Virtual Research Presentation Conference

Direct Observation of Joint Torques in Harmonic Drive Rotary Actuators

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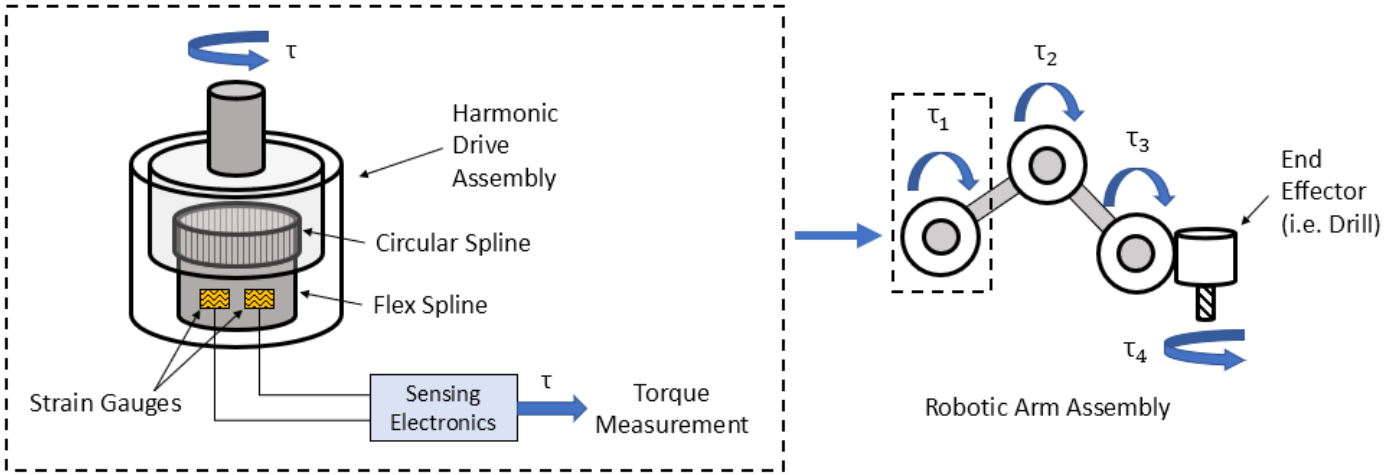
Program: Spontaneous Concept

Assigned Presentation #RPC-257

Tutorial Introduction

Abstract

The overarching objective was to develop a method of directly observing the output torque of a Harmonic Drive actuator. The specific objectives were to (1) explore the feasibility of using strain gauges directly mounted on the Flex Spline for torque measurement, and (2) develop a circuit board capable of resolving a torque signal from a set of strain gauges mounted on the Flex Spline.



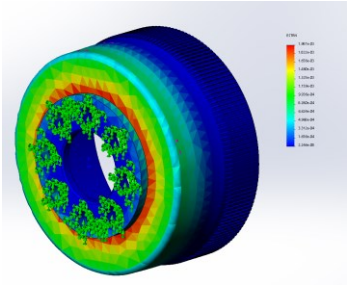
Problem Description

a) Torque feedback enables compliant motion and is needed for dynamic systems which interact with the physical environment. Both planetary and terrestrial robots such as MER, Mars 2020, Robosimian, ATHELTE, Lemur, and EELS rely on Harmonic Drive gearboxes to actuate their respective arms and legs.

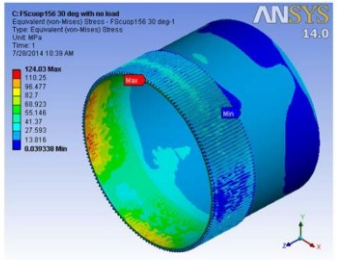
b) To directly observe the output torque of individual joints, modern methods include the use of torque sensors. These are often massive, difficult to integrate, and costly. To overcome these pitfalls, this proposal replaced the torque sensor with a set of strain gauges located at the flange of a Harmonic Flex Spline, thereby taking advantage of existing hardware and reducing mass, simplify packaging, and decreasing cost.

c) Our initial findings show that it is feasible to integrate strain gauges on harmonic cups for output torque measurement. Future JPL Missions such as Exobiology Extant Life Surveyor (EELS) will require joint torque knowledge to traverse down hydrothermal vents on Enceladus and this technology will enable that capability.

Methodology



Kourchians, 2020



(b). von-Mises stress on FG cup inner surface.
Fig 3. Ansys® Simulation Results.

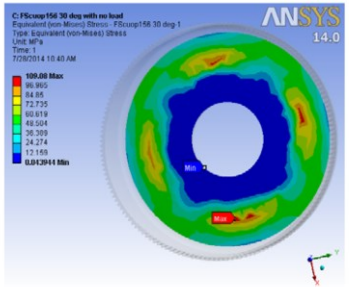


Fig 4. von-Mises stress on bottom flange surface of FG cup.

[B] Sahoo and Maiti, 2016

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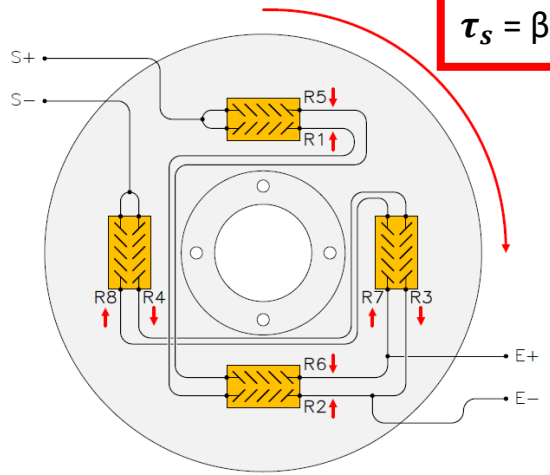
SGT-2D/350M-SY11

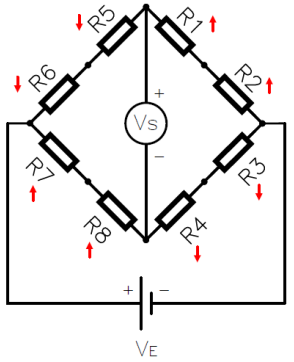
=

$\tau_s = \beta * \varepsilon$



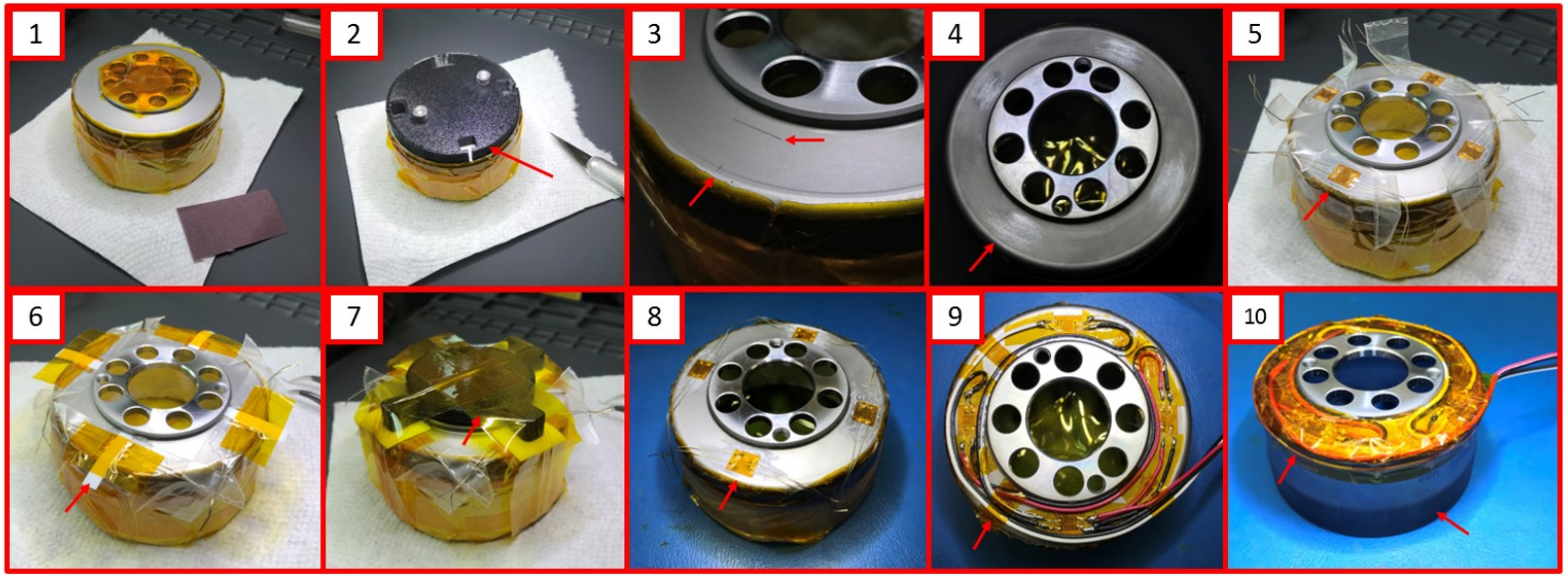
$$\varepsilon = \frac{\left(\frac{V_S}{V_E}\right)_{Strained} - \left(\frac{V_S}{V_E}\right)_{Unstrained}}{GageFactor}$$

β: Torque Sensor Gain (calibrated)



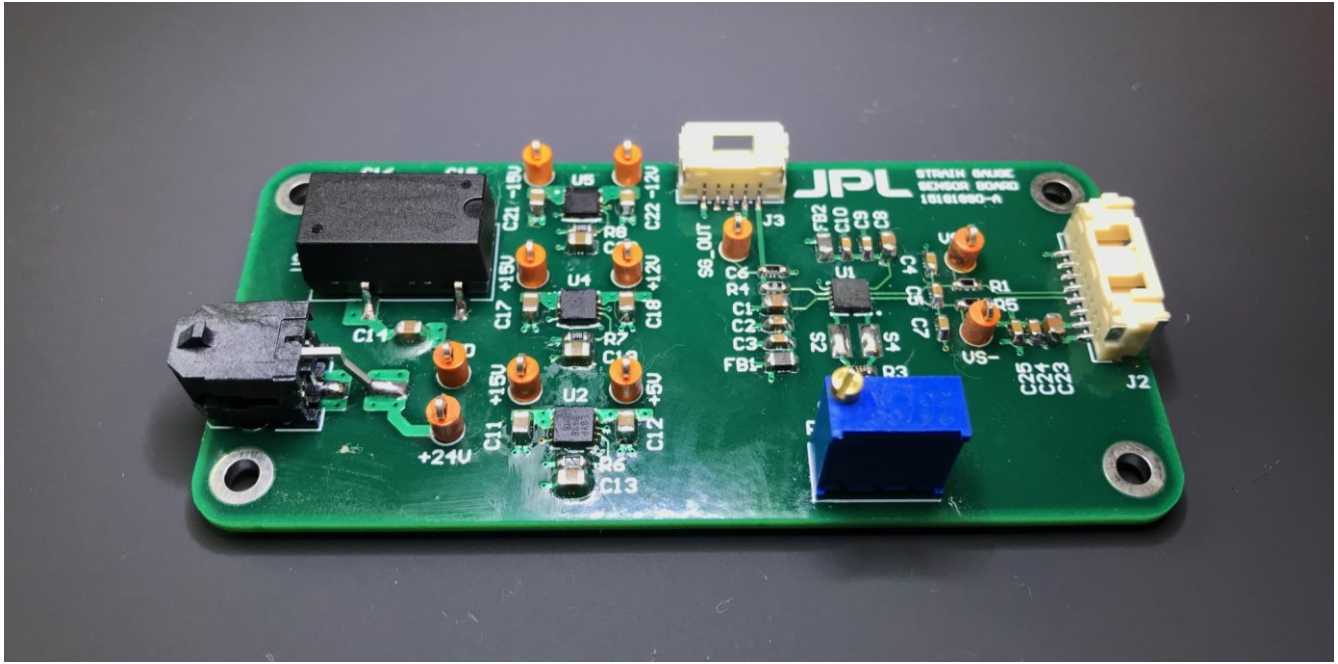
[A] Taghirad, 1999

Methodology

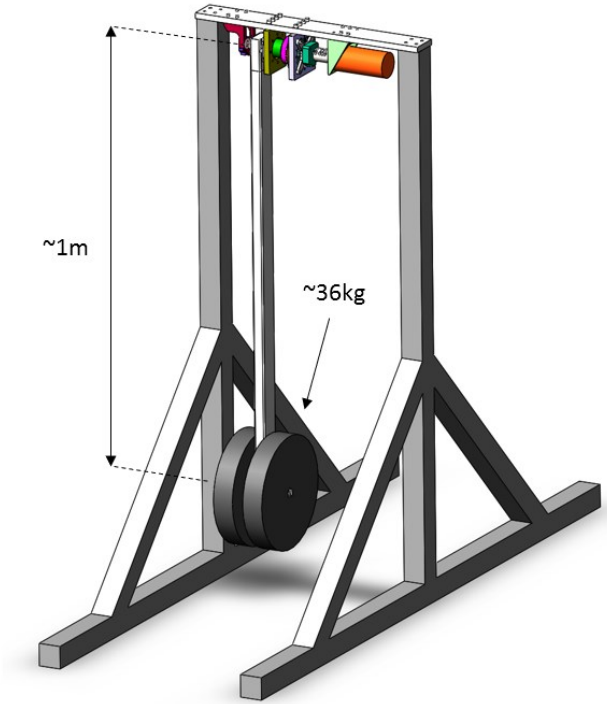


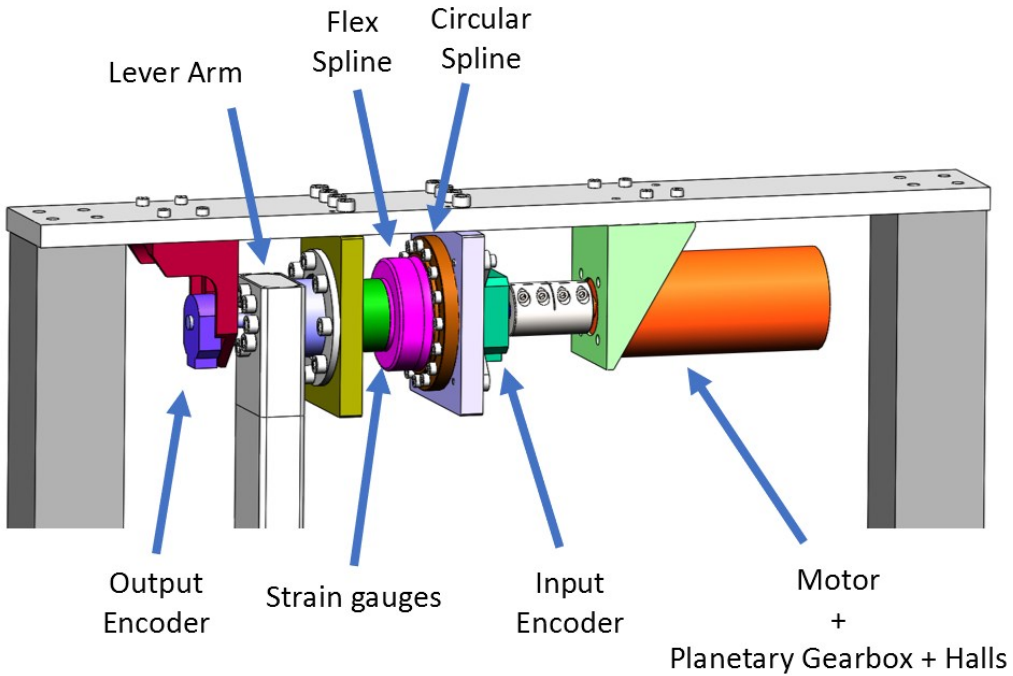
1) Mask sensitive surfaces and clean with iso
2) Mount alignment template and mark with Xacto knife
3) Remove alignment template and clean with iso
4) Sand mount area with 200 grit sandpaper and clean with iso
5) Align strain gauge to marks, apply tape, partially peel back tape, apply M-Bond200 to mount area, gently tape sensor onto mount area and press down hard for 2 minutes
6) Quickly apply Teflon tabs between strain gauge contacts (cover sense grid)
7) Mount preload jig to apply pressure for curing. Cure for 24 hours.
8) Remove preload jig and strain gauge tape carefully
9) Wire strain gauges in a full Wheatstone bridge configuration
10) Apply Kapton tape over strain gauge circuit and remove masking

Methodology

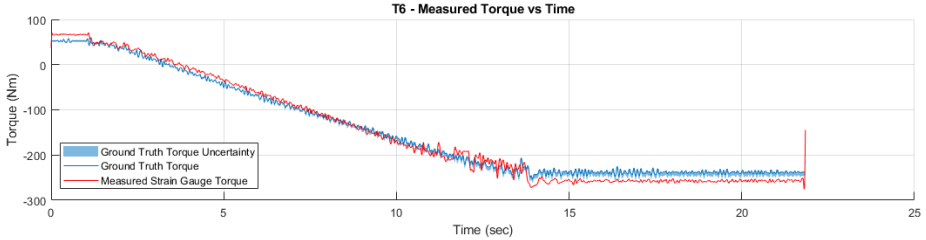


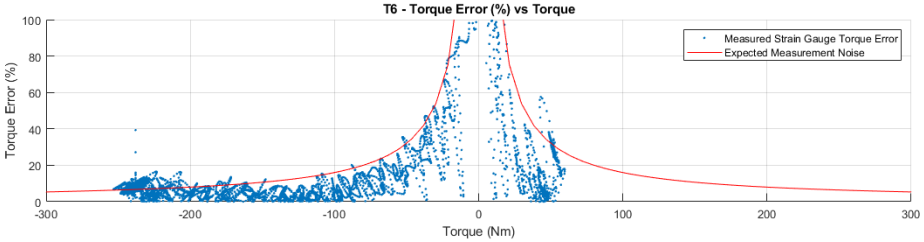
Methodology

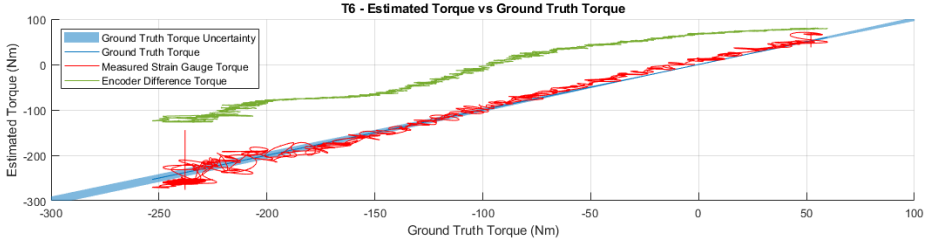


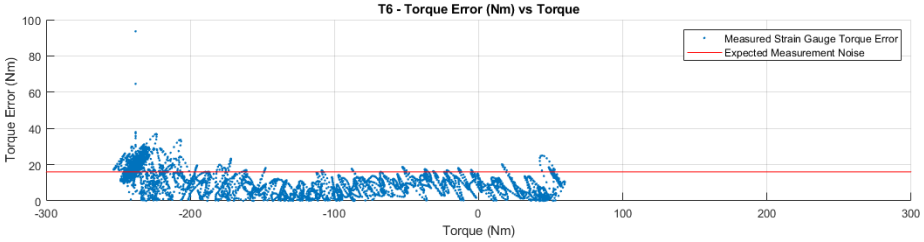


Results

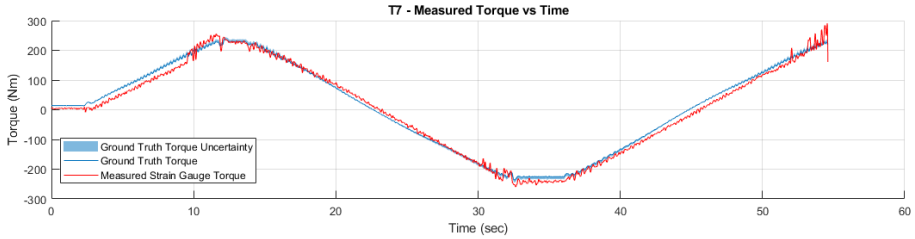

T6 - Measured Torque vs Time
Torque (Nm)
Time (sec)
Ground Truth Torque Uncertainty
Ground Truth Torque
Measured Strain Gauge Torque

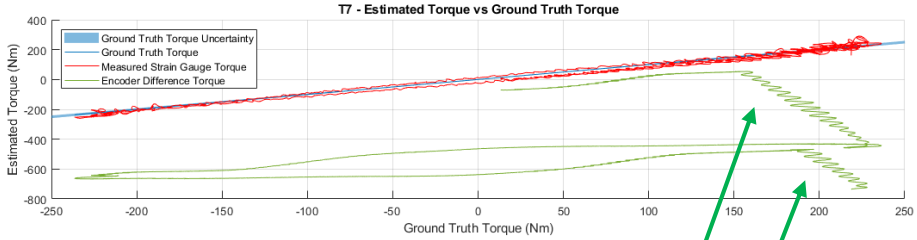

T6 - Torque Error (%) vs Torque
Torque Error (%)
Torque (Nm)
Measured Strain Gauge Torque Error
Expected Measurement Noise

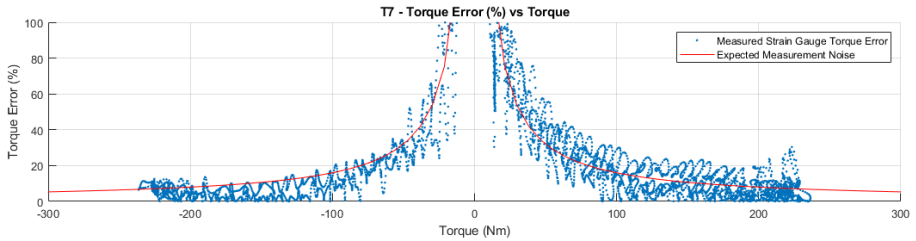

T6 - Estimated Torque vs Ground Truth Torque
Estimated Torque (Nm)
Ground Truth Torque (Nm)
Ground Truth Torque Uncertainty
Ground Truth Torque
Measured Strain Gauge Torque
Encoder Difference Torque

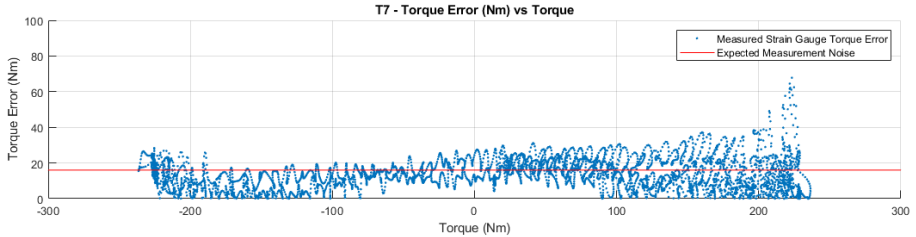

T6 - Torque Error (Nm) vs Torque
Torque Error (Nm)
Torque (Nm)
Measured Strain Gauge Torque Error
Expected Measurement Noise

Results









Observed encoder slip, artifact of low cost encoders

Publications and References

[A] H. D. Taghirad and P. R. Belanger, "Intelligent built-in torque sensor for harmonic drive systems," in IEEE Transactions on Instrumentation and Measurement, vol. 48, no. 6, pp. 1201-1207, Dec. 1999, doi: 10.1109/19.816137.

[B] Vineet Sahoo, and Rathindranath Maiti, “State of Stress in Strain Wave Gear Flexspline Cup on Insertion of Drive Cam -Experiment and Analysis.” Conference: Proceedings of the World Congress on Engineering 2016 At: WCE 2016, June 29 - July 1, 2016, London, U.K Volume: II

[C] Huimin Dong, and Delun Wang, “Elastic deformation characteristic of the flexspline in harmonic drive.” Proceedings of the 2009 ASME/IFToMM International Conference on Reconfigurable Mechanisms and Robots, ReMAR 2009.