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M2Or3J-02: [Invited] Cryogenic vacuum chamber testing of a conductively-cooled, high temperature superconducting rotor for a 1.4 MW electric machine for aeronautics applications

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Electrified aircraft are being developed to address climate change by reducing the fuel burn and emissions of aircraft. The large majority of aviation's impact on the environment is caused by large transport aircraft, or those that can carry about 150+ passengers. At this scale, MW-class electrified propulsion systems are required. To achieve a net fuel burn and/or emissions benefit after adding the mass of this extra system to the aircraft, the performance of the electrified propulsion components must exceed the state of the art. Not only must the specific power of electric machines improve to limit the mass of the system, but their efficiency must also improve to limit waste heat (which necessitates added mass for a thermal management system) and limit oversizing other electrified propulsion components (which must overcome the machines'inefficiency). In numerous cases, the efficiency of electric machines has a stronger influence on the aircraft than their specific power. Superconducting and cryogenic machines typically can achieve higher efficiency than their counterparts that operate above ambient temperature. The paper will describe the motivation for superconducting and cryogenic electric machines (as opposed to machines operating above ambient temperature), including references to system-level aircraft studies, studies comparing superconducting/cryogenic machines to conventional ones, and state-of-the-art electric machines for aeronautics applications.

NASA's high efficiency megawatt motor (HEMM) is a partially superconducting, 1.4 MW electric machine designed for electrified aircraft propulsion. HEMM's high performance is enabled by a superconducting rotor composed of 2nd generation high temperature superconducting (HTS) coils that are designed to operate at temperatures below 62 K. The superconducting rotor is conductively cooled to cryogenic temperatures using a rotating cryocooler embedded inside the machine's shaft. The development of HEMM's electromagnetic design has been supported by testing of sub-scale and full-scale superconducting coils in liquid nitrogen (LN2). This experimental work has been previously published by the authors. Although these LN2 tests have reduced multiple risks in HEMM's design, the HTS coils were not operated at their designed thermo-electro-magnetic operating condition. This paper presents the first test of HEMM where the HTS coils were conductively cooled to their rated operating temperature and then excited at their rated operating current and magnetic field.

The experimental setup consisted of HEMM's full-scale superconducting rotor in a cryogenic vacuum chamber. The temperature of both the thermal interface to HEMM's cryocooler and the structural interface to HEMM's shaft (and cryocooler housing) were accurately controlled. To limit the complexity and cost of the test, only three of the rotor's twelve HTS coils were included. These three coils were installed on adjacent rotor teeth to ensure the magnetic field excitation on the central coil was representative of HEMM; this claim will be supported in the paper by reporting thermal and electromagnetic 3D finite element analyses (FEA) of HEMM and the experiment.

The paper will present measurements of the rotor's temperature distribution during the cool down from room temperature along with a comparison to 3D FEA of HEMM. This discussion will emphasize the duration of the cool down as well as the temperature gradient across bolted interfaces and other mechanical contacts. Thermal and electrical measurements will be presented for operation at different direct current excitations up to the rated current of the rotor. The paper will include a discussion of the ability of HEMM's design to sufficiently cool the rotor and stably operate the superconducting coils at their rated direct current under conductive cooling with a cryocooler.

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