Material Characterization while drilling on Moon: Review of the Preliminary Atmospheric Test Results

D. Joshi[1], A. Eustes[2], J. Rostami[3], C. Gottschalk[4], C. Dreyer[5], Z. Zody[6], W. Liu[7]
[1,2,6]Petroleum Engineering, Colorado School of Mines, 1500 Illinois St, Golden, CO. 80401.
deepjoshi@mymail.mines.edu , aeustes@mymail.mines.edu, zzody@mymail.mines.edu
[3,7] Mining Engineering, Colorado School of Mines, 1500 Illinois St, Golden, CO. 80401. rostami@mymail.mines.edu, wenpengliu@mymail.mines.edu
[4] Mechanical Engineering, Colorado School of Mines, 1500 Illinois St, Golden, CO. 80401.
colbygottschalk@mymail.mines.edu
[5] Center for Space Resources, Colorado School of Mines, 1500 Illinois St, Golden, CO. 80401. cdreyer@mines.edu

Introduction: The LCROSS mission proved the presence of water in the lunar craters[1] and the presence of shallow water-ice in the mid-latitude region on Mars was detected recently through SHARAD instruments[2]. The water-ice present on the Moon and Mars can significantly bring down the cost of space exploration. The biggest obstacle in designing the mining and refining instruments is the variability of the estimated quantity and characteristics of the water-ice. With low-resolution orbital data available, the next step is to acquire ground-truth information by drilling and analyzing samples from the Moon and Mars. This paper discusses the test setting and results of the preliminary drilling tests conducted in analogous lunar samples at atmospheric pressure to extract geotechnical information from real-time high-frequency drilling data. Figure 1 shows the auger based rotary drilling system with the data acquisition system designed to drill test boreholes on the simulated sample. The drill design takes inspiration from the heritage drill systems developed for lunar and Martian environment.

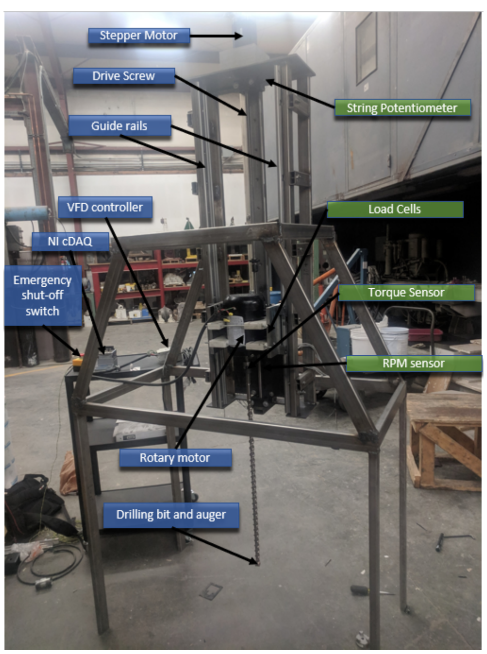

Figure 1: Test Drill setup

The drill unit contains a high-frequency data acquisition system, measuring RPM, axial force, Drilling depth, and torque in real time at 1000 Hz frequency. Table 1 shows the measured and calculated drilling parameters used to evaluate the geotechnical properties.

Table 1: Measured and derived drilling data

Measured Drilling parameters	Calculated Drilling parameters
Axial force	Weight on Bit
RPM	Mechanical Specific Energy
Torque	Penetration Rate
Drilling Depth	Rig state
Time	Drilling power

Basalt based lunar regolith simulant was used as an aggregate to cast analog concrete blocks with varying properties to replicate different subsurface geotechnical properties in the lunar polar craters. The drill was tested on samples with different geotechnical properties to account for the variance in estimated properties in the lunar craters. The drilling parameters like rotary rate, torque, penetration rate, weight on bit (WOB) and mechanical specific energy (MSE) were used to develop an advanced machine learning algorithm capable of processing and analyzing the real-time high-frequency drilling data to estimate a sample's geotechnical properties such as strength which has strong correlation with the water content of the frozen regolith. Figure 2 shows the drilling data log for one of the boreholes drilled in the sample. The data indicates the heterogeneity in the concrete block just based on the analysis of the real-time drilling parameters.

The evolving algorithm is being developed based on drilling responses on initial tests conducted on homogeneous and heterogeneous analogs. The pattern recognition algorithm will be tested on samples with varying heterogeneity to estimate the geotechnical properties accurately. With some modifications, this algorithm can be applied in the Lunar and Martian drills that are developed for various missions to estimate the geotechnical properties in real-time.

This can result in a cost-effective exploration of water-ice resources on Moon and Mars, kick starting the space resources industry and the human colonization on those planetary bodies. This paper offers the details of the design of the drill unit which is based on the general specifications of the units deployed in Moon and Mars missions. The test settings for the drill unit as well as the results of the initial test on selected auger shaped dill string with selected carbide bit will be presented. The data streams recorded will then be used to assess the relationships between various material properties and drilling parameters for real time assessment of geotechnical units beign drilled, including strength and water content at lunar polar conditions.

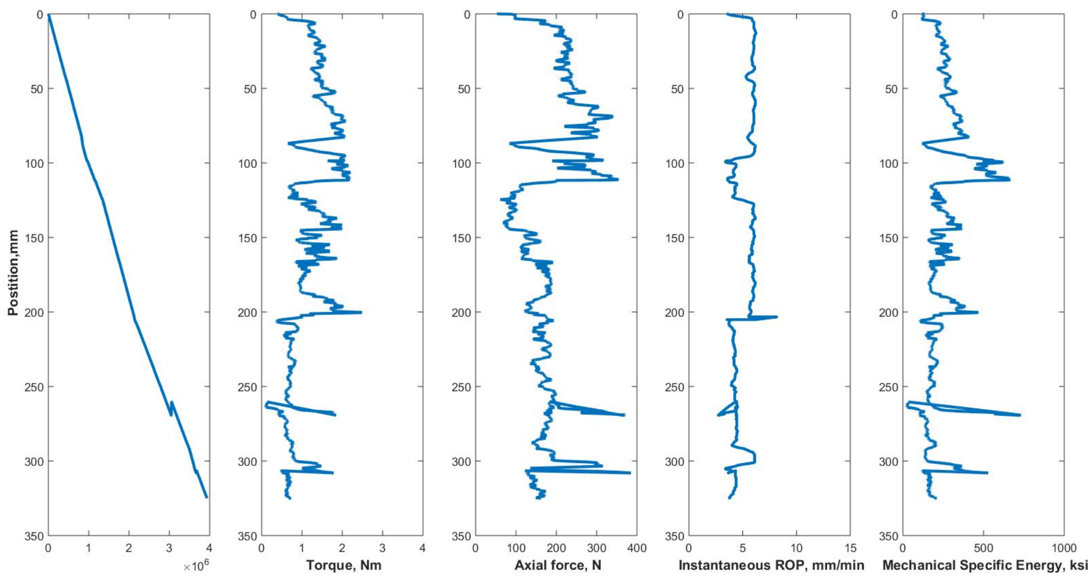

Figure 2: Drilling data log recorded during tests

References:
[1] Colaprete, A., Schultz, P., Heldmann, J., Wooden, D., Shirley, M., Ennico, K., Hermalyn, B., Marshall, W., Ricco, A., Elphic, R. C., Goldstein, D., Summy, D., Bart, G. D., Asphaug, E., Korycansky, D., Landis, D., Sollitt, L., 'Detection of Water in the LCROSS Ejecta Plume', Science, Vol 330. 22 October 2010.
[2] Dundas, C. M, Bramson, A. M., Ojha, L., Wray, J. J., Mellon, M. T., Byrne, S., McEwen, A. S., Putzig, N. E., Viola, D., Sutton, S., Clark, E., Holt, J. W., 'Exposed subsurface ice sheets in the Martian mid-latitudes', Science, Vol 359, 12 Jan 2018.