DESIGN, FABRICATION, INSTALLATION AND TESTING OF IN-VESSEL CONTROL COILS FOR DIII–D*

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Since 1995, DIII–D has performed correction of magnetic field imperfections using a set of six external picture frame coils located on the vessel mid-plane. Recently, these coils have also demonstrated significant benefits when used for feedback of the resistive wall mode, an instability that limits the plasma performance at high beta. Modeling has shown that substantial performance improvements can be achieved by installing new coils inside the vessel and expanding the poloidal coverage both above and below the mid-plane. Two prototype internal coils were installed in 2001 and have tested successfully. Installation of a full set of twelve internal coils and related magnetic sensors in the DIII–D tokamak is scheduled for completion in December 2002.

The design requirements for the new coil system were to maximize the magnetic field at the plasma edge, operate with a frequency range of DC to 1000 Hz, and fit behind the existing graphite wall tiles to avoid any plasma contact. A technical comparison of expected operation of in-vessel and ex-vessel designs indicated a significant performance advantage of the in-vessel coils due to the closer proximity to the plasma, better field penetration, and lower inductance. However, the in-vessel coil environment requires a more robust design because of high cyclic electromagnetic forces in vacuum and temperatures to 350°C during vessel baking.

The in-vessel coil design adopted and installed is water-cooled hollow copper conductor insulated with polyamide and housed inside a stainless steel tube, which forms a vacuum boundary. The coil conductor system is 19 mm outside diameter and is engineered to operate up to 7 kA DC with cooling water flow of 5.5 m/s. The coil set is installed as 2 sets of 6 coils each located on the inside of the outer wall above and below the mid-plane. The coils are single turn with a conductor length of 5 m and an area of 1 m^2. In order to minimize error fields and electromagnetic forces, the radially oriented power and cooling water feeds are coaxial. The coils are shielded from the plasma by the plasma facing graphite tiles.

The primary challenge in the design of these coils was in joining of both the copper conductor and the stainless tube without overheating the polyamide insulator. The challenge was met after significant design evolution by using induction brazing (815°C) for the copper and automated orbital welding of the stainless steel tube. The brazing and welding processes are performed both outside and inside of the vacuum vessel.

In operation, protective instrumentation monitors water flow and temperature to prevent water boiling during off normal conditions. To protect against water leakage into the vessel from a damaged conductor, both the copper conductor and the stainless steel tube form redundant barriers. The polyamide insulator space is filled with nitrogen and its pressure is monitored to detect any water or vacuum leak of a single barrier. During vessel baking, the cooling water is automatically replaced with dry nitrogen to minimize copper oxidization at 350°C exposure temperature.

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