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Thu-Mo-Or2-02: Retrofitting Closed-Loop Rotor-Mounted Cryocooler Superconducting Rotor into an Induction Motor: Design, Analysis, Assembly Procedure, and Experimental Results

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The field of electrified aircraft propulsion is undergoing a transformative evolution, driven by breakthrough advancements in superconducting electrical machines. Significant interest exists in the development of closed-loop, rotor-mounted cryocooler superconducting rotors, with several projects pursuing this innovative approach. This design simplifies the cryogenic requirements of superconducting motors, making them practical for high-torque applications such as commercial electric propulsion and ship propulsion.

This paper presents the design, assembly procedures, and experimental studies conducted on a superconducting rotor retrofitted into an industrial induction motor. The motor is specifically engineered to address challenges associated with a rotor-mounted, closed-loop cryocooler superconducting rotor. Although the machine is not designed to produce substantial power or torque, it is expected to generate 10 kW of power under full load. The team is conducting an extensive experimental campaign to mitigate risks in critical subsystems and ensure the successful demonstration of this motor. The results will serve as a foundation for the design of large-scale, rotor-mounted superconducting machines.

Key advancements in the superconducting rotor employed in this study include a rotor-mounted cryocooler, a spoke suspension torque transfer system, and a novel radiation management system. Risk mitigation efforts feature a rotor-mounted Stirling-cycle cryocooler, which integrates a commercial off-the-shelf (COTS) Stirling-cycle cryocooler into a rotationally compatible configuration for closed-loop conduction cooling. Additionally, the rotor cryogenic thermal management system (TMS) incorporates a novel coil suspension system to transfer torque between the cold field winding assembly and the warm rotor shaft while minimizing conduction heat load to the cryocooler. Innovative techniques are employed to reduce radiation heat leakage to less than 10 W. Furthermore, the rotor features quench-tolerant HTS magnets, which demonstrate passive quench tolerance using conduction-cooled, no-insulation (NI), double-pancake (DP) high-temperature superconducting (HTS) magnets.

For this experiment, the existing stator of a NEMA-standard, three-phase induction motor with a 900-rpm rating was utilized. The rotor was designed with an eight-pole configuration and a 21 mm magnetic air gap to accommodate the vacuum chamber and proposed radiation management system. The vacuum shell outer diameter (OD) is designed to be 11 inches, while the rotor winding holder OD is 12 inches. A single cryocooler is used to cool the superconducting coils and intercept the current leads. The rotor coils are designed to operate at a temperature of 70 K. Since the rotor focuses on addressing challenges related to cryogenic cooling, dynamic operation, and maintaining vacuum integrity during operation, the design has not been optimized for weight reduction. The rotor shaft and vacuum chamber are constructed from stainless steel to facilitate easy welding for vacuum integrity, while the coil holder is a single aluminum shell that houses all the rotor windings.

No-insulation (NI) HTS coils offer passive quench protection by providing alternative current paths around defects and promoting uniform heat dissipation, which minimizes the risk of localized hotspots leading to thermal runaway. Test DP-NI coils were manufactured and tested in liquid nitrogen before being installed on the rotor. The operating current is set to 65 A at 70 K, maintaining a 25% critical current density margin. The coils are glued to the rotor shell using Stycast resin to ensure excellent thermal conductivity. Conduction

cooling is employed for the coils, with a combination of firm and flexible thermal straps used to isolate vibrations from the rotor to the cold head.
This paper provides a comprehensive overview of the rotor design, as well as the assembly and testing efforts. The motor will be tested at the POETS test facility in Champaign, Illinois. These findings contribute to the advancement of rotor-mounted cryocooler superconducting electric motors, paving the way for cleaner and more efficient air transportation.

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