Concept for order-of-magnitude increase in electrical machine power density

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Abstract:
This is a multi-disciplinary project to explore the feasibility of a concept for an order-of-magnitude increase in electrical machine power density employing a novel superconducting machine architecture.

Superconducting field coils, with significantly higher MMF capability than conventional coils, opens up a new design space for electrical machines. One way to utilize the large MMF capability is to minimize or eliminate the use of ferromagnetic material. With the iron and its saturation limit removed, designs with much higher air-gap flux densities can be generated. Magnetic fields that are 5 – 10X current levels are possible with superconductors, but early designers ran into the practical challenge of containing the magnetic field emanating from the machine. Techniques evaluated so far lead to trade-offs that limit power density of the machine. A similar challenge is encountered in high field Magnetic Resonance Imaging (MRI) magnets, and this team believes an approach used to address the problem in those systems is applicable in electrical machines as well – the concept of 'actively shielded' systems. This technique employs a set of main coils combined with a set of bucking coils that serve to minimize the external field with only a modest impact on the field in the region where the machine torque is generated. We borrowed the basic concept and adapted the technique for electrical machines and have obtained early results suggesting significant improvement in the compactness of air-core superconducting machines.

Risk is reduced by using available superconducting material, and by leveraging cryogenic cooling technologies recently developed in the health care industry for MRI applications. This technique does, however, introduce new engineering challenges – specifically on the large forces between the main and bucking coils, and the cryogenic design of the system with both sets of coils. A multidisciplinary trade-off study incorporating electromagnetic, cryogenic, mechanical, materials and manufacturing considerations is performed to generate a conceptual design of the new machine topology. Detailed computer modeling and analysis is used to estimate power density and to identify remaining technical risks towards a practical implementation of the new design. Available technology from adjacent spaces (healthcare, aerospace, power gen, and automotive) is leveraged within this program to take the concept part way towards TRL-3, by generating a conceptual design, and establishing feasibility with analysis and some component level bench tests.

If the projected increase in power density is realized, it will enable electric drives for several applications in NASA, including distributed/hybrid electric propulsion for Ultra-Efficient Commercial Vehicles, and, when light-weight energy storage is available, help transition to Low-Carbon Propulsion by using stored energy from renewable sources on the ground. There is also potential to apply the

technology to other spaces requiring high power density machines like offshore wind, ship propulsion etc.