Motor Research in the Power Electronics and Electric Machinery Group

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Outline

• PEEM Group Overview
  – Power Electronics
  – Electric Machines (Motors)
    • Materials Modeling Research
    • Rare Earth Free/Reduced Electric Machines

• Recycled Hard Disk Drive Magnet Motors

• Additive Manufacturing

• Questions and Discussion
# Accelerating Power Electronics and Electric Motors Technologies

## Power Electronics
- Circuit topologies
- Wired and wireless vehicle charging systems
- Wide bandgap devices
- Power quality and utility interconnects
- Advanced Manufacturing

## Electric Motors
- Innovative designs
- High-performance non-permanent magnet motors
- Permanent magnet motors
- Advanced materials
- Controls

## Packaging
- High efficiency packages
- High temperature packaging
- Highly integrated smart power module

## Applied R&D
- Transportation
- Grid
- Renewables

## Innovative, cost-effective PEEM solutions

## Unique solutions and facilities to meet application needs

### WBG DATA Facility

### Wireless Vehicle Charging

### Power Device Packaging Laboratory

### Novel Flux Coupling Motor
Electric Machine Design and Optimization

- Design optimization using gradient and evolutionary algorithms
- Rotor mechanical stress analysis
- Stator thermal analysis
- Motor/Generator efficiency mapping
- Eddy current losses in magnets and stranded conductors
Advanced Modeling Techniques

Stress Distribution
- Function of cutting/stamping method
- Influenced by mechanical fastening
- Impacted by rotation and other forces

Localized Magnetic Properties
- Function of stress distribution
- Magnetization and loss characteristics are not homogeneous

Empirical Magnetic Domain Analysis
- Traditional Epstein and ring specimen testing
- Impacts of stress, pinning, etc. upon domain wall movement, and ultimately magnetization/loss properties.

Theoretical Magnetic Domain Analysis
- Fundamental theory to confirm and supplement empirical findings.
- Indirect link to FEA - too computationally intensive for direct use in FEA.

Advanced FEA Modeling Tool
- Awarded an allocation of supercomputer 2.25 million core hours
- 2D FEA code successfully working

Bulk Characterization
- Traditional Epstein and ring specimen testing at various temperatures
- Custom analysis of rotational losses, anisotropic magnetization/loss, PWM, etc.

Slide Credit: Tim Burress
Hysteresis and Eddy Current Loss Modeling

M19 silicon steel B-H loop at 5Hz (left) and 500Hz (right)

Ring core field in axisymmetric coordinates

Ferrite toroid and associated Everett function (right)

Model
Identify
Validate

Preisach hysteresis model animation

Experimental Validation
Ferrite Interior Permanent Magnet Machine

• Key Challenges
  – Low Energy Product Magnet
  – Rotor Mechanical Strength

• Results
  – 103kW peak power
  – Significant increase in power density

• Awards
  – DOE VTO Distinguished Achievement Award
  – UT-Battelle Team Research Accomplishment

Team: Tim Burress, Jason Pries, Randy Wiles, Lixin Tang
Switched Winding Synchronous Reluctance Machine

- **Key Challenges**
  - Constant power operation
  - Torque density

- **Results**
  - 65kW Series
  - 85kW Parallel

Simulated Two-Mode Power-Speed Characteristics

Winding Switching Configuration

Synchronous Reluctance Machine Lamination Stack

Team: Tim Burress, Jason Pries, Randy Wiles, Lixin Tang
Non-Rare Earth Electric Motors

• Challenges
  – Power Factor
  – Reliability

• Energy product?
  – Coercivity is important for automotive applications
  – Ways to work around low remnant flux density
  – Would trade \( Br \) and \( BH_{\text{max}} \) for \( Hci \)
High Energy Product AlNiCo

- Redesign of ferrite motor using hypothetical AlNiCo material (simulation)

- Peak Torque: 200N-m
- Peak Power: 148kW
- Torque Density\(^3\): 25.6N-m/L
- Power Density\(^3\): 19.0kW/L
- Specific Torque\(^3\): 7.32N-m/kg
- Specific Power\(^3\): 4.95kW/kg
- Characteristic Current: 200Arms
- Peak Demagnetizing Field\(^4\): 2300Oe

\(^3\)Based on Active Length + End Turn + Cooling Jacket volume
\(^4\)During short circuit operation, averaged over cross section
Recycled Hard Drive Magnet Motors

- Can we repurpose magnets designed for other applications?
  - NdFeB
  - Unique shape and magnetization pattern for motor applications

Contact: Tim McIntyre
Recycled Hard Disk Drive Magnet Motors: Radial Flux

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Recycled Hard Disk Drive Magnet Motors: Axial Flux v1
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Recycled Hard Disk Drive Magnet Motors: Axial Flux v2

Contact: Tim McIntyre
Recycled Hard Disk Drive Magnet Motors: Axial Flux v2

- **Dual Rotor Axial Gap Motor**
  - Balanced axial forces
  - Reduced torque ripple by rotor angular displacement
  - Difficult construction

- **Dual Stator Axial Gap Motor**
  - Balanced axial force
  - Reduced torque ripple by stator angular displacement
  - Easier construction

Contact: Tim McIntyre
Recycled Hard Disk Drive Magnet Motors: Axial Flux v2

Contact: Tim McIntyre, Photo Credit: Randy Wiles
Recycled Hard Disk Drive Magnet Motors: Axial Flux v2

Contact: Tim McIntyre, Photo Credit: Randy Wiles
Printed Magnet Motors

- Motor manufactures prefer simple magnet shapes due to cost
  - Tooling
  - Grinding/Finishing

- Potential untapped optimization benefits using unconstrained magnet geometry
Printed Magnet Motors

- Replace sintered ferrite with printed NdFeB
- 3D printed small mounting plates for back-to-back testing
New Materials

• Printed Laminations
  – Stators
  – Inductors
  – Induction Machine Rotors

• Magnetic Characterization
  – Ring Test
  – B-H Curve
  – Core Losses
Next Generation Motors

• **Displace Existing Materials?**
  – Materials, manufacturing drive topological decisions
  – Well optimized designs push materials to their limits

• **Displace Existing *Designs***
  – New materials
  – New designs
Questions and Discussion?