Seminar

Institute for Plasma Research

Title : An Engineering Study of Concepts for Power Extraction from Tokamak Fusion Reactors

Speaker: Mr. Piyush Prajapati
Institute for Plasma Research, Gandhinagar, India

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Venue: Seminar Hall, IPR

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Abstract: Realization of fusion energy requires demonstration of the conversion of fusion power to net electrical power. Currently this seems feasible only for large reactors like DEMO with high enough fusion gain, Q>10. A staged approach is necessary to bridge the R&D gaps to DEMO. This work shows how moderate-sized, low-power, pulsed reactors can establish a robust technical foundation for the heat extraction and power conversion for DEMO. Such designs can also form the basis for fusion pilot plant concepts that are required to address the R&D gaps on the way to DEMO [1, 2, 3, 4].

In this thesis work, the problem of heat extraction from the blanket and its conversion to electricity has been studied for a moderate-sized pulsed reactor, which we call the Heat Extraction Test Reactor (HxTR), with R = 3 m, A = 2.7 and P_f = 200 MW, Q = 2.8 and a total pulse length of 4000 s [5]. The crucial consideration for the demonstration of power extraction in such a reactor is the blanket design that is compatible with remote maintenance in the nuclear environment. In a moderate sized reactor, due to the sharp curvature the blanket dimensions on the plasma facing and rear sides are different which poses challenges in adopting maintenance schemes that are developed for big reactors like ITER or DEMO. We have developed a novel concept of modular maintenance that can be carried out from the backside. This requirement has been used to map the PF coil locations and port sizes. For heat extraction from the HxTR, a novel solid breeder blanket concept that is modular in nature is proposed. The entire outboard blanket system consists of 18 poloidal sectors with each sector containing 7 twin-modules. A twin module represents a toroidally separated pair of identical blanket module (BM), using a unique arrangement of radially stacked breeder/multiplier zones in a nested 'C' shaped configuration. An important design criterion for the blanket module was to optimize the heat extraction efficiency by ensuring a uniform outlet temperature of ~500°C. A 1-D, multi-region, time-dependent heat diffusion model is developed to simulate the thermal transient behaviour of the blanket module during pulse and dwell time and the results show a nearly uniform outlet coolant temperature. The helium flow and breeder/multiplier thicknesses are optimized to ensure that the temperature of each material is within the tolerant limits arising from the materials. The results obtained have shown excellent agreement with the ANSYS transient simulations.

For power conversion studies, preliminary design parameters of the steam generator and heat exchangers have been found [6]. A crucial problem is to obtain steady power from a pulsed source which necessitates the requirement for an intermediate Energy Storage System (ESS). We have adopted a HITEC molten-salt-based ESS scheme for the ESS. The heat received during the pulse from the blanket, first-wall, and the divertor is stored and is used to drive the power conversion cycle. A study of steam Rankine cycle, and S-CO_2 Brayton cycle has been carried out to optimize the parameters of the power conversion cycles. We have found that the S-CO_2 Brayton cycle exhibits slightly higher thermal efficiency compared to the Rankine cycle. Rankine cycle efficiency with helium cooled blanket is about 42.2%, whereas it is 35.3% with water cooled blanket concept.

Power conversion studies have also been conducted for a different power reactors like 100 MW compact tokamak reactor [7], 300 MW pilot plant and a 500 MW ITER-like reactor [6].

References:

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4. H. Zohm et al., "A stepladder approach to a tokamak fusion power plant", Nucl. Fusion 57 (2017) 086002
5. P. Prajapati, S. P. Deshpande et al. "Conceptual Design of HCSB Blanket for a Moderate Sized Tokamak Fusion Reactor.," Fusion Eng. Des., 2023. (under review)
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