Integrated Traction Drive Thermal Management

Keystone Project 3

Project ID: ELT217

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OVERVIEW

Timeline

- Project start date: 10/01/2018
- End date: 09/30/2024
- Percent complete: 80%

Budget

- Total project funding: $1,250,000
- U.S. Department of Energy (DOE) share: $1,250.000
- Funding for FY 2022: $250,000
- Funding for FY 2023: $250,000

Barriers addressed

- Cost, power density, reliability and lifetime

RELEVANCE

Objectives

- Support activities of Electric Drive Technologies (EDT) consortium members' research teams in thermal management component design and thermal modeling of their integrated traction drives.

Project Impact

- Identify pathways enabling high-performance, compact, and reliable integrated electric drives.
- Help achieve DOE 2025 target of 33-kW/L system power density for an electric traction drive.

SUMMARY

Approach/Strategy

- Research state-of-the-art thermal management solutions for integrated electric traction drives.
- Use combination of various cooling strategies for most efficient heat removal from integrated traction drive components: WEG flow in internal channels, automatic transmission fluid (ATF) jet impingement on stator winding end-turns, usage of high-thermal-conductivity (low-thermal-resistance) component assemblies, and direct cooling with dielectric fluids.

Technical Accomplishments

- Modeling and design of thermal management system for University of Wisconsin team is complete. NREL continues to support evaluation of the team's manufactured integrated traction drive.
- Modeling, design, manufacturing, and testing of thermal management system components for ORNL integrated traction drive are underway.

APPROACH

Support design of a thermal management solution appropriate to each collaborating team's selected integrated drive concept

- Design, model, and test thermal management system components to reduce thermal resistance of the motor and power electronics packaging stack-up to keep component temperatures within selected material operating limits.
- Employ thermal modeling tools: finite element analysis (FEA) and computational fluid dynamics (CFD) to inform efficient design of power electronics integration solutions.
- Preferably use a single fluid loop approach to enable the combined cooling system for electric motor and inverter cooling and increase overall system power density.

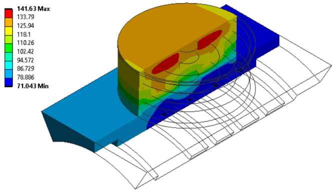
Material selection for the cooling system components is very important

- Transparent for electromagnetic field to minimize interference with electric motor operation.
- Electrically isolating to avoid short-circuiting electrically sensitive parts and ensure reliable phase separation of windings.
- Thermally conductive to improve heat removal from heat-generating components of the integrated drive.

ACCOMPLISHMENTS AND PROGRESS

University of Wisconsin integrated traction drive

- NREL is continuing to provide technical support to the University of Wisconsin's integrated traction drive team.
- Provided thermal data, material information, and technical advice to support integrated thermal management system design for cooling electric motor and power electronics.
- The integrated drive has been manufactured and is being tested and evaluated by University of Wisconsin team.



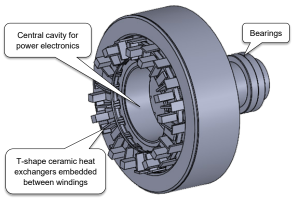
Thermal analysis of an inductor mounted on the motor cooling jacket. Image by University of Wisconsin

Manufactured inductor for current source inverter for University of Wisconsin's integrated traction drive. Image by University of Wisconsin

ACCOMPLISHMENTS AND PROGRESS (CONTINUED)

ORNL integrated traction drive

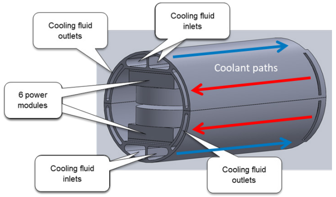
- Outer rotor drive design was changed to cantilever suspension with smaller sized bearings capable of 20,000 rpm without oil lubrication.
- Working on thermal management system reconfiguration: parallel paths of coolant supply to inverter housing and distribution manifold feeding T-shape phase separator heat exchangers.



Design concept of cantilever suspension of the rotor in ORNL's integrated traction drive. Image by ORNL

Extruded aluminum cylindrical heat exchanger for inverter housing

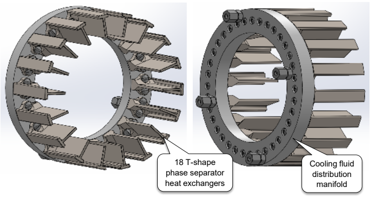
- Designed a cylindrical housing for power electronics integration into central cavity of the electric motor.
- The cylindrical housing incorporates internal channels for coolant flow for removing heat from the power electronics and stator's internal surface.



Design concept of a cylindrical housing for a six-phase inverter with cooling fluid channels in its walls. CAD by Bidzina Kekelia, NREL

3D-printed heat exchangers and distribution manifold for stator cooling

- Designed a coolant distribution manifold and T-shape phase separator heat exchangers to be embedded between stator windings.
- Coolant distribution manifold to be 3D printed from polymer.
- T-shape phase separator heat exchangers to be 3D printed from ceramics (Al_2O_3).



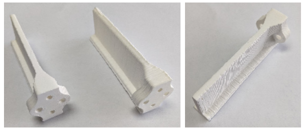
Design concept of a coolant distribution manifold with attached T-shape heat exchangers to be embedded between stator windings. CAD by Bidzina Kekelia, NREL

FUTURE WORK

Experimental evaluation of ceramic heat exchanger performance

- Evaluation of stator winding phase separator T-shape heat exchanger 3D printed with ceramic (Al_2O_3) material is planned. Its heat extraction capability and circulating coolant pressure drop will be experimentally measured.
- Thermal load will be provided by resistance heaters attached to the heat exchanger surfaces. Thermal load values will correspond to losses estimated by ORNL's motor design team (1/18th of total motor thermal load—there are 18 T-shape heat exchangers).
- Water-ethylene glycol (WEG) will be circulated in the heat exchanger, and heat removal performance will be evaluated:
  - Coolant inlet temperature will be set at 65°C.
  - Heat exchanger outside wall surface temperature not to exceed 150°C (or lower, as required by winding protective layer material temperature limits).
  - Overall coolant flow rates will be varied from 5 L/min to 15 L/min (1/18th of overall flow rates per heat exchanger).

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



First samples of 3D-printed T-shape ceramic heat exchangers. Image by Bidzina Kekelia, NREL

CHALLENGES AND BARRIERS

- Material selection for key thermal management system components and their interconnection is critical for the design of an effective and reliable cooling system.
- Coefficient of thermal expansion (CTE) mismatch between components of cooling system poses a problem when thermally cycling electric drive components.
- Leak-free sealing of cooling system components inside electric machine cavity is challenging.
- Design of a single thermal management system for power electronics and electric motor would require cooling fluids with appropriate physical, thermal, and dielectric properties.

COLLABORATION AND COORDINATION

- Oak Ridge National Laboratory (ORNL)
- University of Wisconsin - Madison
- Ames Laboratory

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