Performance Characterization of HT Actuator for Venus. F. Rehnmark[1], J. Bailey[1], E. Cloninger[1], K. Zacny[1], J. Hall[2], K. Sherrill[2], J. Melko[2], K. Kriechbaum[2], B. Wilcox[2], [1]Honeybee Robotics (398 West Washington Blvd, Ste 200, Pasadena, CA 91103, rehnmark@honeybeerobotics.com), [2]JPL (4800 Oak Grove Dr, Pasadena, CA 91109, jeffery.l.hall@jpl.nasa.gov).

Introduction: A high temperature (HT) actuator capable of operating in the harsh environment found on the surface of Venus has been built and tested at JPL's Venus Materials Test Facility (VMTF) [1,2]. The actuator has been used to power a rotary-percussive rock sampling drill operating in carbon dioxide gas at full Venus temperature and pressure (see **Figure 1**). The technology can be scaled to power other mechanisms for planetary exploration in harsh environments, such as deployment devices, manipulators and mobility platforms.

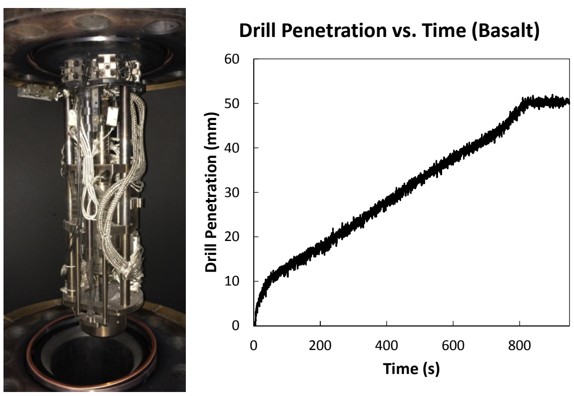

Figure 1. Venus rock sampling drill with results of drilling trial performed at Venus temperature and pressure (VTP).

Actuator sizing for the high temperature environment must account not only for variability in the driven load but also for reduced torque and efficiency available from the motor. Analysis and testing is underway to investigate these effects. Life testing is also planned with the goal of demonstrating margin against proposed mission sampling timelines.

Motor Torque and Efficiency at High Temperature: The drop in motor torque and efficiency at elevated temperature is due to two important temperature dependencies which must be accounted for when designing for operation across a wide temperature range. The first is the increase in electrical resistance of the motor coils at elevated temperature, which both increases i^2R losses in the motor and decreases the theoretical stall current (and therefore stall torque) of the motor for a given supply voltage. The second is the reduction in magnetic flux linkage density between the rotor and stator. This decreases the motor torque constant K_t, which, in turn, reduces the stall torque of the motor. The motor speed constant K_e is decreased by the same amount, thereby increasing the no-load speed. The overall effect is a reduction in both maximum efficiency and maximum power output which, incidentally, occur at different operating points [3].

Motor Performance Testing: The continuous output torque of the drill motors is limited by their ability to dissipate waste heat generated in the coils. Constant torque load dynamometer tests were performed at room temperature and 482°C under Earth atmospheric pressure to determine the steady-state temperature rise under each condition. As expected, the increased resistance of the motor coils at high temperature limits the motor's continuous output torque capability. However, the thermal endurance of the motors improved significantly in drilling trials in the simulated Venus atmosphere, likely due to the combined benefits of good thermal conduction to a massive heat sink (i.e., the drill) and enhanced convection in the high pressure carbon dioxide atmosphere.

Modeling and Simulation: Like ordinary brushless DC motors, custom HT actuators can be designed to meet mission requirements using conventional modeling and simulation tools. If the temperature dependency of winding resistance and magnetic flux density are known, motor performance at any temperature can readily be simulated.

Summary: HT actuator technology is available to meet the needs of planetary exploration missions to harsh environment destinations such as Venus. Conventional methods can be used to size these actuators and account for losses at high temperature.

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References: [1] Zacny, K. et al. (2017). *Development of Venus Drill*, Proc. of IEEE Aerospace Conf., Big Sky, Montana. [2] Rehnmark, F. et al. (2017). *High Temperature Electromagnetic Actuator and Sampling Drill for Venus Exploration*, Proc. of ESMATS 2017, Hatfield, UK. [3] Montone, D. *Temperature Effects on DC Motor Performance,* downloaded from http://www.pittman-motors.com/Resources.aspx