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Design and Hardware Progress on a Magnetically-Geared Actuator for Extremely Cold Lunar Environments

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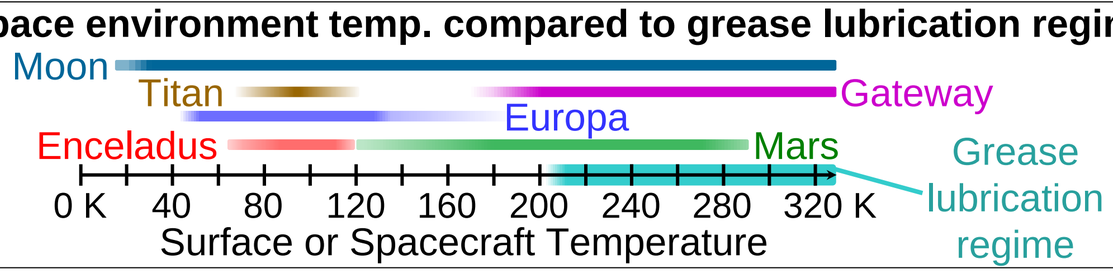
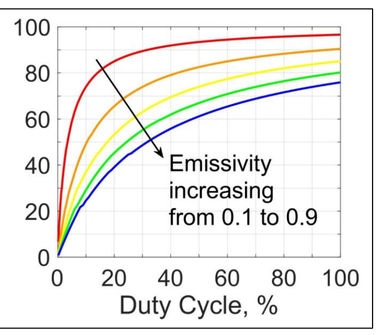
Motivation & MDECE Project Overview

- Rotational actuators almost always require a gearbox but lubricating it is challenging in cold environments

Space environment temp. compared to grease lubrication regime



Theoretical limit on average total efficiency (%) of heated actuator for indefinite operation [1]

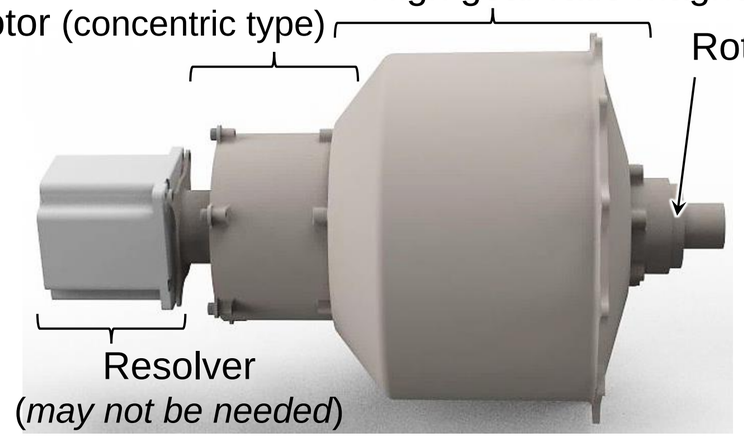


- **R&D & ground test project, Oct 2020 – Sep 2024** [2,3]
- **Goal:** Develop 2 unheated rotational actuators that can operate for a long duration in extreme cold (ambient temp. of -243 ºC (30 K))
- **Approach:** Eliminate gear lubrication
- **Key Performance Parameters:** Min. operating temp. ▪ dust-free life ▪ efficiency (magnetic actuator) ▪ output resolution (piezo actuator)
- **Relevant environment:** Broadly applicable; focusing on lunar PSR
- **Promising applications:**
  - Magnetic actuator: rover mobility ▪ in-situ resource utilization ▪ robotic arm joints ▪ rotors for powered flight
  - Piezoelectric actuator: precision pointing (e.g., laser communication) ▪ low power robotic arm joints

Driving Requirements & Design Overview

Mechanical output	• Continuous	105 Nm at 2 rpm (22 W)
	• Peak	208 Nm at up to 1.5 rpm (≤ 33 W)
Life	• 6,000 output revolutions (min), 50,000 (goal)	
Size / mass	• Mass	4.73 kg (max), < 3.15 kg (goal)
	• Volume	1440 cm^3 (max), < 960 cm^3 (goal)
Thermal environments	• Cold	shadowed PSR, regolith 30 K (goal)
	• Hot	in sun at 85° S, regolith 313 K (goal)

Magnetically-geared motor (concentric type)



Notable characteristics:

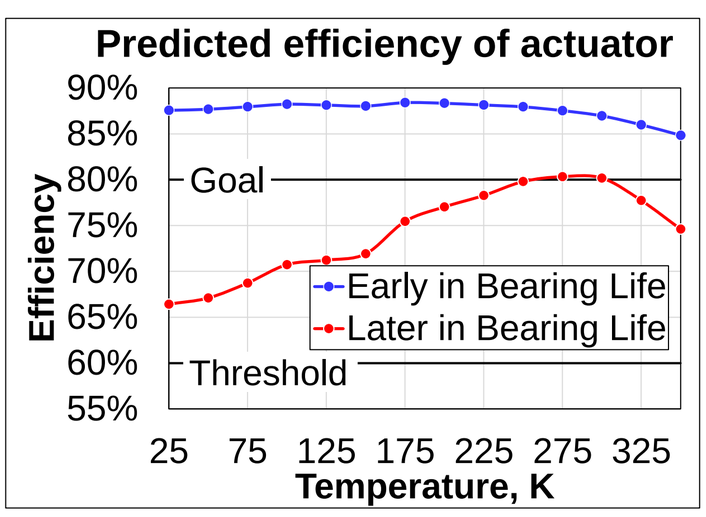
- Gear ratios: 13:1 (motor), 43:1 (cycloidal)
- Air gaps 0.25 mm thick
- 14 ball bearings
- 20 needle bearings

Design Progress

- CDR completed July 2023
- Expect actuator to be operable from 24 K (-249 ºC) to 371 K (98 ºC)
- Predicted life (over 150 K to upper limit)
  - 46,500 output revolutions (bearing lubrication limited)

Specification		Unit	Threshold	Goal	Predicted
Torque output	Continuous	Nm	≥ 105		**105**
	Short duration		≥ 208		**≥ 208**
Speed Output	Continuous	rpm	≥ 2	≥ 2	**2**
	Short duration		> 0	1.5	**1.5**
Mass (w/o, w/ resolver)		kg	≤ 4.73	≤ 3.15	**4.55**, **5.30**
Size aspect ratio		-	0.50 to 1.75		**1.44**
Envelope volume		cm^3	≤ 1,440	≤ 960	**2,317**

Predicted efficiency of actuator

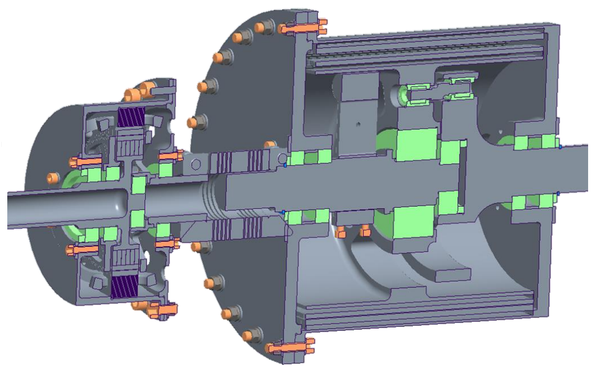


Hardware Progress

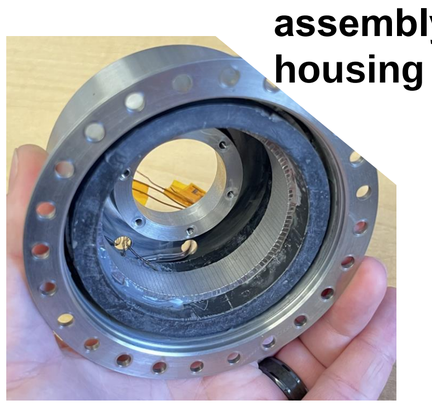
Cycloidal magnetic gear
- Cycloidal magnetic gear functions & exhibits expected gear ratio
- Measured max torque 103% of design req. (94% of prediction)

Magnetically-geared motor
- No coils shorted after cold soak at 77 K

Proof-of-concept actuator



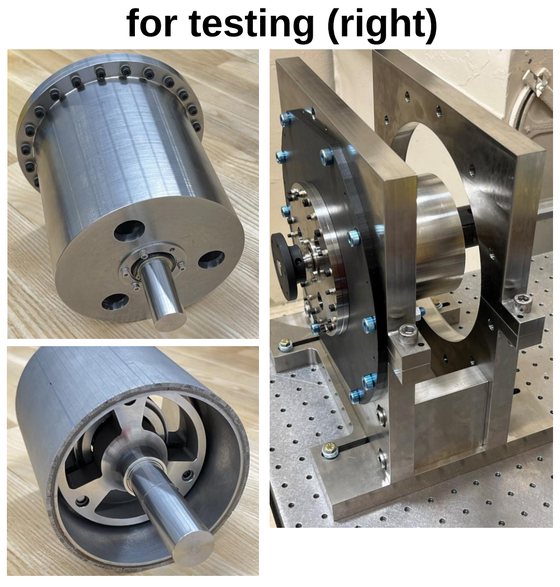
Stator / ring gear assembly in motor's housing



Stator after cold shock & soak at 77 K

Sun gear for the magnetically-geared motor

Assembled cycloidal magnetic gear (left) mounted for testing (right)



Acknowledgements

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References

1. Scheidler, J.J. et al., in Proc. IEEE Aerospace Conference, 2022.
2. Scheidler, J.J. et al., in Proc. IEEE Aerospace Conference, 2023.
3. Scheidler, J.J. et al., in Proc. European Space Mechanisms Symposium, 2023.