Optimization of the HETS He-cooled divertor concept: Thermal-Fluid and structural analysis

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The High Efficiency Thermal Shield (HETS) concept was proposed by ENEA for divertor application in the context of the ITER project and as part of the European Power Plant Conceptual Study. The design is modular, and the segment dimensions are of the order of a few centimeters for the purpose of limiting the induced mechanical and thermal stresses. The requirement for high temperature operation led to the structural material choices of tungsten for the armour, and tungsten alloy for the pressure-retaining boundary.

Tungsten and alloys have an operating temperature range 300-1300^{o}C, limited by the ductile to brittle transition (DBT) and recrystallisation temperatures respectively. The DBT temperature under neutron irradiation is estimated to be around 600^{o}C, which narrows the “design window” to a range of 600-1300^{o}C.

The coolant is helium gas operated at pressures in the range 10-14 MPa with inlet temperatures in the range of 500-800^{o}C. The final choice of operating parameters is made in conjunction with the choice of mass flow rate, in order to keep temperature values within the structural material operating limits, and pressure drop and pumping power to a minimum.

The geometrical complexity of the designs made prediction of heat transfer coefficients, needed for conducting thermal and structural analysis difficult, and the calculated values from empirical correlations uncertain.

Previous studies demonstrated that the design assumptions were conservative. This paper presents and summarizes results of thermal-fluid and structural analyses, with different heat flux loads, fluid pressures and inlet velocities. The inlet coolant velocity was varied from 175 to 300m/s, resulting in mass flow rate variations in the range 0.052-0.0891kg/s, and the incident heat flux was raised from 10MW/m^2 to 15-20MW/m^2. Two helium gas pressures were studied: 10MPa and 14MPa, to see the effect of pressure on the resulting primary stress and strain.

The computational fluid dynamics analysis demonstrates that the flow passage with a sharp corner at the point of flow reversal behaves like an abrupt enlargement, leading to considerable pressure losses as compared to the results obtained by rounding the corner. Rounding the sharp corner causes the passage to behave like a diffuser, where pressure is recovering due to the flow cross sectional area expansion, leading to reduced total pressure losses, without any degradation of the thermal performance of the component.

The finite element structural analyses results demonstrate that the static stress requirements, including the limits for stress concentration regions, are met or are within the calculation uncertainties. Also, the deformation limits are satisfied, as the strains calculated are within the 1% average and 5% local values specified in the design code, although an inelastic analysis might have produced higher values than the 0.123% calculated. A lifetime evaluation was not performed as time dependent data for tungsten alloys, i.e. creep (thermal and irradiation) and fatigue, are scarce and not code qualified.

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