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Thermal Performance Benchmarking

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June 7, 2016 EDT070

OVERVIEW

Timeline

- Project start date: FY15
- Project end date: FY18

Budget

- Funding for FY16: $200K

RELEVANCE

- Work with industry to reduce the weight, volume, and cost of vehicle traction-drive systems by providing information to influence future product designs
- Guide future electric drive technologies (EDT) research and development (R&D) efforts

OBJECTIVES

Overall objective: Understand the current state of the art (SOA) in thermal management systems and develop technologies to improve the SOA

- Identify thermal advantages and disadvantages of systems
- Establish baseline metrics for the thermal management systems
- Increase the publicly-available information related to automotive traction-drive thermal management systems
- Determine the operating temperatures for the EDT components in real-world operation

FY16 objective: Benchmark the thermal management systems for the 2014 Honda Accord power electronics system and 2015 BMW i3 power electronics and electric motor

SUMMARY

Relevance

- This work will increase the understanding of the current SOA in motor and power electronics thermal management systems and identify methods to improve the SOA.

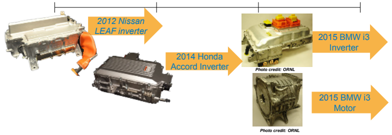
Approach

- Collaborate with industry and ORNL to identify the appropriate components to benchmark
- Characterize the thermal performance of the power electronics and motor thermal management systems and share the results with industry
- Identify areas of improvement to advance the SOA and establish baseline metrics for the thermal management systems

Accomplishments

- Completed characterizing the performance of the 2012 Nissan Leaf power electronics thermal management systems.
- Completed characterizing the performance of the 2014 Honda Accord power electronics thermal management systems.

APPROACH



Collaborate with industry and ORNL to identify the component system to benchmark

Experimentally measure the performance of the thermal management systems

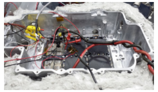
Create thermal models of the thermal management systems

Analyze and report data

- Identify thermal bottlenecks in the systems and provide solutions to improve the SOA
- Establish baseline metrics for the thermal management systems
- Share results with industry and research institutions
- Support other EDT projects (power electronics thermal management R&D, electric motor thermal management R&D, benchmarking EV and HEV technologies [ORNL])

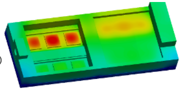
Measure power electronics

- Junction-to-liquid thermal resistance
- Component thermal properties
- Heat exchanger thermal resistance and pressure drop
- Heat exchanger volume and weight



Use computational fluid dynamics (CFD) and finite element analysis (FEA)

- Validate the models using experimental results
- Compute thermal resistances that cannot be experimentally measured (e.g., cooling jacket-to-liquid)
- Create transient thermal models (FEA or lumped parameter models)

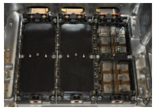


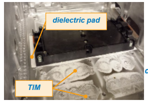
Collaborate with ORNL to quantify the heat distribution within the components

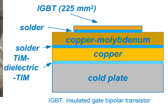
- Quantify heat distributions within power electronics and motor at different operating conditions
- Quantify the temperatures experienced by the components under drive cycles

ACCOMPLISHMENTS

Characterized the performance of the Nissan LEAF inverter thermal management system

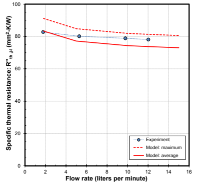


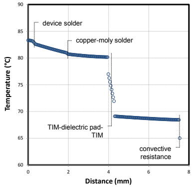




- Three power modules are mounted to a cast-aluminum cold plate.
- Thermal interface materials (TIMs) are applied between the modules and cold plate.
- Modules use dielectric pads for insulation instead of metalized-ceramic substrates.

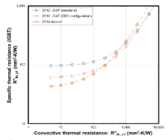
Measured thermal resistances and temperature profile



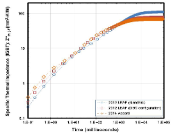


- The average and maximum thermal resistances were obtained from the FEA models and show 6% variation compared with the experimental results.
- Minimal effect of flow rate on the thermal resistance indicates that the passive stack provides the dominant resistance in the system.
- Passive stack accounts for about 80% of the total thermal resistance and the dielectric pad interface is the largest resistance.
- LEAF design may have cost and reliability advantages.

Performance comparison

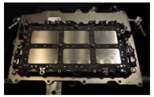


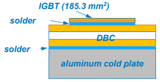
- At about 100 mm^2-K/W, the Accord module's thermal resistance is about 38% and 12% lower than the LEAF and direct bonded copper (DBC)-modified LEAF designs, respectively.
- The Accord module's thermal resistance decreases at a faster rate with decreasing convective thermal resistance.



- The LEAF module shows lower transient thermal impedance at lower time scales.
- The use of copper molybdenum plate directly under the IGBT spreads the heat and provides thermal capacitance to improve the transient thermal performance.
- The Accord module has better steady-state thermal performance.

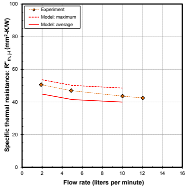
Characterized the performance of Honda Accord inverter thermal management system

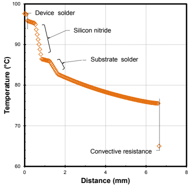




- The IGBTs and diodes are soldered onto a DBC and silicon nitride ceramic layer is used in the DBC.
- Thermal grease is not utilized as a TIM.
- Cold plate with intricate finned structure with fin channel widths ~ 0.95 mm
- The fins appear to be machined onto the aluminum plate.

Modeled the power electronics thermal resistance and temperature





- At 10lpm, the junction-to-coolant thermal resistance is about 44% lower than that of the 2012 LEAF.
- The lack of thermal grease reduces the passive-stack thermal resistance to ~ 50mm^2-K/W.
- The silicon nitride layer contributes the largest thermal resistance in the passive stack-up structure.
- The thermal performance of the Accord is more sensitive to the convective heat transfer.

FUTURE WORK/CHALLENGES & BARRIERS

FY16

- Characterize and identify methods to improve the performance of the 2014 Honda Accord power electronics system
- Characterize and identify methods to improve thermal performance of the 2015 BMW i3 power electronics and electric motor thermal management systems

FY17

- Characterize the thermal performance of the 2016 Toyota Prius power electronics and motor thermal management systems

Challenges:

- Experiments may not exactly replicate the actual automotive environments or operating conditions.
- More information is needed to identify the power electronics systems that provide the best thermal performance at its cost.

COLLABORATION

Oak Ridge National Laboratory (ORNL)

ACKNOWLEDGMENTS

Susan Rogers and Steven Boyd,
U.S. Department of Energy

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VTO Annual Merit Review
Washington, D.C.
June 7, 2016
NREL/PO-5400-66049