Ultra-High Speed, High-Temperature Motor

Project ID: elt254

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University of Illinois, Urbana-Champaign

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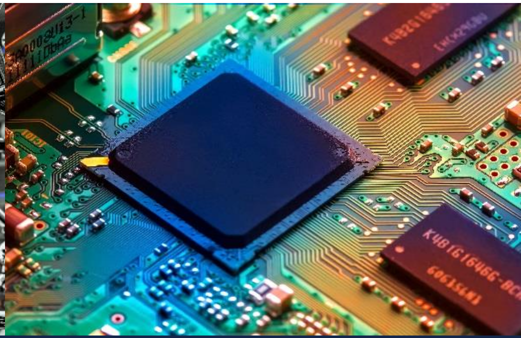
DOE Vehicle Technologies Office Annual Merit Review







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Overview

Timeline
- Start: Oct 2019
- End: Mar 2022
- 20% complete

Budget
- Total project funding
  - DOE: $700,000
  - University cost-share: $175,000

Partners
- Project Lead: University of Illinois
- John Deere Electronic Solutions

Barriers
- Advanced cooling/thermal management techniques to reduce size, cost and improve reliability.
- New and improved materials to lower cost and improve performance and reliability, including electrical steel and improved enamels.

Relevance

- **Objectives**
  - Two enabling technologies are needed to develop a 125 kW motor at 50 kW/L
    - Stator insulation materials capable of operating at 650°C.
    - Soft magnetic composites rated for operation at 60,000 RPM.

- **Impacts**
  - High-temperature insulation enables higher power densities and increased reliability against transient thermal loads.
  - Soft magnetic composites enable lower power losses during high-frequency operation and can be manufactured without energy-intensive melt-processing and welding operations.

Milestones

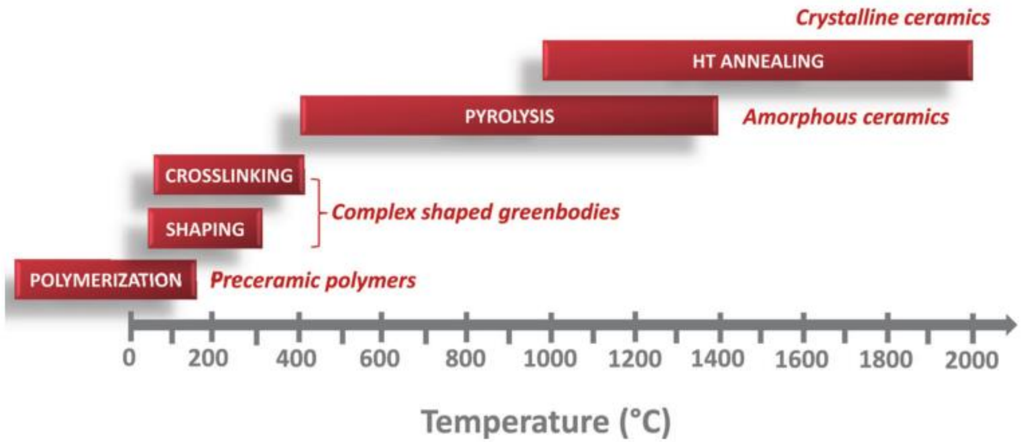
Month/Year	Description of Milestone or Go/No-Go Decision	Status
Dec 2020	Optimize motor design with geometry, electromagnetic, and thermal design specifications that meet 125 kW, 50 kW/L, and 60,000 RPM at hotspot temperature of 650°C.	In progress
Feb 2021	Construct soft magnetic composite-based rotor core and stator section and determine BH curve characteristics.	In progress
May 2021	Establish communications between inverter and controller hardware for dynamometer testing.	In progress
Jun 2021	Validate the motor and inverter compatibility using hardware-in-the-loop testing to drive the motor finite-elements model.	In progress
Jun 2021	Demonstrate operation of the soft magnetic composite rotor at 60,000 RPM and operation of the winding enamel at 650°C.	In progress

Approach

High-Temperature Enamel

- Preceramic polymer resins are rated for temperatures approaching the melting point of copper wire
- Thin-film manufacturing methods allow precise control over dielectric strength and flexibility

Goal: increase current-carrying capacity to increase power density and reduce thermal failures



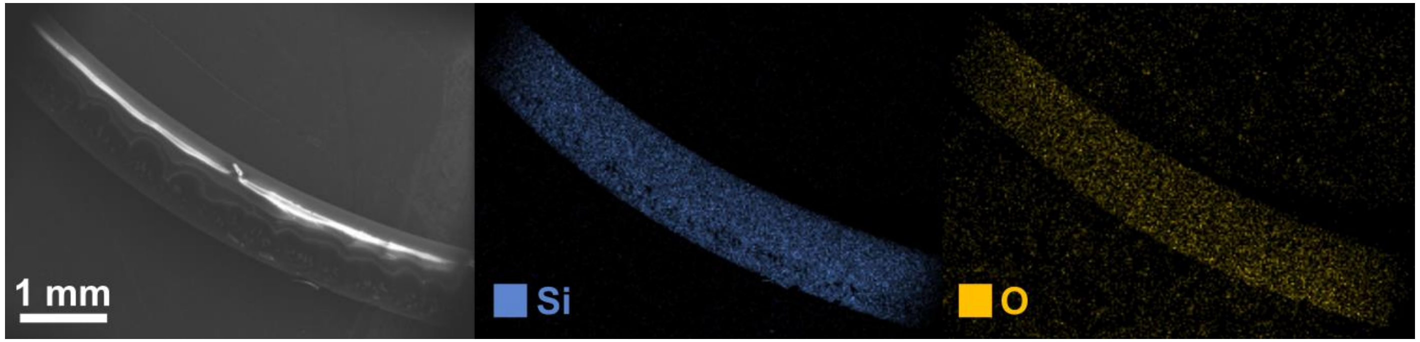
Soft Magnetic Composites

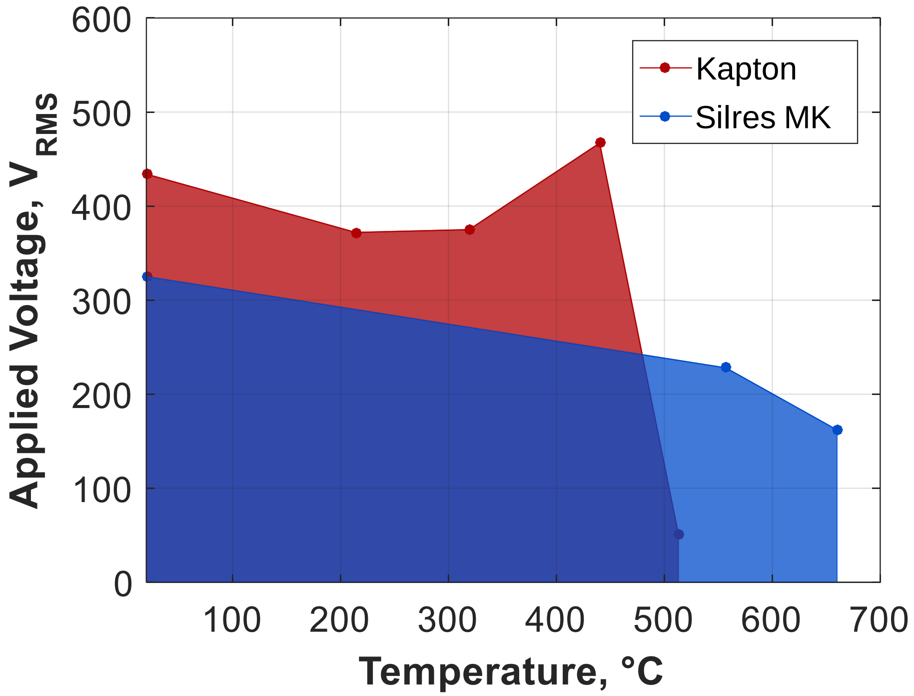
- Combining sol-gel methods with 3D-printing can produce composites with improved high-frequency performance over laminated steels

Goal: reduce magnetic switching losses to increase power density

Technical Accomplishments – Materials Development

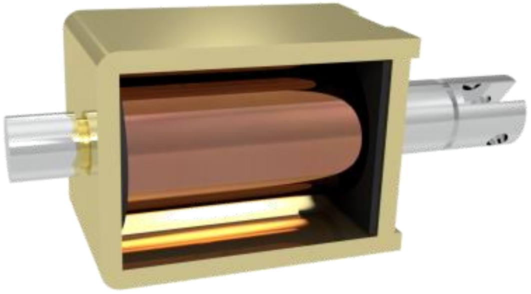
- Copper wire with preceramic enamel has been developed to compare with commercial Kapton enamel
- Dielectric tests (ASTM D1676) show that preceramic enamels operate 150°C higher than Kapton





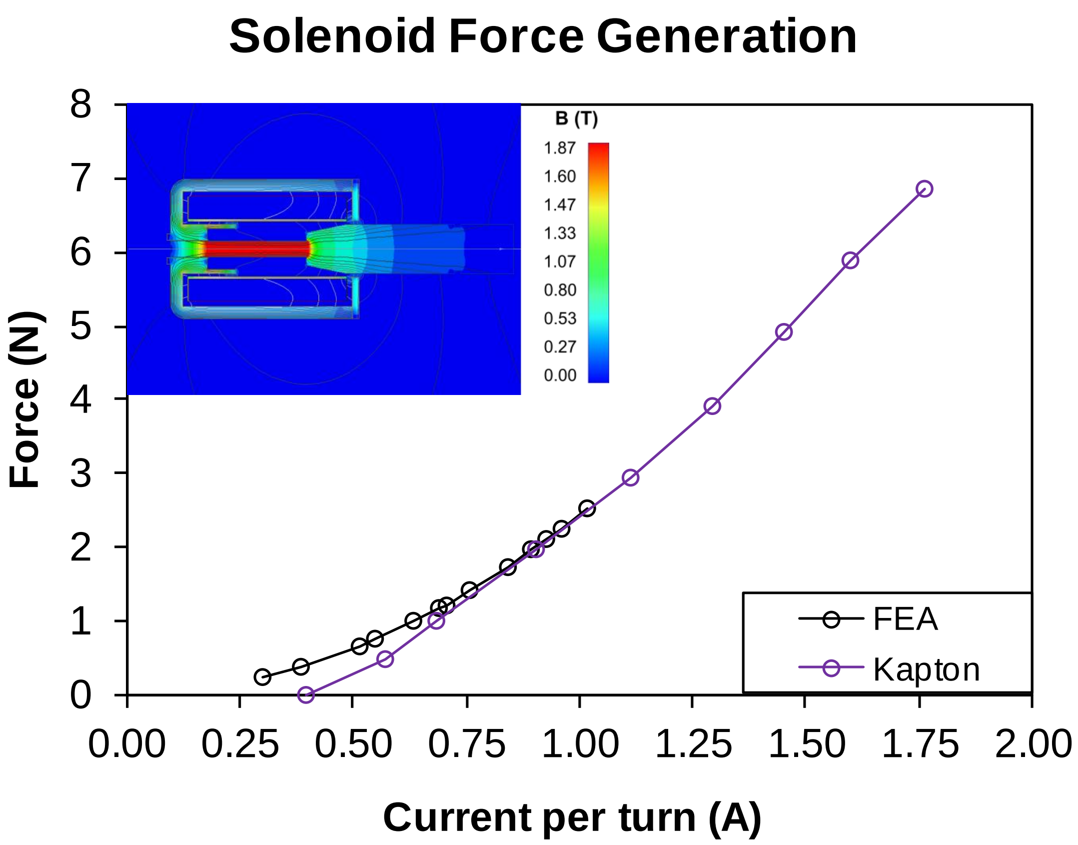
Preceramic enamels are rated for higher temperatures than Kapton enamels.

Technical Accomplishments – Motor Prototype



Prototype Design

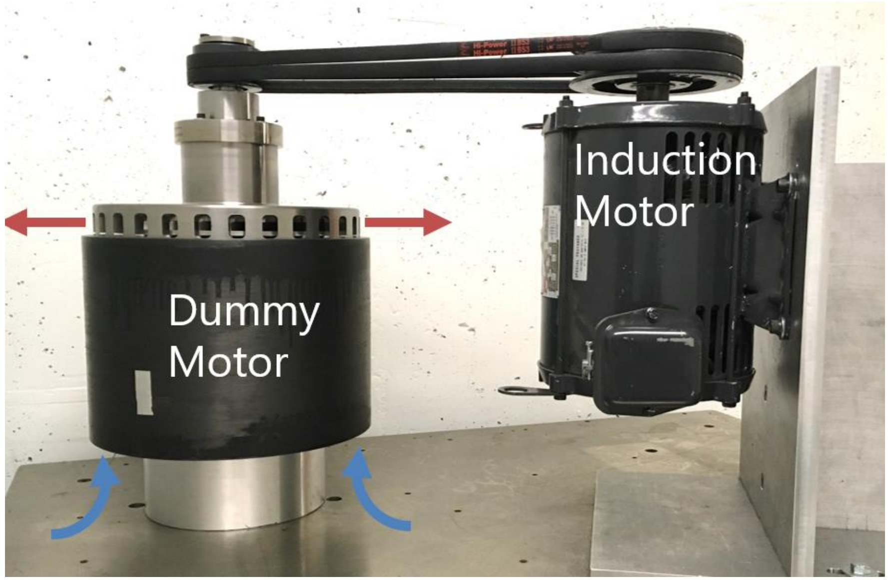
Kapton Prototype



A low-cost motor prototype has been developed to compare the force generation of Kapton- and preceramic-enameled coils.

Technical Accomplishments – Rotor Test Stand

- A vertical test stand has been constructed to test sample rotors from 0-60,000 RPM
- Soft magnetic composite rotors are being tested to observe critical speeds and harmonic modes for comparison with rotordynamics simulations



A test stand has been developed to validate the mechanical integrity of soft magnetic composites at 60,000 RPM

Responses to Previous Year Reviewers' Comments

Please note: this is the first year that the project has been reviewed.

Collaboration and Coordination with Other Institutions

Prime recipient: University of Illinois, Urbana-Champaign

- Multiphysics design of motor
- Materials development and motor assembly

John Deere Electronic Solutions

- Inverter and controller development
- Motor commissioning and dynamometer testing

Remaining Challenges and Barriers

- **Manufacturing**
  - High-temperature magnet wire must be made at 500 km production volume for the proposed motor.
  - Soft magnetic composite rotor needs a suitable matrix for spinning at 60,000 RPM.
- **Integration**
  - Precise assembly is critical for high-speed operation.
  - Motor, inverter, and controller compatibility must be established.
  - Motor cooling system and vacuum system create important considerations in designing seals.

Proposed Future Research (FY 2020 and 2021)

- **Manufacturing**
  - Leverage industrial expertise to scale up magnet wire production.
  - Determine the mechanical and magnetic characteristics of a soft magnetic composite suitable for operation at 60,000 RPM.

- **Integration**
  - Build on strong industry collaboration to establish motor and inverter compatibility using hardware-in-the-loop simulation tools.
  - Co-design suspension and cooling system to ensure proper sealing for bearing and cooling fluids.

Any proposed future work is subject to change based on funding levels.

Summary

- **Technical Highlights**
  - Preceramic-enameled wire has been fabricated and shown to outperform Kapton magnet wire in high-temperature operation.
  - A simplified motor model has been designed and manufactured to benchmark the performance of preceramic magnet wire against Kapton.
  - A rotor test stand has been constructed to test soft magnetic composites at 60,000 RPM.

- **Impact toward VTO Objectives**

The high-temperature enamel and high-speed magnetic composite materials explored here are critical to achieving VTO's goals for 50 kW/L power density at the motor level. High-temperature operation allows higher torque generation in both transient and continuous modes of operation while high-speed operation eliminates volume from the magnetic cores.