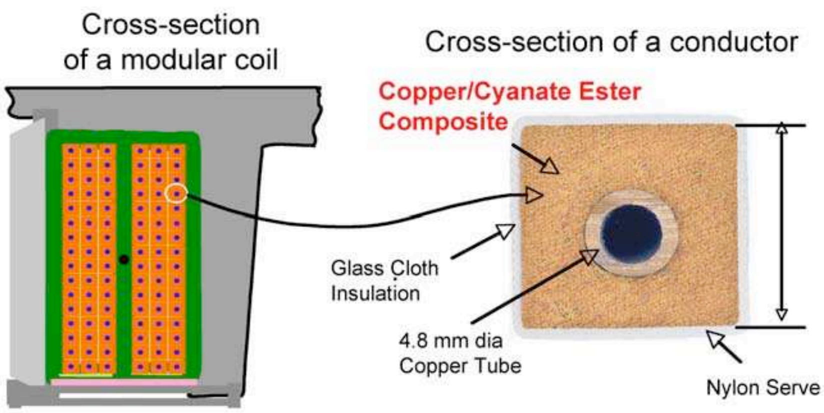

Fig. 4. Cross-sectional views of QPS winding and conductor.

We have characterized the performance of CTD-403 using small samples as well as larger, racetrack-shaped coils, and have developed a process wherein the resin is injected at room temperature and the temperature then raised in stages to 170 degrees C, and then cooled; the entire cycle lasts ~26 hours. Tests with model stranded conductors show good wicking into the interstices between the strands.

The use of vacuum-sealed coils will permit assembly of the completed two field periods of the QPS magnet system inside a bell-jar style vacuum vessel (Fig. 5). The steps in the process are (a) to install the support columns, the lower dome with VF coils, and a half period of the modular coils; (b) assemble the other half of the modular coil set and the cylindrical

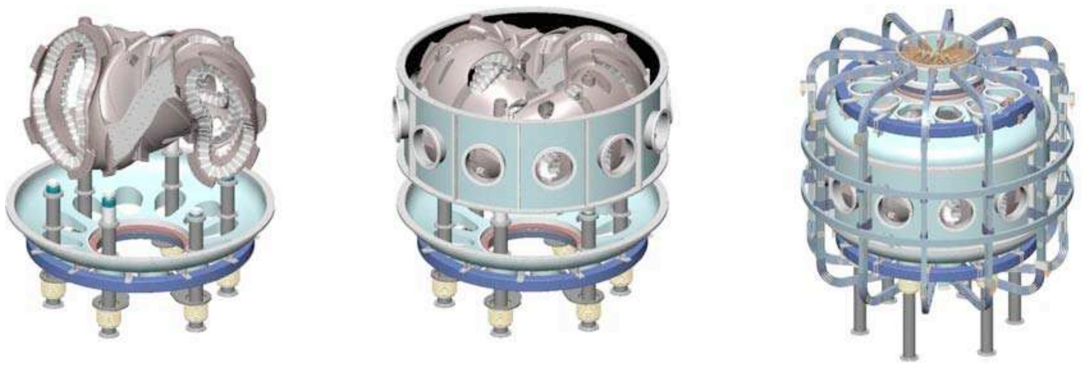

Fig. 5. Assembly of the QPS stellarator coils in the vacuum tank.

part of the vacuum vessel; (c) raise the lower dome and VF coils, and install the upper dome with VF coils and the TF legs; and (d) install the outer legs of the TF coils, the other VF coils, abd the pumping ducts and pumps. The outer cylindrical section of the vacuum vessel is suspended from the of the modular coil assembly to ensure that all the coil sets remain accurately aligned. The vacuum vessel provides the structural support for the TF and PF coils. Twelve large ports on the mid-plane, 24 large oval ports on the top and bottom domes, and the ability to raise or lower the sections of the vacuum vessel provide access to the internal modular coils for maintenance and for installation of interior diagnostics.

The QPS project has had successful physics and design reviews, and is now testing all steps of the coil fabrication process in advance of determining a baseline cost and schedule for the next step in the approval process. Several test coils are being built to test the winding, canning, and potting processes and the geometry and fabrication of the current feeds and cooling paths. The test coils include smaller circular coils, a kidney-shaped coil, and a full-size coil wound on the prototype machined cast winding form.

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