Operation of Pegasus-III Spherical Tokamak at 0.6 T for Non-Solenoidal Startup Development[†]

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Non-solenoidal techniques for tokamak startup present an opportunity for reducing the cost and complexity of magnetically confined fusion energy systems. Critical to the development of techniques such as helicity and microwave injection, is developing an understanding of the relevant physical processes including magnetic reconnection, turbulence, relaxation, and microwave absorption which all depend upon the applied toroidal magnetic field. To facilitate this development to sufficiently high current for transition to steady-state current drive systems, the toroidal field (TF) coils on the Pegasus Spherical Tokamak have been redesigned and built for operation up to 0.6 T.

The capability of creating low-aspect ratio plasmas is maintained by removal of the central solenoid which is replaced with a larger-area, water-cooled toroidal field coil bundle comprised of 24 copper conductors capable of 48 kA/turn. Air-cooled aluminum plate conductors are mounted in pairs to I-beams for reinforcement and are linked to the central TF conductors through interleaving interconnects to eliminate net toroidal current. The outer conductors are designed with a relief at the tokamak midplane and the I-beams are gapped to provide a flexible joint to relieve the stress due to thermal expansion of the TF bundle. Strain gauges and thermocouples are mounted at key locations on the TF coil structure to compare the performance of the coil with the electro-thermal stress and heat transfer calculations performed for the magnet design. Operation up to 0.3 T is possible without active cooling of the TF bundle, but operation at 0.6 T for a 50 ms flattop period requires the implementation of a 10 kW water cooling system to maintain the desired 5-minute shot cycle. A membrane vacuum degassing system is used to ensure low dissolved oxygen content in the cooling water to prevent long-term corrosion of the copper conductors.

The TF coil is presently powered by twelve 3.6 MVA (900 V, 4 kA) IGBT-based H-bridge buck converters with 3.2 MJ of stored energy. The full pulse length of the 1 mH TF coil requires about 80 ms to achieve the required 48 kA/turn current and can be maintained for 60 ms given the available stored energy. Electro-thermal circuit modeling shows that the 3600 A rated IGBTs operate well below their rated junction temperature with negligible impact to their operational lifetime. The resistive heating of the TF bundle results in about 0.5 mm of expansion which is well-within the design criteria of the magnet yet easily measured with the deployed strain gauges. Commissioning of operation at 0.6 T entails monitoring of the TF bundle temperature and strain measurements as the current and pulse length are doubled to ensure accuracy of the modelling and operation within known stress limits.

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