Electric Motor Thermal Management

Keystone Project 2

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DOE Vehicle Technologies Program
2019 Annual Merit Review and Peer Evaluation Meeting

Project ID: ELT214

Overview

Timeline

- Project start date: FY 2019
- Project end date: FY 2021
- Percent complete: 15%

Budget

- Total project funding
  - DOE share: $250K (FY 2019 Planned)
- Funding for FY 2019: $250K

Barriers

- Cost, Power Density, Life

Partners

- Motor Industry
  - Suppliers, end users, and researchers
- Oak Ridge National Laboratory (ORNL)
  - Motor development, modeling, and material research
- Ames Laboratory
  - Motor material research
- Sandia National Laboratory
  - Motor and materials Research
- National Renewable Energy Laboratory (NREL)
  - Lead for thermal and reliability research

Relevance

- This is a new project that is part of the new Electric Drive Technologies Consortium and focuses on NREL's role under Keystone 2

Keystone 1

- Power Electronics

Keystone 2

- Electric Motors

Keystone 3

- Traction Drive System

Relevance

- Research enabling compact, reliable, and efficient electric machines
  - Motor 10x power density increase (2025 versus 2015 targets) [1]
  - Motor 2x increase in lifetime [1]
  - Motor 53% cost reduction (2025 versus 2015 targets) [1]

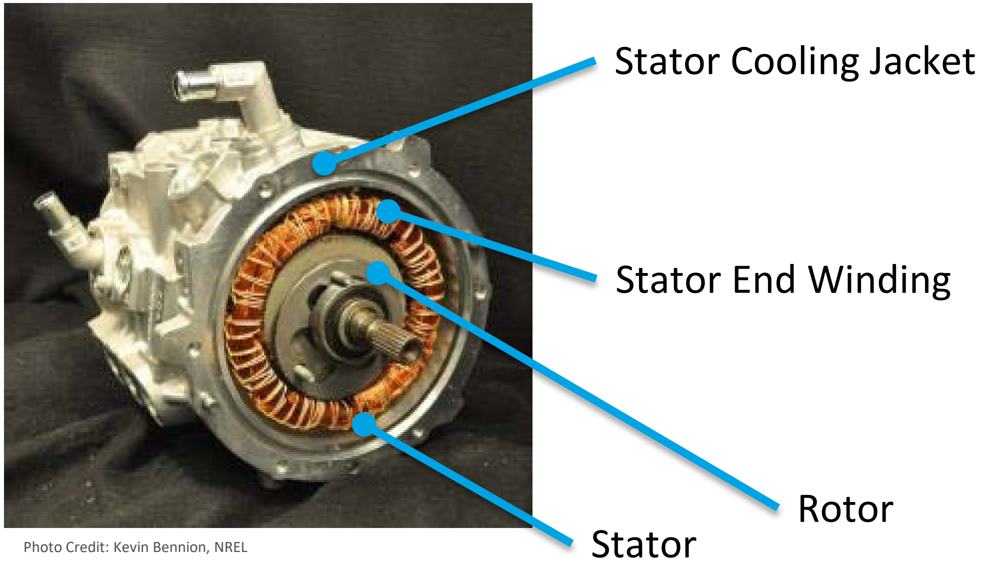
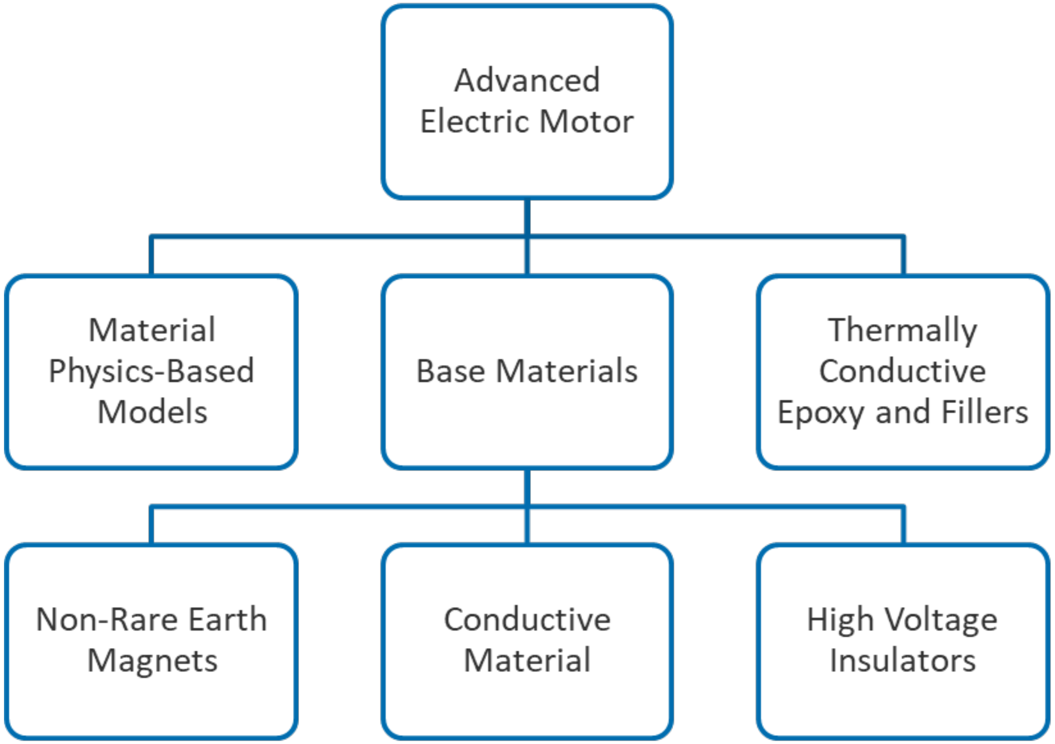


Photo Credit: Kevin Bennion, NREL

[1] U.S. DRIVE Electrical and Electronics Technical Team Roadmap, 2017.

Relevance



Electric Drive Motor R&D Areas [1]

- Material conductivity thermally drives the amount of material necessary to create the required magnetic field to create mechanical power [1]
- Material performance characterization techniques are not well known or identified in the literature [1]
- It is important to reduce the thermal resistance of the motor packaging stack-up to help increase the power density [1]

[1] U.S. DRIVE Electrical and Electronics Technical Team Roadmap, 2017.

Relevance

- Increased accuracy of key parameters can enable fewer design iterations and reduce time and cost

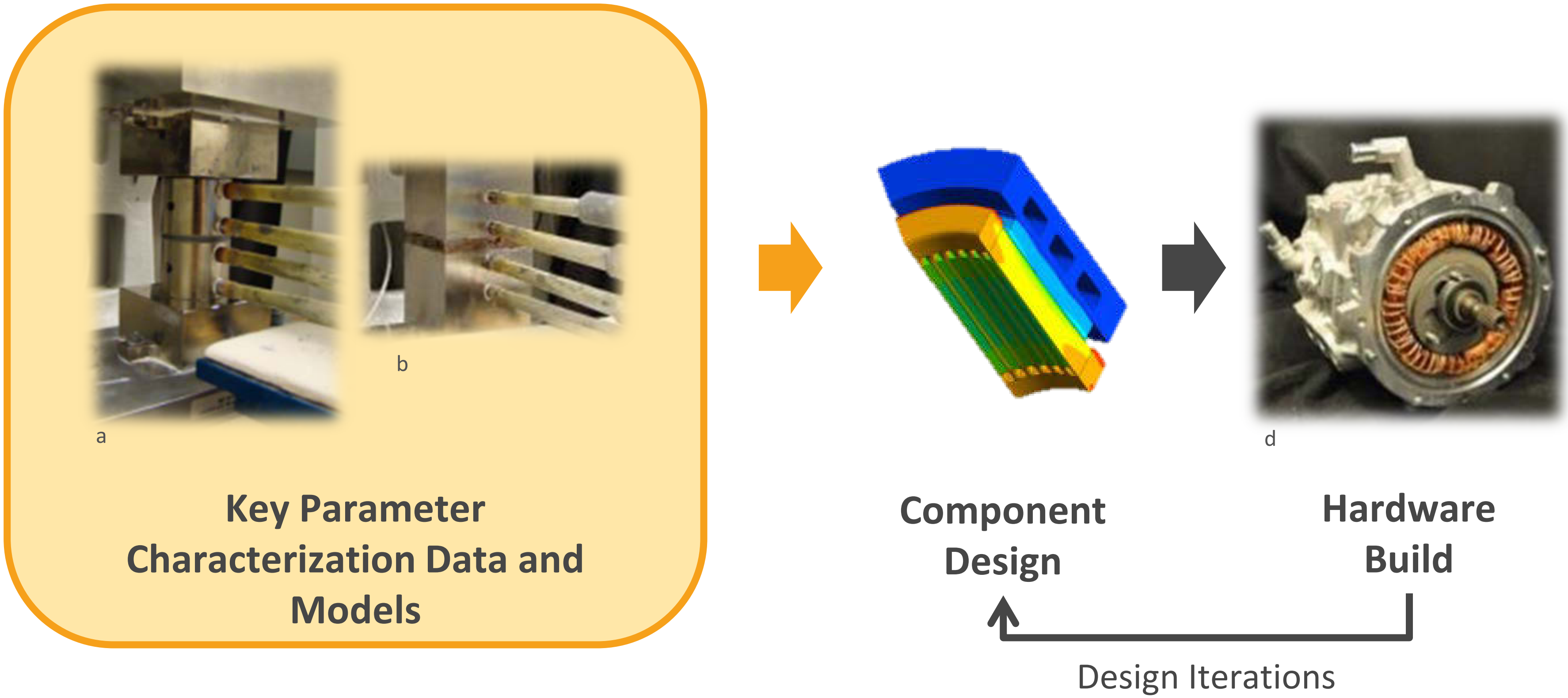


Photo Credits:
a,b: Emily Cousineau, NREL
d: Kevin Bennion, NREL

Resources

- Sample of Existing Equipment and Resources
  - Thermal Interface Material Stand
  - Xenon Flash
  - Differential Scanning Calorimeter
  - Vertical Thermal Shock Chamber
  - Thermal Cycle Chambers
  - Vibration System
  - Hot Press
  - Dual Column Tabletop Universal System
    - Instron 5966 dual column testing system
    - An environmental chamber has a temperature range from -100°C to 350°C

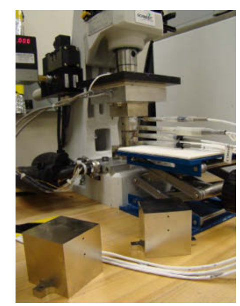


Photo Credits:
Emily Cousineau, NREL and Doug DeVoto, NREL

Milestones

Date	Description
December 2018 (Complete)	Milestone • With project partners, define evaluation criteria for motor material research including sample configurations and operating temperatures
March 2019 (Complete)	Milestone • Complete instrument setup for evaluating low thermal conductivity materials at temperatures up to 200°C.
June 2019 (In Progress)	Go/No-Go • Experimentally quantify measurement uncertainties and thermal resistance ranges for each metering block material.
September 2019 (In Progress)	Milestone • Prepare report on research results.

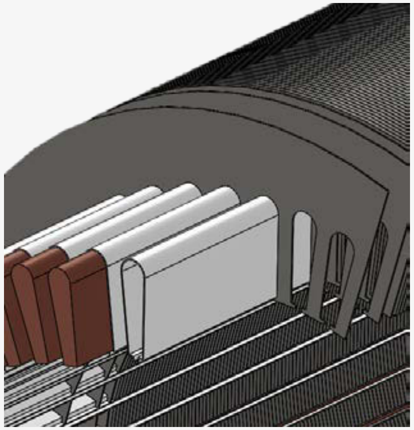
Overall Approach

- Research emphasis on motor materials and impacts of thermal interfaces

Material Mechanical and Thermal Properties

Interface Thermal Characterization and Reliability

a



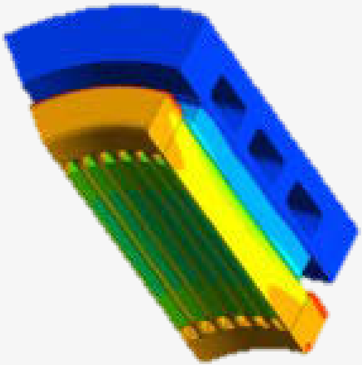
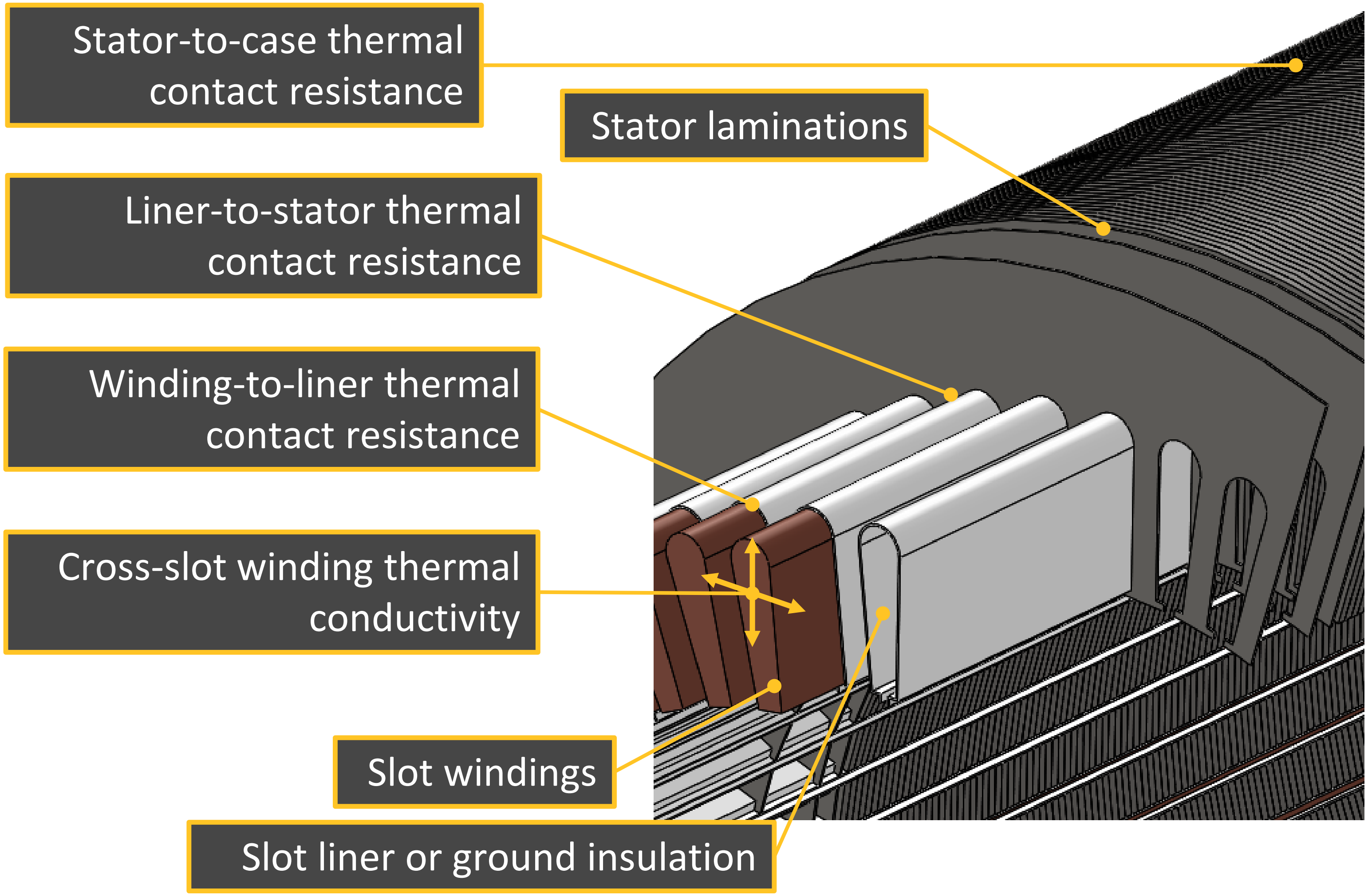


Photo Credits:
a: Doug DeVoto, NREL

Approach: Material Thermal Characterization



Technical Accomplishments and Progress

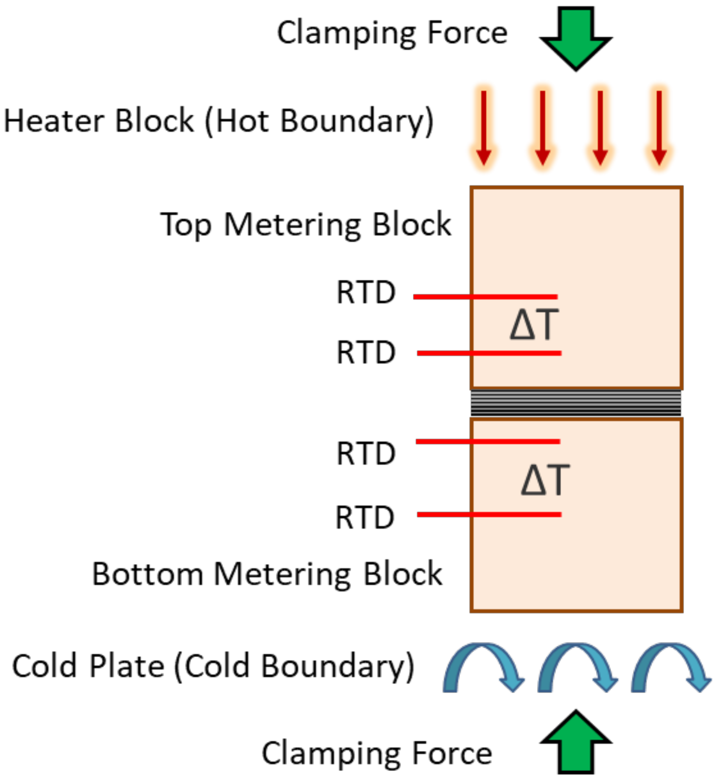
Designed and built experimental setup to:

- Improve measurements of low-thermal-conductivity (high-resistance) materials
- Enable material and interface thermal resistance characterization up to 200°C

Photo Credit: Emily Cousineau, NREL

Technical Accomplishments and Progress

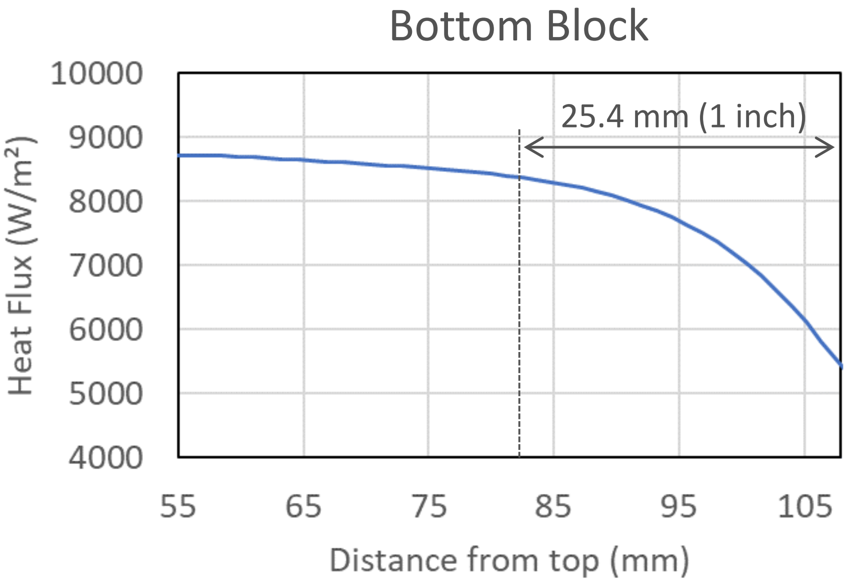
- Challenge
  - High systematic error on high thermal resistance (R_{th})samples
  - Caused by RTD temperature measurement uncertainty (±0.030°C)
- Heat flux measurement relies on the temperature difference (ΔT) between RTDs.
  - High R_{th} leads to low heat flux which reduces the ΔT measured by the RTDs
- Modifying the metering block material increases ΔT measured by RTDs which reduces overall systematic error

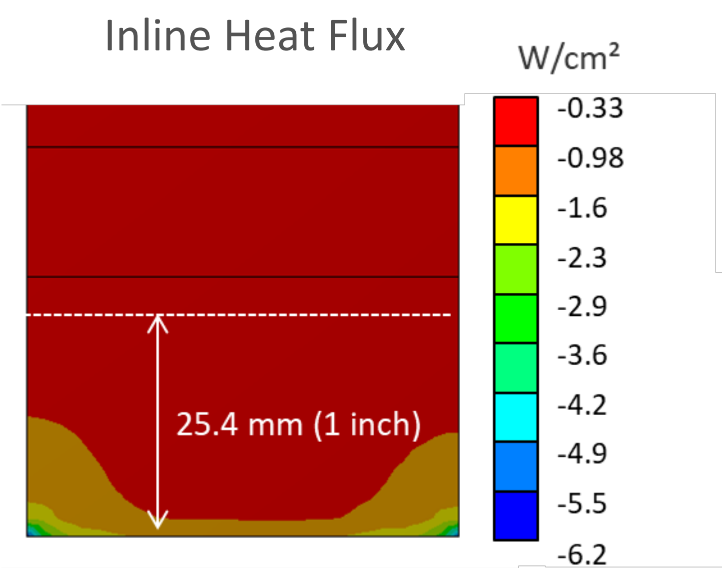


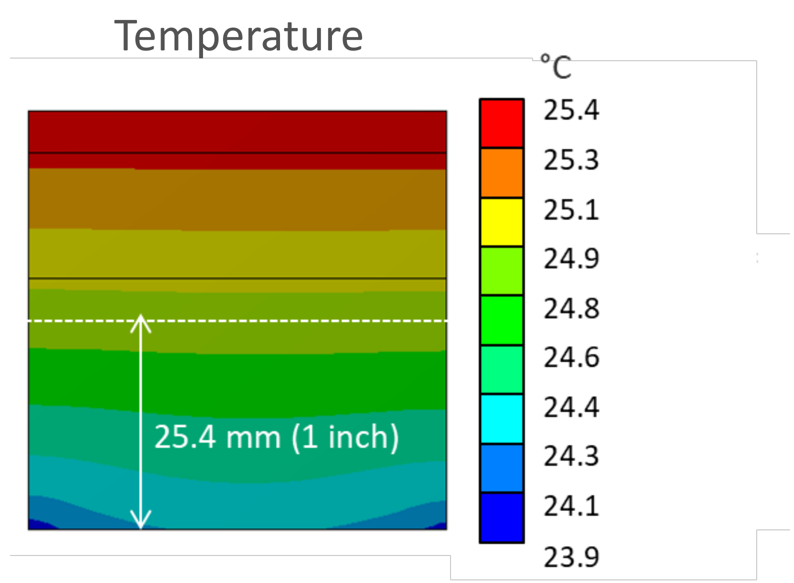
RTD: Resistance Temperature Detector

Technical Accomplishments and Progress

Impact of Temperature Measurement Location

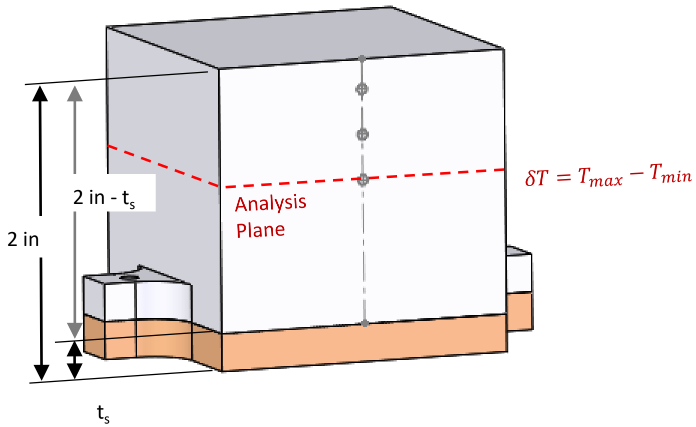


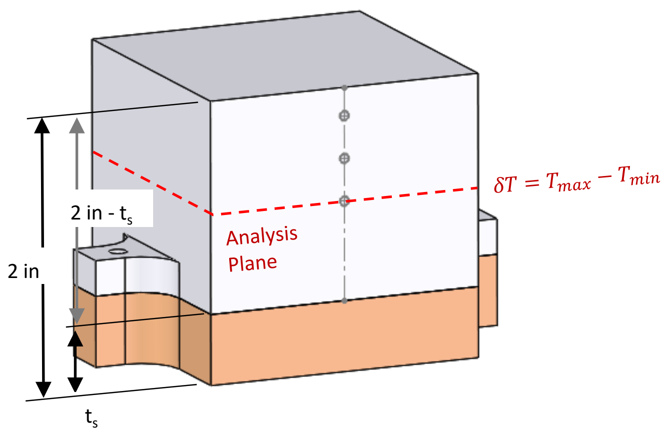


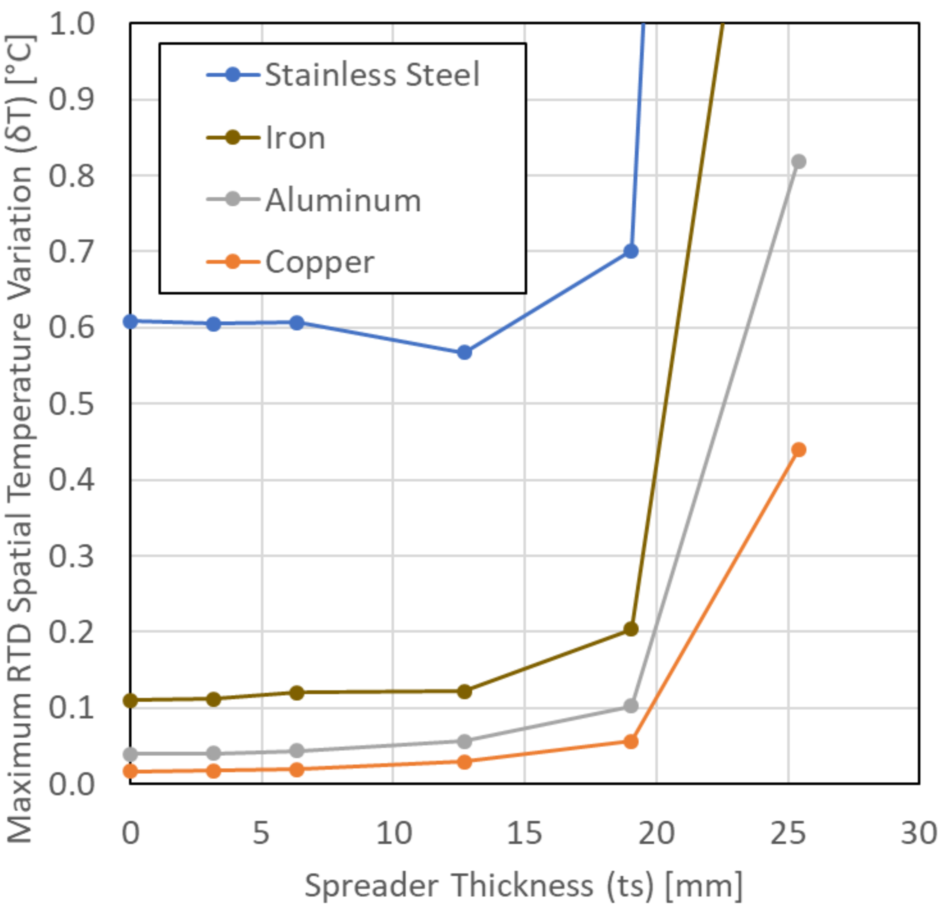


Technical Accomplishments and Progress

Copper Spreader Thickness Impacts







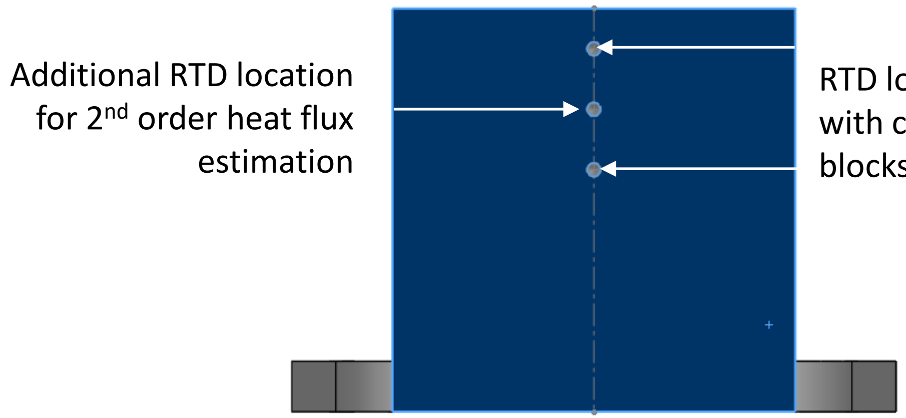
Technical Accomplishments and Progress

- Example analysis with very high thermal resistance sample
  - Lower thermal conductivity metering blocks increase ΔT, resulting in more accurate estimation of heat flux
  - Lower thermal conductivity metering blocks result in greater uncertainty in the in-place temperature with the RTD measurement
  - Even for stainless steel, with predicted in-plane variation 22 times greater than copper, there is significant overall improvement in systematic uncertainty

Metering block type	Metering block thermal conductivity	Sample R_{th} (actual)	Systematic Error including RTD uncertainty and in-plane temperature variation
	[W/m-K]	[mm²-K/W]	[%]
Copper	391	17780	18.4%
Aluminum	154	17780	9.60%
Iron	58	17780	3.30%
Stainless Steel	14	17780	1.20%

Technical Accomplishments and Progress

- Design analysis summary
  - Spreader block does not benefit design
  - Largest temperature field distortion caused by the mounting tabs
  - Lower thermal conductivity metering blocks improve measurement accuracy for low-conductivity materials



Technical Accomplishments and Progress

- Built measurement metering blocks for square and round cross sections

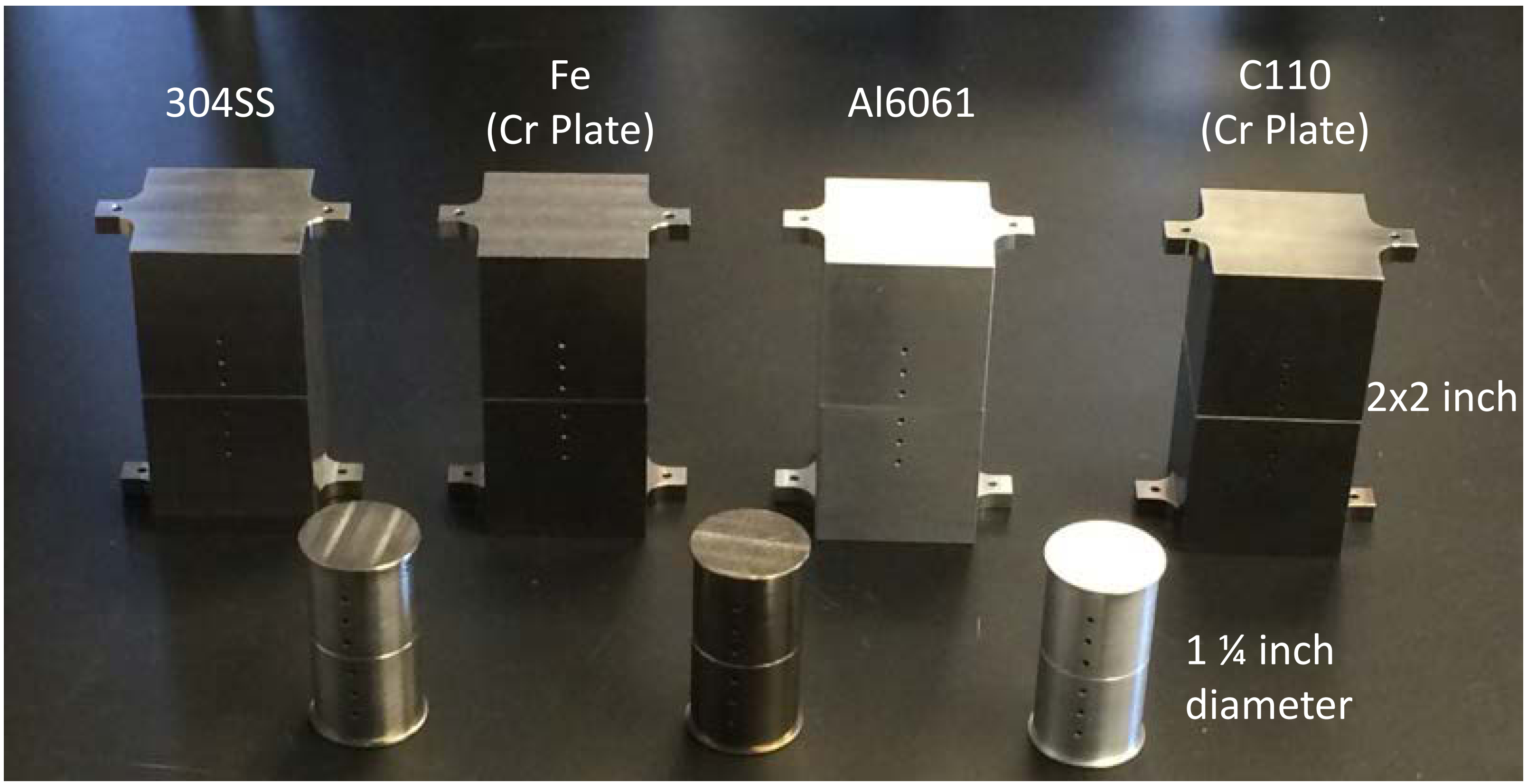


Photo Credit: Emily Cousineau, NREL

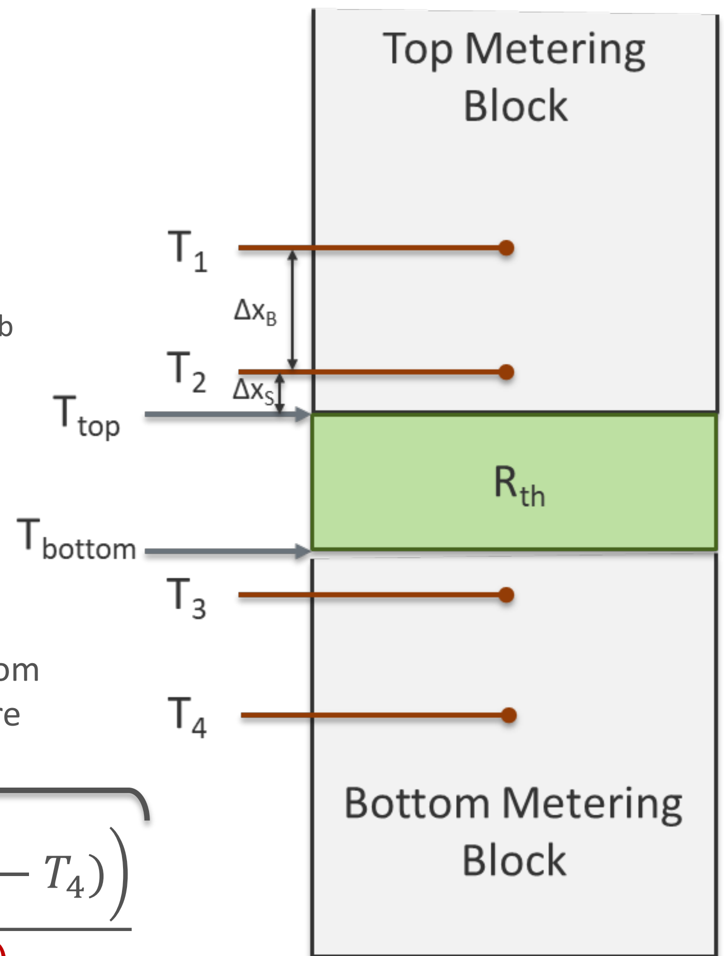
Technical Accomplishments and Progress

- Designed for evaluating materials up to 200°C
- Accurate control for pressure and displacement
- Improves accuracy over range of materials including high-resistance materials applicable to motor winding and insulation materials

Photo Credit: Emily Cousineau, NREL

Technical Accomplishments and Progress

- Developing robust calibration procedure for calibrating different metering block materials
  - R_{th} is the total thermal resistance between T_{top} and T_{bottom}
  - Below is the model in terms of directly measured quantities, with one exception: k_{mb}
    - This parameter is critical to accurate measurement
    - Calibration procedure determines k_{mb} utilizing a reference R_{th}



$$\underbrace{R_{th} = 2 \cdot \Delta x_B \frac{\overbrace{\left(T_2 - \frac{\Delta x_S}{\Delta x_B}(T_1 - T_2)\right)}^{\text{Sample top Temperature}} - \overbrace{\left(T_3 + \frac{\Delta x_S}{\Delta x_B}(T_3 - T_4)\right)}^{\text{Sample bottom Temperature}}}{k_{mb} \cdot (T_1 - T_2) + k_{mb} \cdot (T_3 - T_4)}}_{\text{Heat Flow}}$$

Responses to Previous Year Reviewers' Comments

- This is a new project with no reviewer comments

Collaboration and Coordination

- Other Government Laboratories
  - ORNL
    - Collaboration on motor designs and material thermo-mechanical properties
    - NREL support for computational fluid dynamics for fluid flow and heat transfer analysis
  - Ames
    - NREL supporting material thermo-mechanical property measurements
  - Sandia
    - NREL supporting material thermo-mechanical property measurements
- Industry
  - Motor industry suppliers, end users, and researchers
  - NREL providing
    - Experimental data, modeling results, analysis methods
  - Industry providing
    - Information on materials, boundary conditions for experimental and analytical work, and application information

Remaining Challenges and Barriers

- Research enabling compact, reliable, low-cost, and efficient electric machines
  - Motor 10x power density increase (2025 versus 2015 targets) [1]
  - Motor 2x increase in lifetime [1]
  - Motor 53% cost reduction (2025 versus 2015 targets) [1]

Material and Interface Thermal Characterization

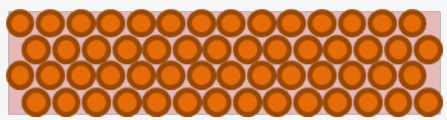
- Material thermal conductivity
- Methods to quantify thermal interfaces
- Data for interface thermal resistance
- Reliability measurements to support increased lifetime targets

[1] U.S. DRIVE Electrical and Electronics Technical Team Roadmap, 2017.

Proposed Future Research

- FY 2019

Winding



Wire size, Type, Insulation, Impregnation Material

Slot Liner/Ground Insulation

Materials for Wide-Bandgap (WBG) Inverters

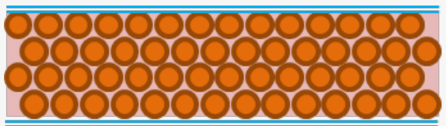
Slot Liner/Ground Insulation to Lamination Interface

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

Proposed Future Research

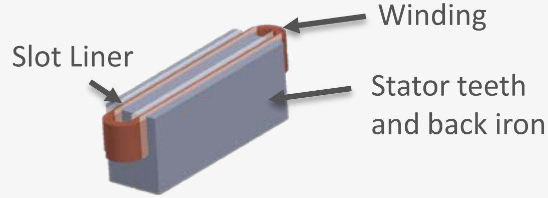
- Beyond FY 2019

Slot Winding Bonded to Slot Liner



Slot Liner to Winding Interface

Motorette



Slot Liner to Stator Interface, System Validation

Photo Credit: Doug DeVoto, NREL

Thermal Measurements and Reliability

Temperature Cycles   Vibration Cycles   Voltage Cycles

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

Summary

Relevance

- Supports research enabling compact, reliable, low-cost, and efficient electric machines aligned with Roadmap research areas

Approach/Strategy

- Engage in collaborations with motor design experts and component suppliers within industry
- Collaborate with ORNL, Ames and Sandia to provide motor thermal analysis support, reliability evaluation, and material measurements on related motor research at National Laboratories
- Develop and document thermal and mechanical characterization methods of material and interface properties

Technical Accomplishments

- Developed experimental hardware for low-thermal-conductivity materials capable of characterization up to 200°C.

Collaborations

- Motor industry representatives: manufacturers, suppliers, researchers, and end users (light-duty and medium/heavy-duty applications)
- Oak Ridge National Laboratory
- Ames Laboratory
- Sandia National Laboratory

Acknowledgments

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Thank You

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