Predictive model for lunar percussive excavation

Alex Green, Dennis Lieu, Rob Mueller, Kris Zacny, W. David Carrier III

Mechanical Engineering Department, University of California, Berkeley CA 94720
Lunar Surface Systems, Kennedy Space Center FL 32899
Honeybee Robotic Spacecraft Mechanisms Corporation, New York NY 10001
Lunar Geotechnical Institute, Lakeland FL 33807
alex_n_green@berkeley.edu

NASA's mission is to pioneer the future in space exploration, scientific discovery, and aeronautics research[1]. An integral part in the advancement of our knowledge regarding our celestial neighbors is to have the capability and technology to drill and excavate their surfaces and examine their soils, regolith, ice and rocks.

Drilling and excavation on earth generate large reaction forces. These forces are balanced by large body forces that come from massive drill rigs and excavators. Such a brute-force approach will not be possible on other planetary bodies. The cost of planetary subsurface exploration is heavily dependent on the mass requirements of a planetary lander or a rover system[2].

Robotic planetary systems are focused on scientific exploration as well as mining and processing regolith, In Situ Resource Utilization (ISRU). One goal of ISRU is to produce propellant from oxygen rich lunar regolith for travel back to earth. Consequently, near term space excavators will have to be heavy enough to sufficiently combat excavation forces without lifting off the surface. Excavation forces are highly dependent on soil density and shear strength, both of which are functions of soil cohesion and friction. Soil cohesion and friction can be reduced by dynamically exciting a vibratory or percussive digging blade[34]. Digging force reductions of up to 80% have been documented[52]. Through force reduction the excavator mass requirements for ISRU become less extreme, and in turn, the mission cost attributed to lower launch mass is greatly reduced.

Although research has been done to corroborate the force reduction principle,[256] there does not exist a published predictive model for percussive or vibratory excavation. Without a predictive model, NASA engineers are left devoid of any design guidelines for robotic soil excavation.

The research presented will deal with the work being done to generate and validate a simple, yet robust, excavation equation which will predict the expected draft force for a percussively actuated plow blade based on a prescribed frequency and force.

---

[1] NASA homepage mission statement. Viewed 1 Feb. 2010
http://www.nasa.gov/about/highlights/what_does_nasa_do.html

[2] Zacny, Kris; et. al. "Five-Step Parametric Prediction and Optimization Tool for Lunar Surface Systems Excavation Tasks" Paper written for contact NNJ08TA85C, Lunar Surface Systems Concept Study

[3] Barkan D. D. Dynamics of Bases and Foundations McGraw-Hill Book Company, Inc. 1962

[4] Viking Kennith. "Vibro-Drivability A field study of Vibratory Driven Sheet Piles in Non-Cohesive Soils" Doctoral Thesis Royal Institute of Technology (KTH) May 2002

[5] Sulatisky, M.T; Ukrainetz P.R. "Draft reduction by Vibratory Soil Cutting" Transactions of the Canadian Society of mechanical Engineering Vol. 1, Issue 4, 1972

[6] Trapp, A.D; et. al. "The performance of Longitudinally Vibrating Earth Cutters" Journal of Agricultural Engineering Research, Volume 19, Issue 4, December 1974