

FEA Modelling of Amorphous Metal Ribbon (AMR) and Metal Amorphous
Nanocomposite (MANC) Materials Enabled High Power Density Vehicle Motor
Applications.

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Metal alloys with a frozen liquid (glassy) structure led to products called **amorphous magnetic ribbons (AMRs)** produced by **planar flow casting**. In the late 1980's post-casting nanocrystallization steps were developed to produce magnetic **metal amorphous nanocomposites (MANCs)** with magnetic nanocrystals embedded in an amorphous magnetic matrix. Nanocrystals provide high magnetic inductions; and an exchange coupled amorphous phase provides high electrical resistivity. Applications of AMRs and MANCs in high speed motors, HSMs require low power losses at high-f to control T-rise. Power losses, are partitioned into losses with different f-dependences, including: (i) hysteretic, (ii) classical eddy current, and (iii) excess loss components. Hysteresis loss dominate at low- and eddy currents at high-f.

AMRs and MANCs have usable peak inductions comparable to Si-steels. Classical eddy current losses limit MANC switching. High resistivities allow high-frequency switching required for high power densities in HSMs. To minimize classical eddy current losses, small thickness and high resistivity are desired. Resistivity in MANCs is larger than Si-steels by 3-4x due to the amorphous matrix and increased further by alloying with **virtual bound state (VBS) elements**.

Rare earth (RE) permanent magnet (PM) motors are ubiquitous but soft magnetic materials (SMMs) provide great potential for energy and cost savings and particular efficiencies in new motor topologies. Supply constraints on **rare earth (RE) elements** focus attention on economical SMM alternatives in motors. Heavy REs, like Dy (a grain refiner in NdFeB permanent magnets) are the most critical REs. RE-lean or -free permanent magnets offer economic benefits and reduced scarcity for traction motors: **Axial-flux permanent magnet motors (APFM)**, introduced in late 1970s-80s, offer efficiency improvements reducing rotor losses and higher power density. Axial-flux construction requires less core material and high torque-to-weight ratio. Since AFPM machines have thin magnets, they are smaller than radial flux counterparts making them attractive in space-limited applications.

We will describe Finite Element Analysis (FEA) modeling of a dual stator axial, Flux Switching with Permanent Magnet (FSWPM), motor built in a DOE AMO program. This 2.5 kW motor supports ~0.5 kW/kg specific power density proposed to be increased to >4.0 kW/kg in a 2nd generation HSM. A motor test bed, operational at NCSU, has a 3-phase converter for drive current consists of a DC link capacitor and 6-pack SiC MOSFET modules. At 1200 V and 30 A maximum rating, the module can drive an our FSWPM HSMs. Materials developments for achieving higher power densities will be described, in the context of FEA electromagnetic models incorporating materials losses, using high frequency losses as heat sources in FEA thermal modeling and considering material's mechanical properties in high speed motor designs.

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