ME- PhD Thesis Defense

Investigations on Radial Inflow Turbine for Supercritical CO_2 Power Cycles

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Hybrid Mode: (Click here to join)

ABSTRACT

Supercritical carbon dioxide (sCO_2) cycles are in vogue as potential replacements for steam and captive power generation using industrial waste heat, concentrated solar power, and energy storage. sCO_2 turbines typically operate at high inlet pressures (~15–20 MPa), resulting in high inlet densities of working fluid ranging between 100–140 kg/m^3. Higher density at the turbine inlet leads to compact turbines necessitating significantly higher rotational speeds compared to a similar-capacity steam or gas turbine operating at similar efficiencies. The required rotational speeds for sub-megawatt sCO_2 turbines range between 100,000 and 200,000 rpm, making only the low-specific speed designs practically realizable. Radial inflow turbines are preferred for small-scale (≤ 5 MW) power generation on account of higher efficiencies, design simplicity, and economics. Low-specific speed designs in radial inflow turbines lead to long and narrow flow passages in both stators and rotors. The combined effect of elevated pressures, dense working fluid, high operating speeds, and small size with narrow flow passages leads to distinctive flow characteristics and loss mechanisms not observed in conventional steam or gas turbines. Therefore, the methodologies and correlations used in the design of gas turbines need to be reevaluated and adjusted for sCO_2 applications.

This research describes the method for designing sCO_2 radial turbines using first principles. Basic meanline design, profile generation for stator and rotor blades, and comprehensive computational fluid dynamics (CFD) simulations are presented. The engineering challenges associated with small size, high operating speeds along with limitations in manufacturing, material strength, flow physics, and rotor dynamics are addressed by incorporating these concerns in the design stage. A key outcome of this exercise is the theoretical identification of feasible operating speeds for sCO_2 radial inflow turbines at different power scales within the realm of engineering limitations. Significant variations in optimal design parameters for sCO_2 radial turbines as compared to gas turbine-based correlations have been highlighted through CFD investigations. It is found that sCO_2-based design considerations lead to a 3-5% increase in turbine efficiency. Another important contribution of the research is the identification and quantification of loss mechanisms in a sCO_2 radial inflow turbine. Assessment of loss mechanisms suggests the dominance of Coriolis effect for high-specific speed designs. In contrast, viscous frictional losses supersede designs with low-specific speeds. The parasitic loss, which includes leakage and disk friction loss at the rotor backface is found to be significant in sub-MW scale sCO_2 radial turbines resulting in a 4–15% drop in turbine efficiency. Sizable backface clearance due to small turbine disc diameters, denser fluid, and high rotational speeds are the primary reasons for high parasitic losses. A novel radial labyrinth seal is proposed to be installed at the housing facing the backface of the impeller to minimize parasitic loss. In the case of low-specific speed designs, the viscous losses in the volute are substantially high, contributing to around 30–40% of the total loss. A boundary layer-based quasi-one-dimensional loss model is developed to predict the volute losses in the preliminary stage. The loss model calculates volute loss within ±10% error while consuming negligible computational resources compared to full-scale 3d CFD simulations. Finally, the insights and learning from this research have translated into a 60 kW sCO_2 radial turbine prototype that is intended to be installed in the sCO_2 technology demonstration test loop at Thermal Systems Laboratory, Indian Institute of Science, Bangalore.

ABOUT THE SPEAKER

Syed Jiaul Hoque is a Ph.D. student in the Dept. of Mechanical Engineering, IISc Bangalore. He obtained his B.Tech degree in Mechanical Engineering from Kalyani Govt. Engineering College, WB in 2015, and M.Tech degree in Mechanical Engineering from IIT Delhi in 2017. Subsequently, he has worked as an engineer in Eaton India Innovation Center for two years. His research area is broadly the development of turbomachinery.