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M3Or3A-02: [Invited] Liquid hydrogen cooling of superconducting motor AC windings

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Electric machines for aviation applications are under intensive development at present. Pushing performance to 30kW/kg at the 10-20MW scale requires a step change in air-gap field and hence current density. Fully superconducting machines show great promise for achieving the power to weight ratios required, and the use of liquid hydrogen as the aircraft propulsion energy source presents the opportunity to cool the superconductors with minimal additional refrigeration plant.

However, designing such a cooling system is not a simple task. Superconducting armature windings in a 3MW motor will generate many kW of heat at cryogenic temperatures, due to AC losses, depending on the conductor used. Liquid hydrogen will likely be stored at 24-26K, not the 20K required for some conductors. Intermediate coolant loops of pumped helium will be needed, if flowing liquid hydrogen through the motors is not practical or desirable.

In this paper we explore the design-trade-space of cooling systems targeted at two different armature conductors for a 3MW synchronous air-core motor: a magnesium diboride (MgB2) winding requiring a nominal 20K operating temperature, and a REBCO Roebel-cable winding requiring a nominal 40K operating temperature. MgB2 performance has a strong temperature dependency at greater than 20K which alters the physical dimensions of the windings as well as the losses generated, which in turn impacts the heat transfer characteristics. The dependency is lower with Roebel cable, but to ensure these effects are captured, each conductor is evaluated at a range of temperatures around the nominal, assuming a fixed safety factor below critical current. AC losses have been calculated for each of the windings, based on experimental correlations and heat transfer coefficients and areas are estimated for the likely coil geometries and cooling system components. A lumped-parameter model has been developed to simulate the cooling circuit thermodynamics and this allows us to estimate coolant flows, temperatures and pressures in the systems being considered.

The two conductors lead to very different cooling system options and we can compare the advantages of each from an overall powertrain complexity and performance perspective.

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