MAST UPGRADE CENTRE COLUMN DESIGN AND ANALYSIS

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The MAST-U (Mega-Amp Spherical Tokamak Upgrade) experiment is now passing into the detailed design stage and will involve significant advances over the existing MAST machine including increasing the toroidal field from 0.52 to 0.78 Tesla, the solenoid flux swing from 0.9 to 1.7 volt-seconds and the pulse length from 0.5 to 5 seconds (at 0.54 Tesla toroidal field). To meet these and other enhancements, the existing MAST centre column sub-assembly will be completely replaced in MAST-U. This sub-assembly comprises (a) the centre rod which forms the inner legs of the TF circuit, (b) the solenoid which fits closely over the centre rod, (c) the "air side" coils which are solenoid-like magnets – one within the bore of the centre rod (Pc) and one outside the solenoid (Px), (d) the two stainless steel crowns which are keyed and bonded to the ends of the centre rod for torsional support and (e) axial supports for the solenoid and airside coils.

This paper describes the detailed design of the centre rod, the solenoid magnets and the means to manage the massive internal twisting torque on the centre rod (138 kNm in MAST-U compared with 58 kNm on MAST) due to the interaction of the two magnets. Managing this torque requires about 60% of the total torque to be off-loaded externally to the vacuum vessel with the remaining 40% passing internally along the central length of the rod.

Construction methods for these two magnets follow those used on MAST but with notable changes to cope with the enhancements. Particular new features are (a) cooling with chilled Galden at -30 ºC rather than water at room temperature for both magnets, (b) an insulation matrix of cyanate ester rather than epoxy resin for the solenoid (and possibly the centre rod) to increase the insulation mechanical strength and raise the maximum service temperature from about 70 to over 100 ºC and (c) a separately wound and impregnated solenoid to reduce the overall construction time by about 12 months compared with MAST. This parallel magnet manufacture precludes the use of flared ends on the rod and so torsional stresses on the off-loading joints between the rod ends and the crowns are increased by a factor of 2.5 compared with MAST. Detailed stress analysis of the rod to crown bonded joints, which are insulated and castellated, reveals the likelihood of de-bonding cracks initiating in the castellation corners. However further crack opening analysis indicates that these cracks will arrest before they reach damaging levels.

The torsional loads pass from the crowns to stainless steel torsion rings (and then on into the vacuum vessel) via demountable dowelled joints which are also radially constrained by the bore of the solenoid. The design of this critical joint has been optimised with a structural analysis that includes the effect of interference fits, contact and plasticity. The analysis has been verified with mechanical tests on a prototype dowelled joint.

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