High Temperature Mechanisms
A Breakthrough Development

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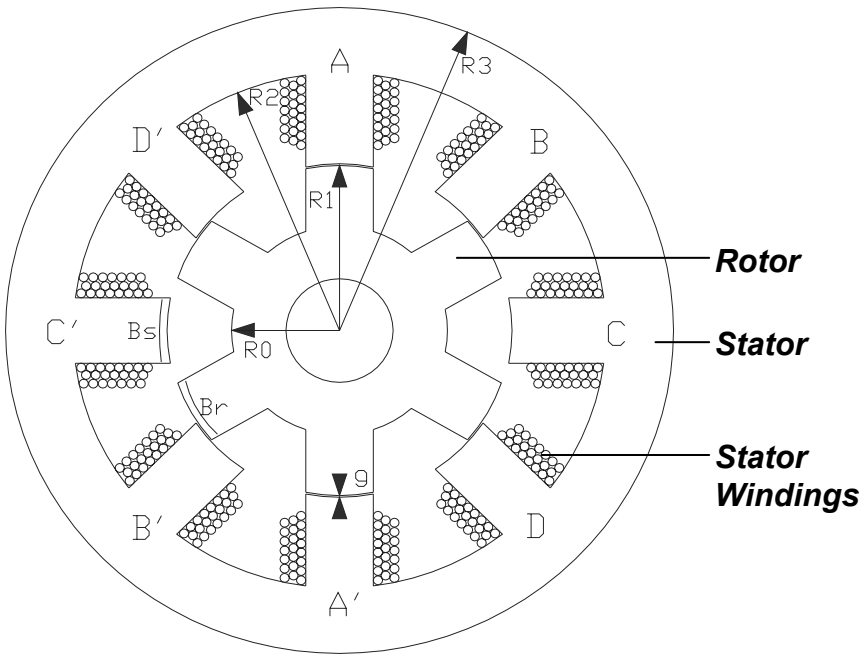
Introduction

- The extreme high temperature /high pressure environments on Venus are unique compare with other NASA Solar System exploration mission, environment condition is 460C, 90 bar, 97% CO2 at the Venus surface, sulphuric acid clouds at 50 km
- No exist off-the-shelf motors or known R&D prototype motors are capable of operating under Venus surface conditions for any appreciable amount of time
- Two types of high temperature motor have been developed by Honeybee Robotics:
  - HT Switched Reluctance Motor
    - Completed Phase I & II study (2.5 years)
    - Final prototype was used to actuate a high temperature drill
  - HT DC Brushless Motor and Resolver
    - Completed 6 month study (Phase I)
    - Next generation BLDC motor along with high temperate sample acquisition scoop and high temperature joint are under development in Phase II study

Switched Reluctance Motor

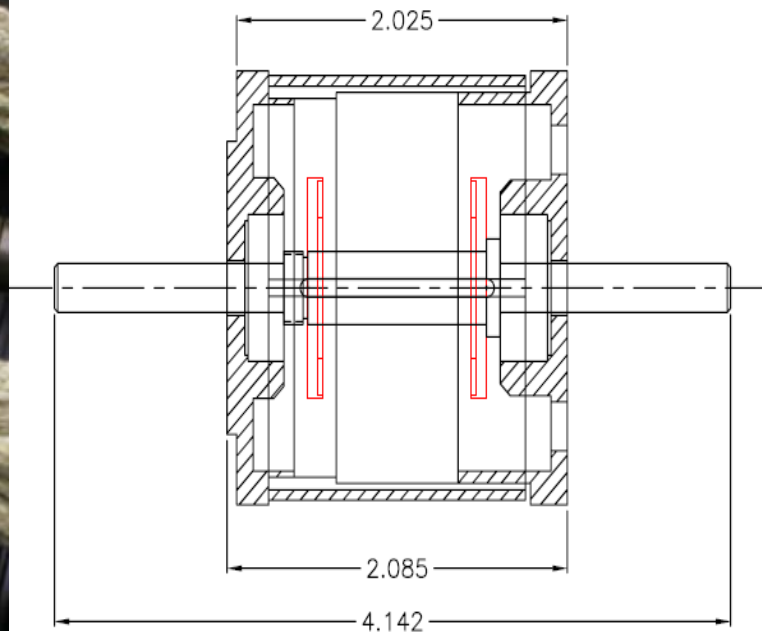
- The switched reluctance motor is a direct current, brushless electric motor.
- It has salient poles on both the rotor and stator, but only the stator carries windings. The rotor has no windings, magnets, or cage winding.
- Both the rotor and the stator are built up from a stack of magnetic-alloy, salient-pole laminations.
- The operating principle of SRMs is based on the tendency of a rotor pole pair to align with the energized stator pole pair.



The four current phases are listed as A, B, C and D, with A-A', etc., being a pole pair.

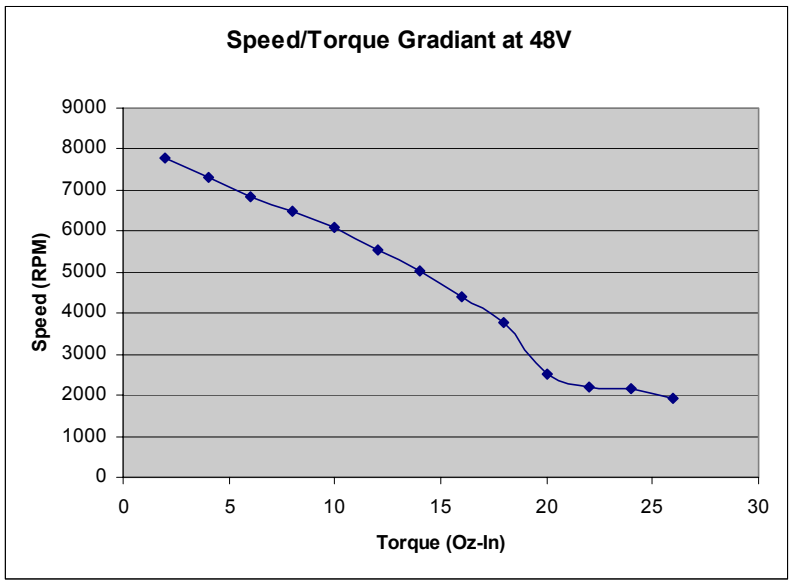
Switched Reluctance Motor

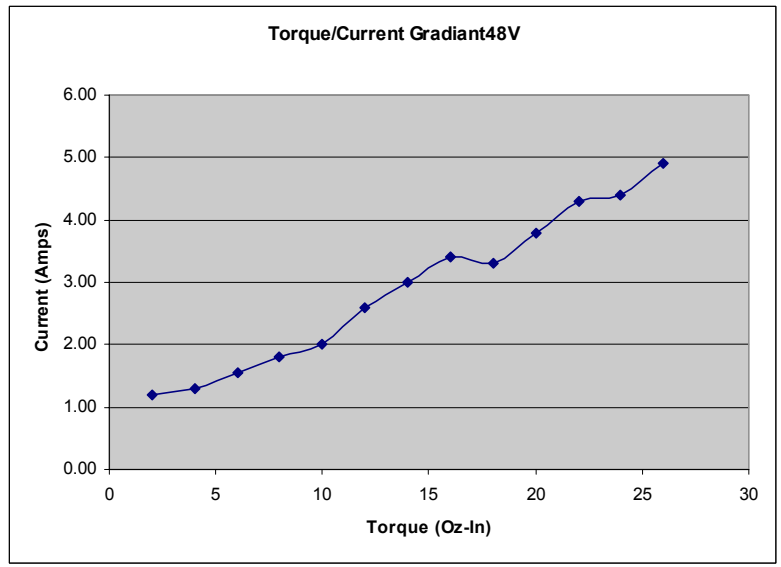
- The SRM design uses materials and components selected based on the requirement to survive above 460°C, at earth atmosphere.



Switched Reluctance Motor

- The prototype motor performance is mainly driven by the requirements of future Venus drilling and sampling systems (weight-on-bit, auger rotation speed, etc.) and robotic arms (payload mass, reaction loads, positioning requirements, etc.)
- It has been operated non-continuously for over 20 hours at Venus-like conditions (460°C temperature, mostly CO2 gas environment) and is still functioning properly.





HT Switched Reluctance Motor

- Since the Maxon RE-25 motor has been used to actuate various prototype drills system developed by Honeybee Robotics and a flight version of the Maxon RE-25 is the largest motor used on the Mars Exploration Rover mission, some of the Maxon motor's performance characteristics provide a reasonable comparison for high temperature motor.
- All test data are from motor test controlled by a custom controller which we are still optimizing.

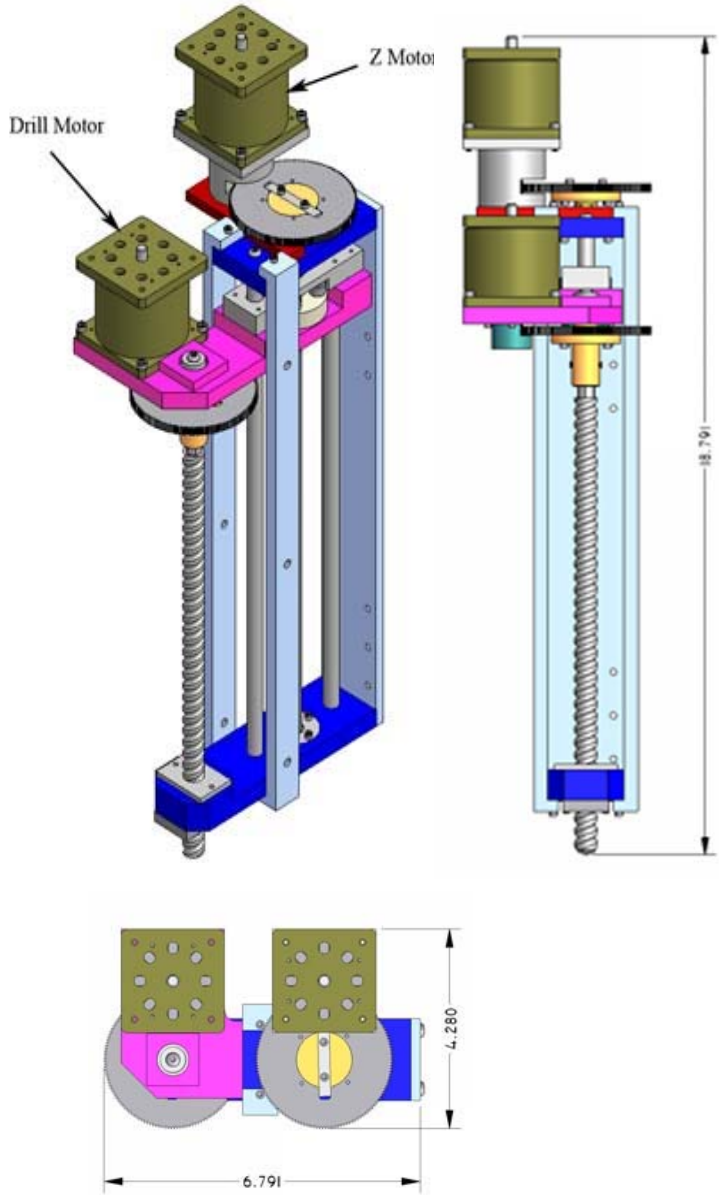
Characteristics	Units	Maxon RE-25 *	SRM Prototype
		Range at 25°C	Range at 460°C
Applied Voltage	V	4.5 - 48	20 - 48
Maximum Speed	Rpm	5500	7500
No-Load Speed	rpm	4790 - 5500	7000-7500
No-Load Current	mA	7 - 80	1000-1200
Stall torque	mNm	119 - 144	200 – 250

Motor Characteristics Comparison of Existing Maxon RE-25 to Current SRM Prototype

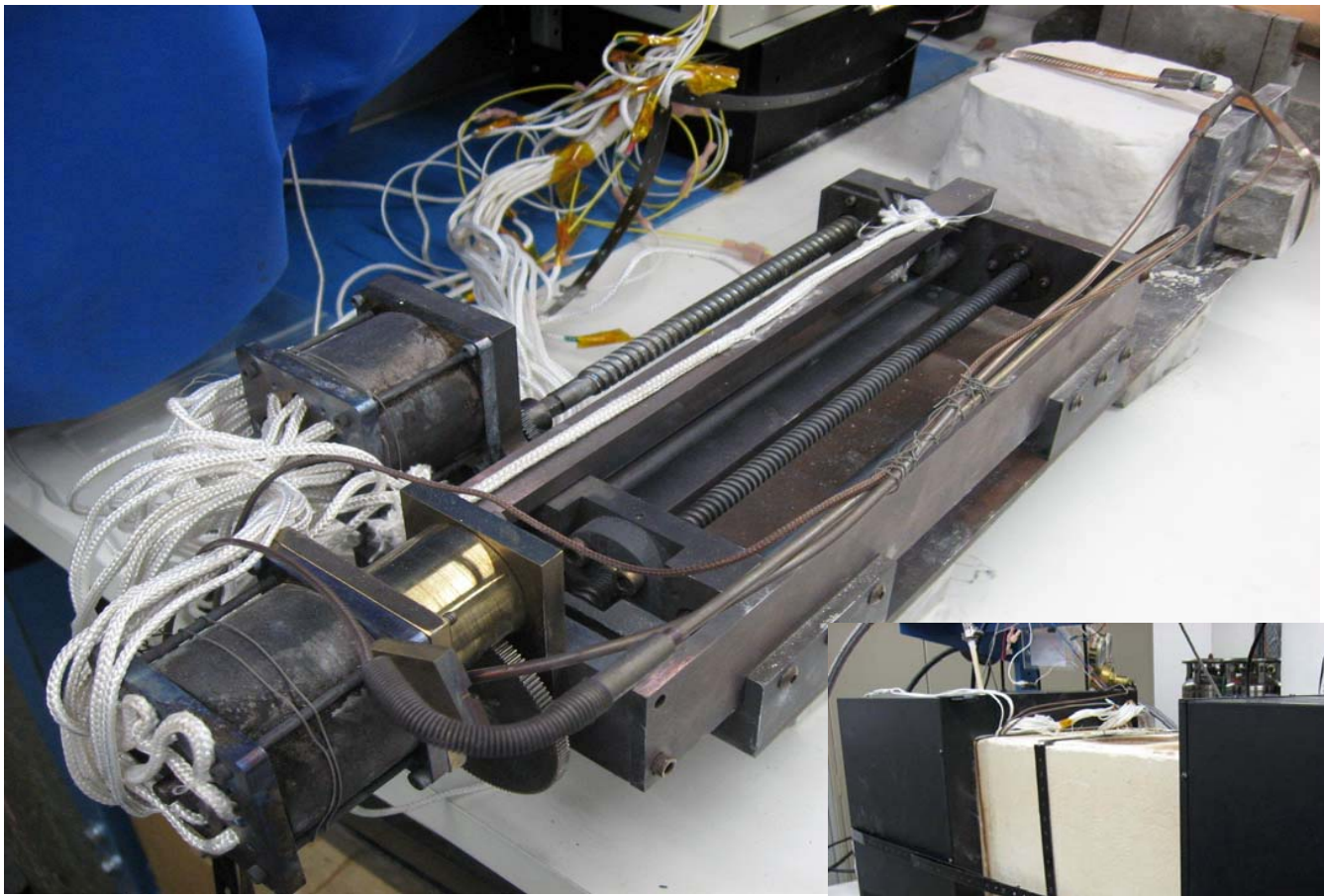
*Maxon DC Motor, RE-25 mm,"
http://test.maxonmotor.com/docsx/Download/catalog_2008/Pdf/08_077_e.pdf

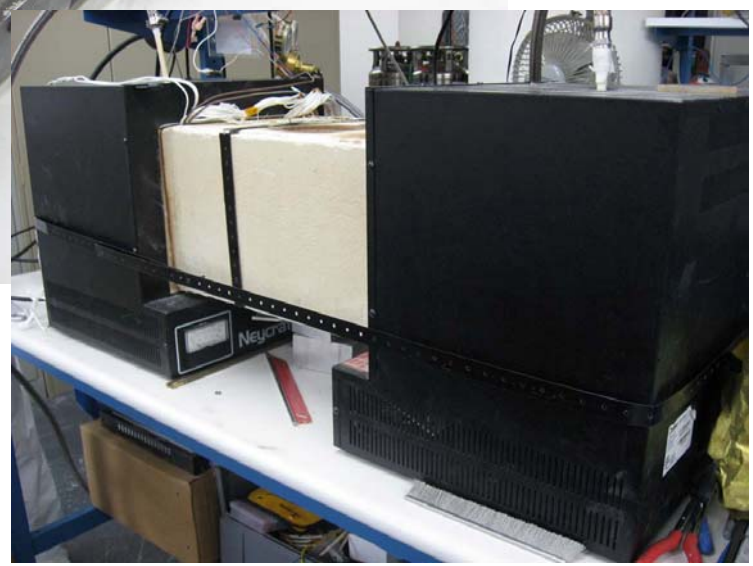
High Temperature Drill

- The prototype high temperature drill can operate with low thrust reaction in low gravity environment.
- Overall envelope is 6.8 inch x 4.3 inch x 18.8 in with 10 inches of drill stroke. (system was designed to fit existing test chamber).
- Two high temperature switched reluctance motors were integrated into the system to actuate the Z and Auger axes. Both were driven by the custom controller Honeybee has developed using sensorless control algorithm.
- All components of the drill including gears, bearings and bushings were selected based on the requirement to survive above 460°C, at earth atmosphere.



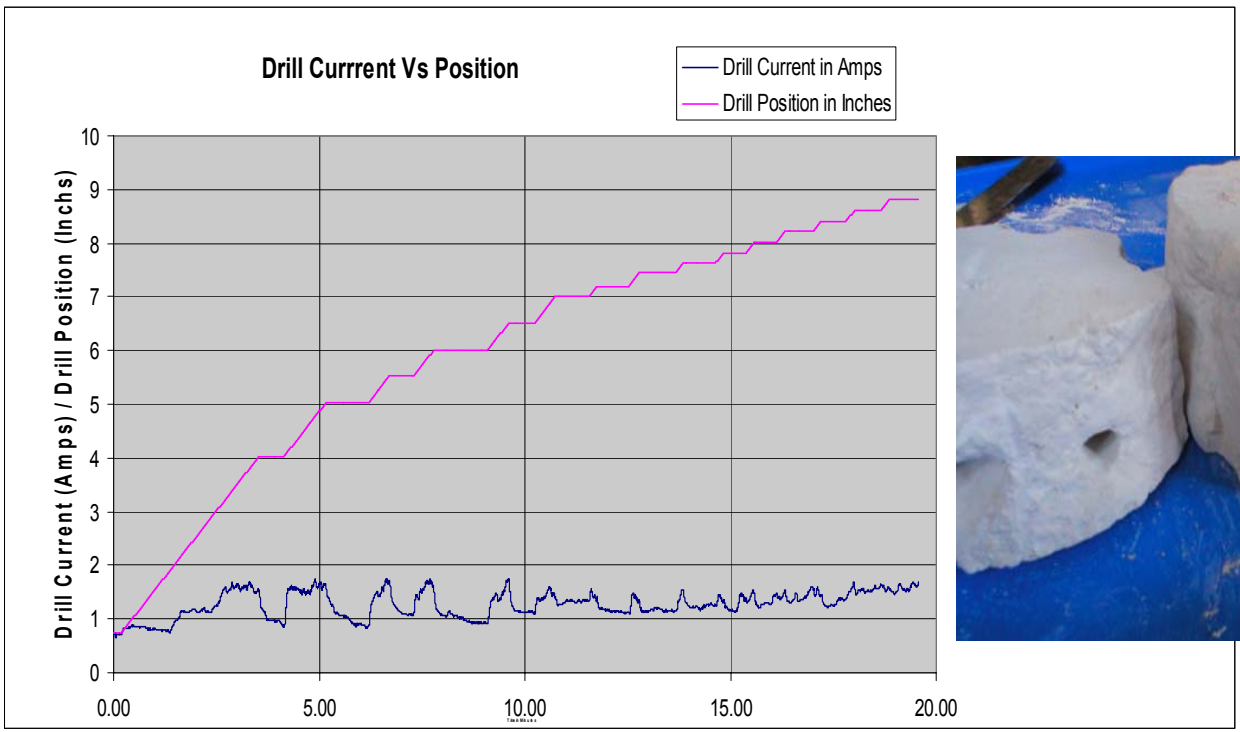
High Temperature Drill





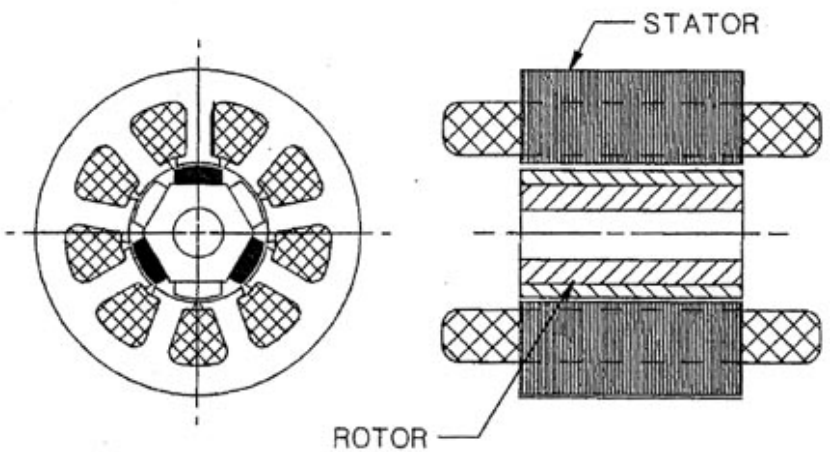
High Temperature Drill

- The high temperature drill conducted three drilling tests at Venus-like conditions (460°C temperature, mostly CO2 gas environment) successfully drilled into chalk to 6 inches deep in each test.
- Typical test data show that the drill's average Z-axis rate, in chalk, is about 0.3 in/min (6 inches in about 20 minutes); average drilling current is about 1.5 amps at 400 rpm.
- The extreme temperature drill remains functional after operating more than 20 hours at Venus-like conditions.

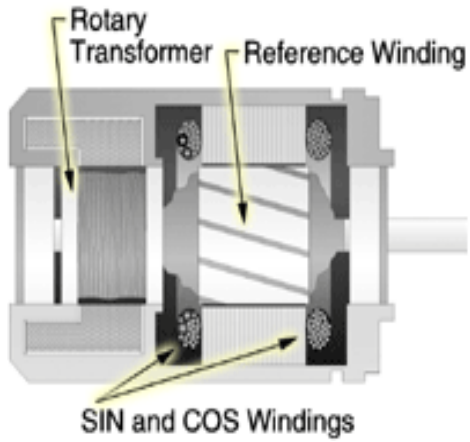


HT Brushless DC Motor & Resolver

- A brushless DC (BLDC) motor is configured as a permanent magnet rotating past a set of current-carrying conductors.
- A resolver looks very similar to a motor, that is, one end has terminal wires, and the other end has a mounting flange and a shaft. Internally there is a rotor and stator. A “signal” or reference winding revolves inside a fixed stator. The output of the signal changes as the winding is moved (the rotor). This changing signal is directly proportional to the angle which the rotor has moved through.
- The resolver, coupling to the motor, can provide motor shaft position. It can also be used to commutate the motor.

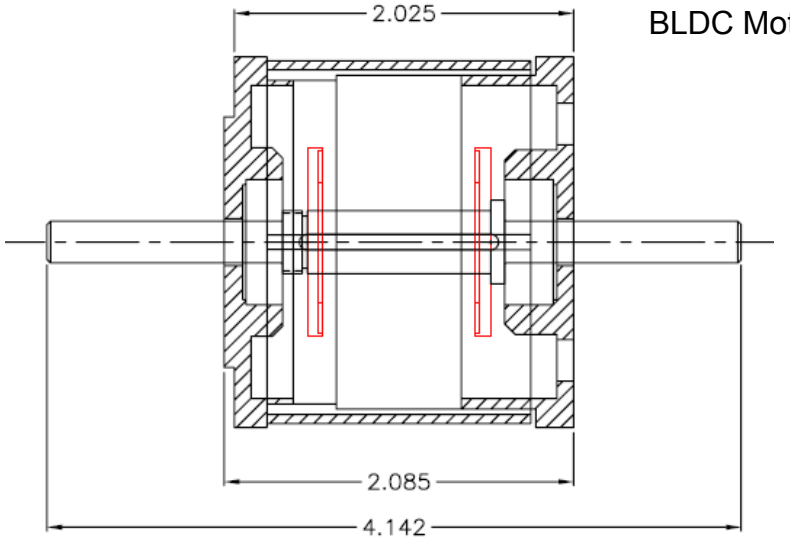


BLDC Motor

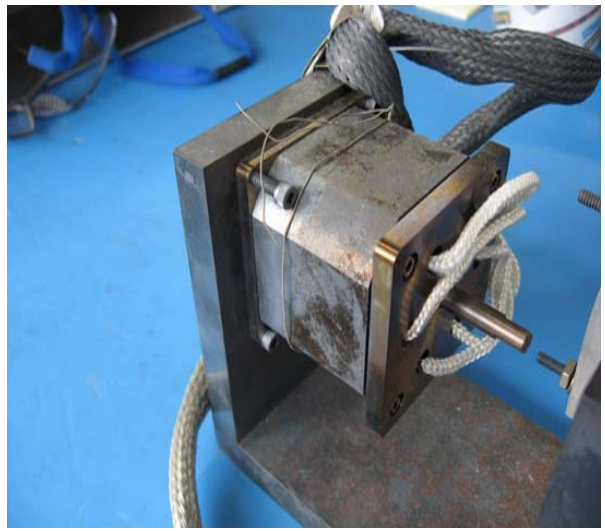


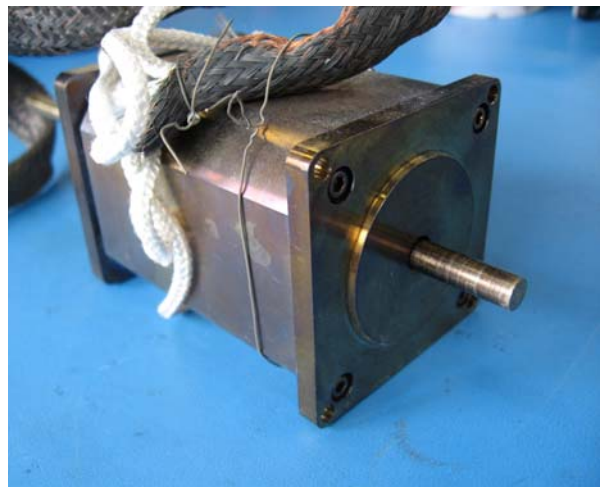
Resolver

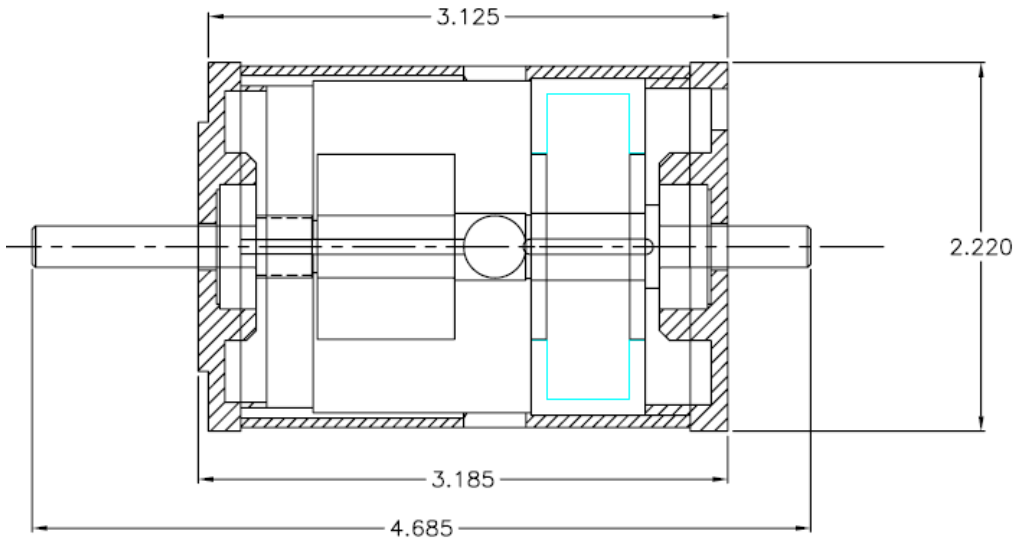
HT Brushless DC Motor & Resolver



BLDC Motor







BRUSHLESS RESOLVER

Motor shaft length was deliberately oversized to allow coupling with an output shaft and the high temperature resolver.

HT Brushless DC Motor & Resolver

- The BLDC motor and resolver design also uses materials and components selected based on the requirement to survive temperatures above 460°C, at earth atmosphere.
- The motor was tested at temperatures up to 460°C at speeds up to 1000 rpm and under different load conditions from no-load to an applied torque load of 80 mN-m.
- The test on the resolver was performed at the same time as the BLDC motor by connecting it in tandem with the motor. The output from the resolver was compared with the COTS resolver attached to the motor for commutation.
- The first generation high temperature BLDC Motor and resolver demonstrated the feasibility of the design through verification that the motor and resolver can operate at Venus-like condition for an extended period of time.
- The 2nd generation BLDC motor and resolver are under development.
- To demonstrate immediate applicability to potential Venus missions, the high temperature motor/resolver development will form the basis for development of a sample acquisition scoop and a robotic joint, both of which will also be tested to TRL6.

Summary & Conclusions

- The SR and BLDC motors are no longer expected to limit the life of Venus surface operation.
- Scalable high temperature motor, resolver and bearing developments allow for creation of long lasting sample acquisition and manipulation systems, booms, robot arms and even mobility systems that operating outside of an environment-controlled landed platform on the surface of Venus.
- The motor and resolver's capability to survive for hours (and potentially longer) in Venus-like environment is a major benefit to future Venus science missions since it would allow time for communication ground loops to optimize sample target selection and allow for multiple samples to be acquired from the surface.
- Aside from Venus exploration, other potential NASA and non-NASA applications for high temperature motors and mechanisms include actuation of fluid pumps, gimbals robotic joints and manipulation systems, as well as turbine, expendable launch vehicle and furnace tending system components.

The End