



Design and Evaluation of a sCO₂ Pin-Fin Cold Plate for Motor Cooling

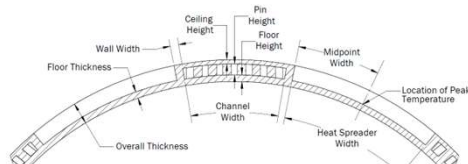
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Objective:

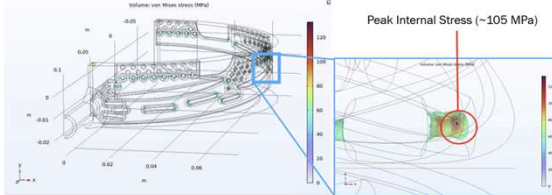
This study presents the design, optimization, and evaluation of an additively manufactured multichannel pin-fin cold plate tailored for cooling of a motor with near-critical sCO₂. The design was developed through parametric thermal and hydraulic simulations using experimentally informed sCO₂ pin-fin correlations to address design challenges including flow maldistribution, thermal non-uniformity, and structural integrity under the required pressure for operation. The thermal performance of the cold plate was then compared to existing correlations for pin arrays and supercritical fluids. The final design balances thermal performance, manufacturability, and temperature uniformity, offering insights for future near-critical sCO₂ thermal management.

Cold Plate Design Process:

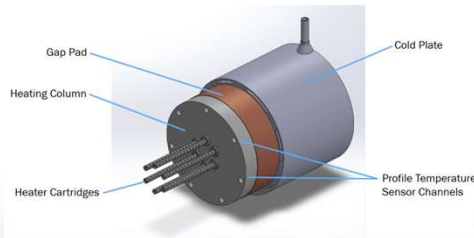
- The design of the cold plate utilized alternating pin array channels and heat spreaders used for distributing heat flux.
- A finite element analysis (FEA) paired with a fluid flow simulation to determine the header structures which act as both flow distribution features and load bearing structures.



Cross-section of cold plate with geometric parameters used for optimization.



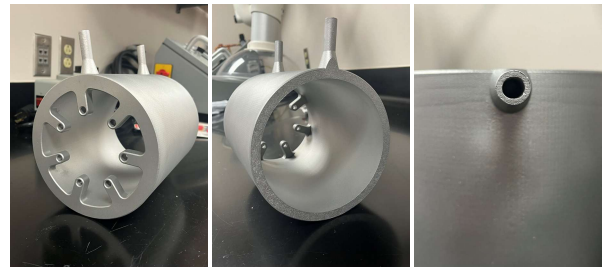
Example FEA model used for diagnosing failure points and testing structural integrity.



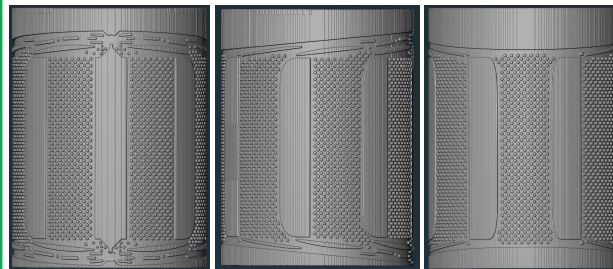
Cold Plate and Heating Column Assembly.

Manufacturing and Assembly:

- Design was printed using AlSi10Mg laser powder bed fusion using an external vendor and assembled in the Penn State HEATER Lab.
- The build quality was analyzed using X-Ray CT scanning through the Penn State Center of Quantitative Imaging.
- The inner surface of the cold plate has a 1.5° taper to interface with the heating column also made of machined aluminum.
- Hydraulic pressure testing was then performed by pressurizing the cold plate at increasing pressures for 10 minutes up to 10 MPa.



As-built build quality of additively manufactured cold plate.

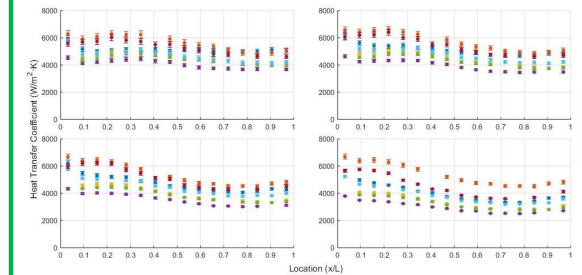


X-Ray CT scan results at 30 μm resolution of internal alternating pin array channels and header design.

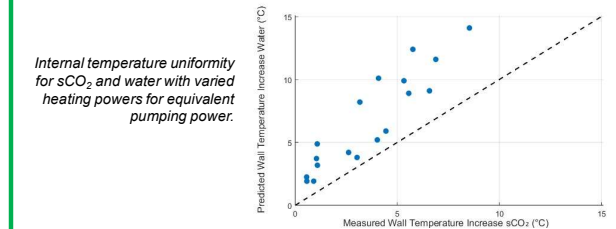


Assembly process of post-machined cold plate and heater column with heating elements and instrumentation.

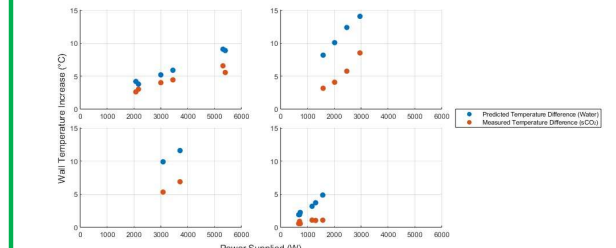
Testing Results:



Local heat transfer coefficients along length of cold plate.



Internal temperature uniformity for sCO₂ and water with varied heating powers for equivalent pumping power.



Internal Temperature Increase along length of channel separated by mass flow rate 300 kg/hr (top-left), 150 kg/hr (top-right), 100 kg/hr (bottom-left) and two-phase 150 kg/hr (bottom-right).

Conclusions:

This study demonstrated the design process and thermal performance of a cold plate intended for use with near-critical sCO₂. Local heat transfer performance showed consistent performance along the length of channel, mitigating localized thermal transport behavior, while simultaneously leveraging the benefits of near-isothermal behavior compared to a standard single-phase coolant.

Next Steps:

- Explore effects of higher heat flux on thermal transport for pin array and non-uniform geometries.
- Geometry optimization based on inducing localized heat transfer performance using non-uniform and repeating geometries.

Acknowledgements:

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