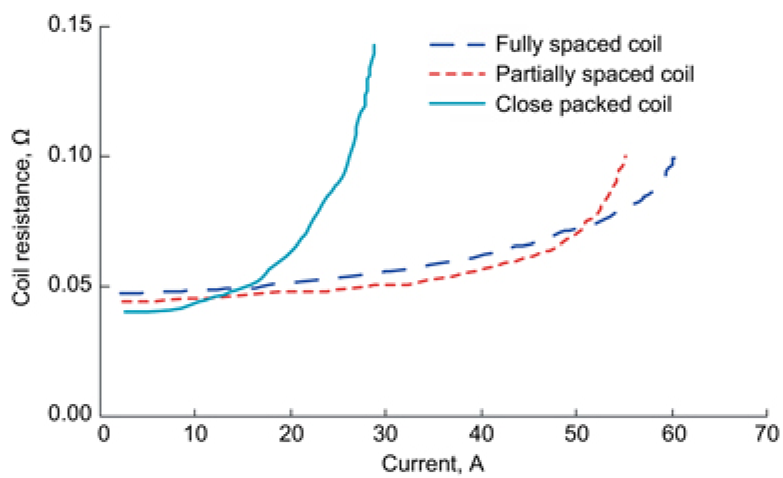
Switched-Reluctance Cryogenic Motor Tested and Upgraded

Pollution-free flight is one of NASA's goals for the 21st century. One method of approaching that goal is to use hydrogen-fueled aircraft that use fuel cells or turbogenerators to produce electric power to drive electric motors that turn the aircraft's propulsive fans or propellers. Hydrogen fuel would likely be carried as a liquid, stored in tanks at hydrogen's boiling point of 20.5 K (-422.5 °F). The liquid hydrogen could provide essentially free refrigeration to cool electric motor windings before being used as fuel. Either superconductivity or the low resistance of pure copper or aluminum in liquid hydrogen could be applied to greatly increase electric current density and motor power density.

At the NASA Glenn Research Center, a testbed motor with copper windings was operated in liquid nitrogen at current densities and torque densities that would not be possible at room temperature. Coil current capacity measurements and locked-rotor torque measurements were made to guide planned upgrades in coil geometry and power electronics and to validate analysis methods that can be extended to liquid-hydrogen-cooled motors.

In early operation (ref. 1), the motor produced 10.6 kW (14.2 hp) in liquid nitrogen. In the first phase of upgrading, we doubled the drive voltage per pole in the motor by splitting each coil in half and driving each half with the same type of power amplifier that had been used for the whole coil. Because the phases (and even "half phases") in a switched reluctance motor operate virtually independently of each other, we could excite the windings on just one pole pair and then project the measured results to full-motor performance by multiplying the torque and power produced by 6. This yielded a projected power of 15.0 kW (20.1 hp).

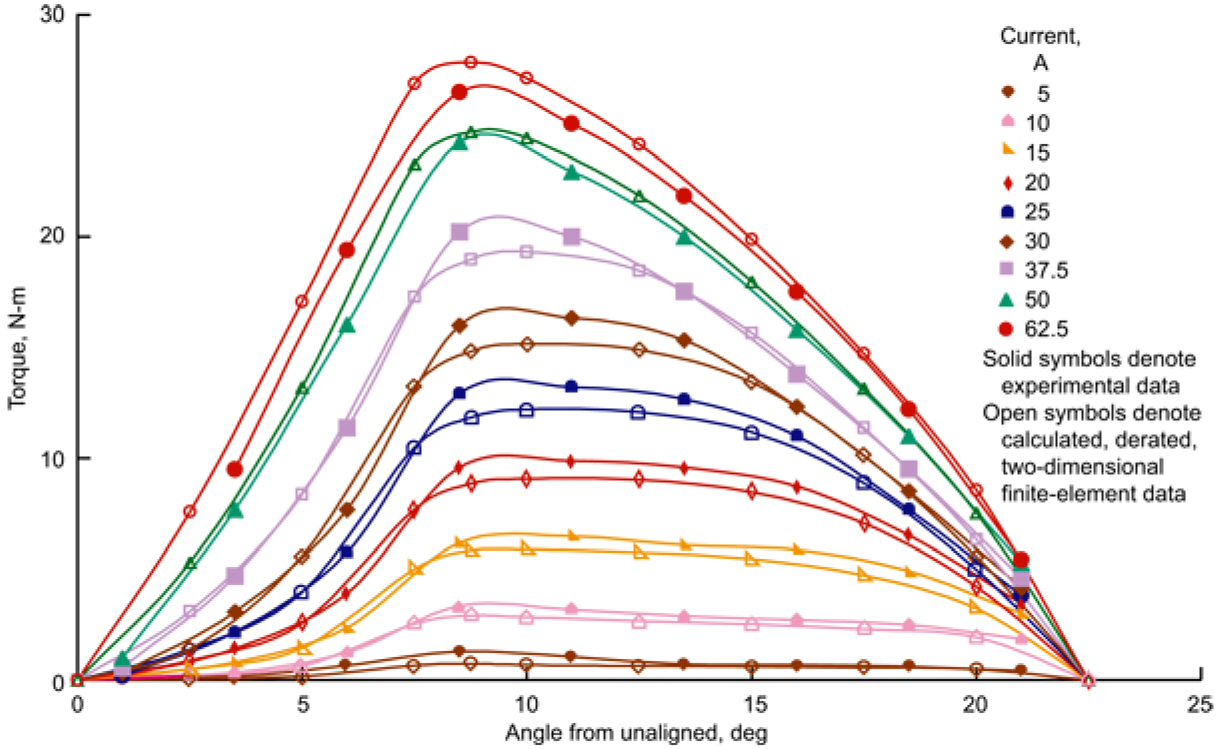


Coil resistance in switched-reluctance motor in liquid nitrogen versus current for three types of coils.

Long description of figure 1. This plot shows that spacing greatly increases the current-carrying capacity of the coils since the spacing increases the surface area.

The current-carrying capacities of three types of coils installed in the switched-reluctance motor were measured. The close-packed coil had no spacing between the layers of wire on the coil end turns. The partially spaced coil had no gap between the two inner layers but spaces between the other layers, and the fully spaced coil had gaps between each pair of layers of wire. The coil resistance in the motor in liquid nitrogen as a function of current is shown in the preceding graph. The close-packed coil can carry less than 30 A, whereas the two coils that have spacing on the end turns can carry more than 53 A each. The current density corresponding to the latter current is 5300 A/cm^2.

Locked rotor torque measurements were made as a function of rotor position and of current up to 62.5 A in liquid nitrogen and compared with torques from a two-dimensional finite-element calculation. The results are shown in the following graph, where the finite element torques were multiplied by a derating factor of 89 percent. The factor, selected to produce a reasonable fit between experiment and calculation over the range of the angular and current variables, is needed to correct for axial fringing, which the two-dimensional finite-element method cannot calculate. The current capacity and torque measurements indicate that substantial improvements in motor power density should be possible with appropriate improvements in coil geometry and power conditioning.



Comparison of 11-percent derated two-dimensional finite-element and experimental torques as a function of current and angle.

Long description of figure 2. This plot shows that the 11-percent derated torque agrees reasonably with experimentally measured values over a range of current and angles.

Reference

1. Brown, Gerald V.: Cryogenic Electric Motor Tested. Research & Technology 2003, NASA/TM--2004-212729, 2004, pp. 162-163. Switched-Reluctance Cryogenic Motor Tested and Upgraded at http://www.grc.nasa.gov/WWW/RT/2003/5000/5930brown.html

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