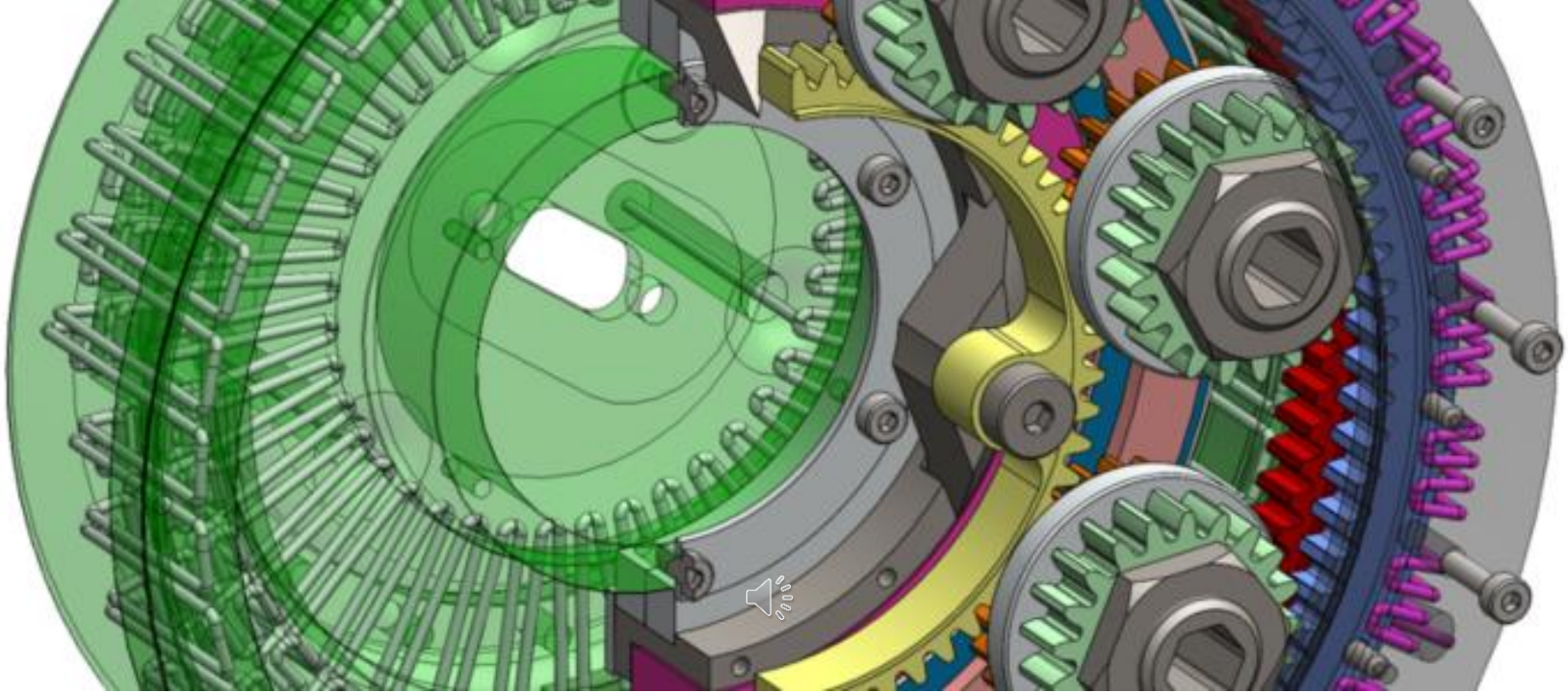

Virtual Research Presentation Conference

3D Printed Actuators with Innovative Integrated Thermal Management

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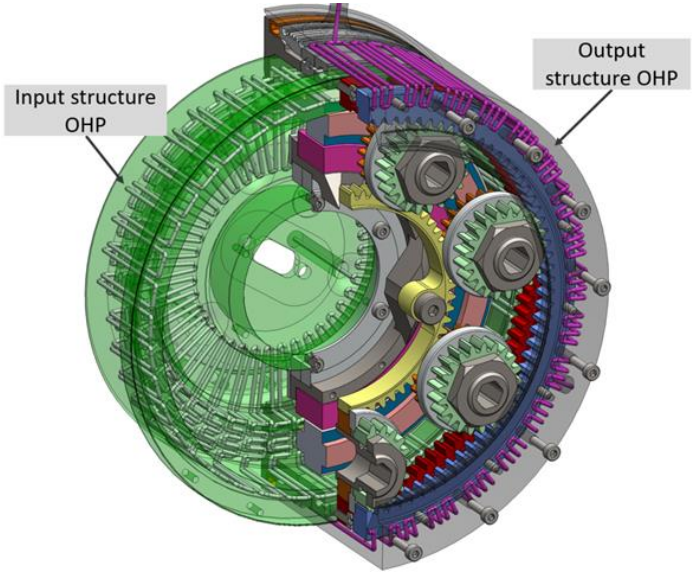
Program: Topic
Assigned Presentation #RPC-173

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Abstract

An electric actuator incorporating novel features for thermal management is designed and analyzed. Reducing intra-actuator thermal resistance is not only beneficial for cold missions (helping to pre-heat the gearbox) but can also enable high power applications in benign environments. The proposed design increases the thermal conductance between the motor windings and the motor casing by at least two orders of magnitude over the state of practice actuator designs. The design leverages Additive Manufacturing (AM) to integrate a complex 3 dimensional Oscillating Heat Pipe (OHP) directly within the actuator structure. An analysis of a proposed revised design incorporating OHPs into the input structure indicated 100 times improvement in thermal conductance over base material. Thermal enhancement leads to 10 times improvement in actuator power density.



Actuator 2ϕ design

Problem Description

a) **Context (Why this problem and why now):** Thermal management of actuators has been a problem for every flight mission. For example, MSL's robotic arm actuators are typically not operated until noon, needing to take full advantage of ambient Martian conditions to passively pre-heat the lubrication within an actuator's gearbox. A new and more direct engineered thermal path from within the electric motor (which generates heat and requires cooling) to the gearbox (where lubrication must be pre-heated) is needed to create a significant improvement to both the thermal and temporal efficiency of JPL's flight actuators specifically to ***time limited and power limited missions such as Europa Lander.***

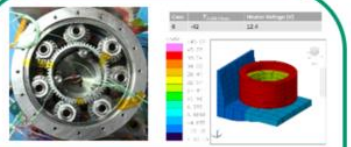
b) **SOA (Comparison or advancement over current state-of-the-art):** ***Comparison with Current JPL flight actuator (MSL WATER):*** Inefficient thermal management (Both overheat concern at motor, and heater power required to warm up gearbox), ***Comparison with Industry:*** Only very large actuators with cooling channels (JPL requires a miniature version to accommodate on the robotic arm / heat rejection and transporting heat to the gearbox)

c) **Relevance to NASA and JPL (Impact on current or future programs):** Short duration Ocean worlds cannot rely upon environmental heating for their actuators. By harvesting waste heat from the electric motor to thermally condition the gearbox, missions such as Europa Lander can perform more science in less time with less power. For this technology the following category of missions are enabled: 1. Time limited missions requiring rapid sampling (Europa Lander) 2. Power limited missions (Icy moons) 3. Missions require high power density (Helicopters, swimmers, and melt probes)

Methodology

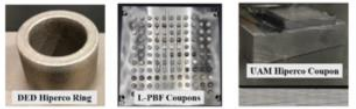
a) Formulation, theory or experiment description

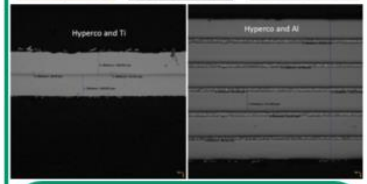
FY19



- Actuator baseline Design/hardware fabrication
- TVAC test and thermal model correlation

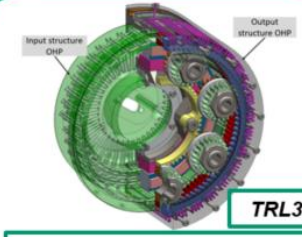
TRL2





*Extensive testing and prototyping concluded that full laminate stack printing is not possible with today's technology.

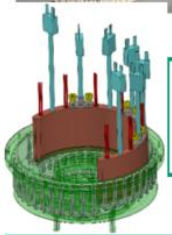
FY20



TRL3

Actuator 2ϕ design

TRL3



Actuator 2ϕ parts fabricated (PBF)

TRL4

Actuator parts performance validation in lab environmnet

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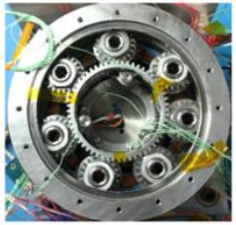

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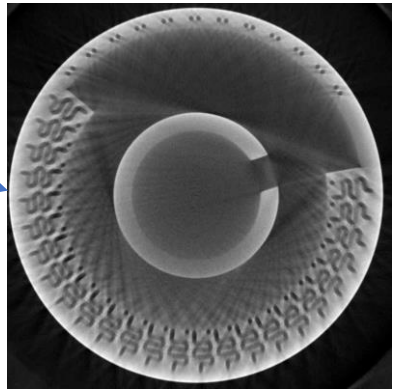
Characterization Testing and Thermal Vacuum Test of Full Actuator Prototype (Electric Motor and Gearbox) And Extended Life Testing of full actuator prototype

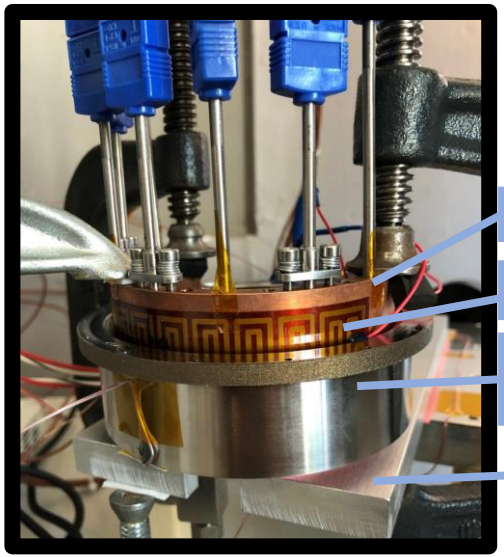
TRL5/6

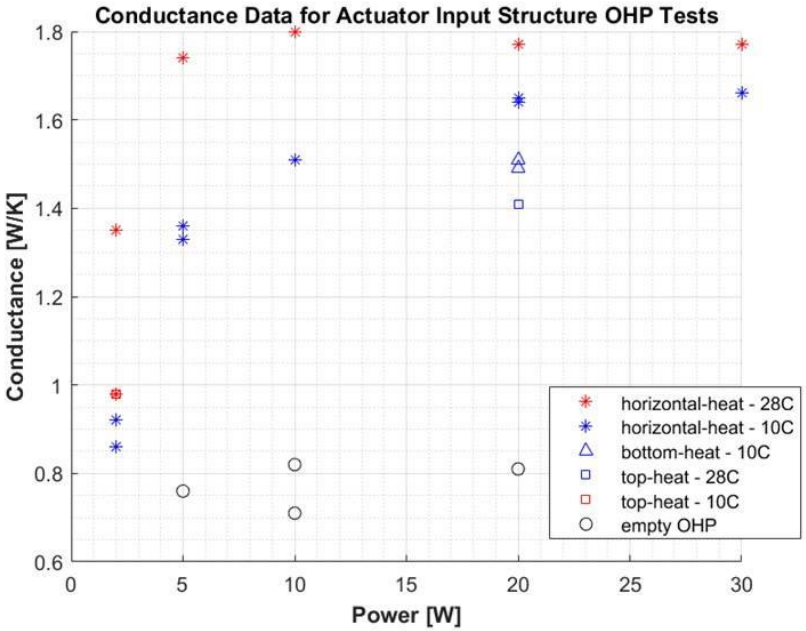
b) Innovation, advancement

- Use additive manufacturing techniques (PBF) to efficiently bridge the heat source (electric motor) to the heat sink (gearbox/housing) with 2ϕ OHP (Oscillating Heat Pipe)
- 100x improvement in thermal conductance over base material (Inconel)
- Thermal enhancement led to 10x improvement in power density



Results





- **Working fluid**: R134a
- **Fill ratio**: 51% @ 18.5°C
- **OHP volume**: 6.09 mL
- **Dead space volume (ports + valve)**: 0.11 mL
- **CAD based OHP volume**: 7.27 mL

Preliminary results show that 3D printed input structure with 2φ OHP improves the thermal conductance by a factor of 2.25. Additional tests with different fill ratios expected to improve the performance.

Publications and References

Publications:

[1] Elham Maghsoudi, Ben Furst, Jay D. Jasper, Takuro Daimaru, and Kimihide Odagiri, “Efficient Thermal Management for Sampling Arm Actuators,” Published in Proceeding of 2020 International Conference on environmental Systems (ICES).

[2] Emma Nelson, Elham Maghsoudi, Jay D. Jasper, and Thomas Peev, “Thermal Characterization of an In-runner Double Row Planetary Actuator,” Submitted to 2020 Aerospace Thermal Control Workshop,Torrance, CA, March 2020.

References:

[1] Wrist and Turret et RSM Actuator Mars Science Laboratory Detail Specification, JPL D-37255 Rev C, MSL 576-1577,August 2008

[2] Nikola Georgiev and Joel Burdick, “Design and Analysis of the Bearingless Planetary Gearbox,” 2017 IEEE/RSJInternational Conference on Intelligent Robots and Systems (IROS), September 24-28, 2017, Vancouver, BC, Canada.

[3] Takuro Daimaru, Shuhei Yoshida, amd Hiroki Nagai, “Study on thermal cycle in oscillating heat pipes by numerical analysis,” Applied Thermal Engineering,Vol. 113, 2017, pp. 1219-1227.

[4] Takuro Daimaru, Hiroki Nagai, Makiko Ando, Kosuke Tanaka, Atsushi Okamoto, and Hiroyuki Sugita, “Comparison between Numerical Simulation and On-orbit Experiment of Oscillating Heat Pipes,” International Journal of Heat and Mass Transfer, Vol.109, 2017, pp.791-806.