Testing of a Novel Lunar Regolith Compaction Device for Site Preparation. C. L. Carey[1], R. D. Austerberry[2], J. D. Petrin[3], and P. J. van Susante[4], [1,2,3,4]Dept. of Mechanical Engineering-Engineering Mechanics, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931 (contact: pjvansus@mtu.edu).

Introduction:

The moon remains a focal point of current space exploration, and sustainable methods will need to be used if these efforts are to take root and become a jumping off point to further planetary body research. To achieve a sustainable presence on the moon, meaningful infrastructure including roads, habitats, launch/landing pads and more will be needed. Terrestrial construction and soil mechanics informs us of the basics necessary to build these features, but the tools used on earth are impractical for use on the moon or other extraterrestrial bodies. Construction vehicles are very large by design to leverage high reactive forces in moving large amounts of material, and often heavily utilize hydraulic actuation. Similar equipment would require replacement of these primary mechanisms to operate in or near vacuum and would be inaccessibly costly to transport via rocket. Additionally, many planetary bodies of interest have lower gravity than earth, meaning that available reactive force per unit mass is less effective as well. These problems are especially true for compaction, which typically uses large masses to compress and vibrate at the surface. Michigan Technological University's (MTU) Planetary Surface Technology Development Lab (PSTDL) has been investigating a novel compaction method to address these issues as a part of NASA's LuSTR 21 Grant. This abstract will include details regarding the state of the compaction system design and its performance.

Methods:

To achieve compaction, PSTDL has developed a vibratory needle compactor, which uses an array of pins to directly vibrate material at depth. This method reduces the mass necessary to impart vibratory forces, and by extension compaction, to greater depths than traditional surface compactors often used terrestrially. Figure 1 shows the fundamental design, including a surface pressure plate which improves the compaction quality near the surface, and pins that can be deflected independently such that obstacles do not hinder a whole compaction surface.

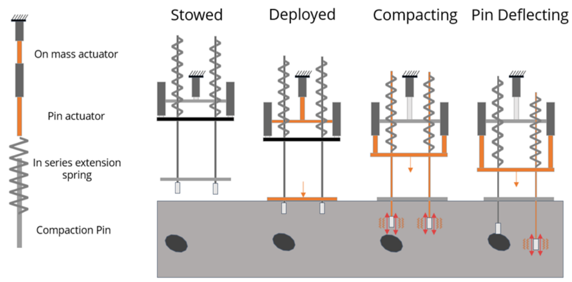

Figure 1: Compactor concept of operation

Several iterations of the design have been explored to optimize and better understand individual design features. Figures 2 and 3 show the most recent test system, a modular system allowing for changes to the vibration, surface pressure plate, pins, and springs. This system uses excentric masses to produce vibration in the pins, which are isolated from the structure by springs. Testing was conducted in a bin of MTU-LHT-1A [1], a lunar highlands simulant, and compaction results were obtained by measuring the full simulant mass and a grid of height measurements with a known area. Acceleration data was also collected to characterize dynamic behavior in regolith of varying compaction levels.

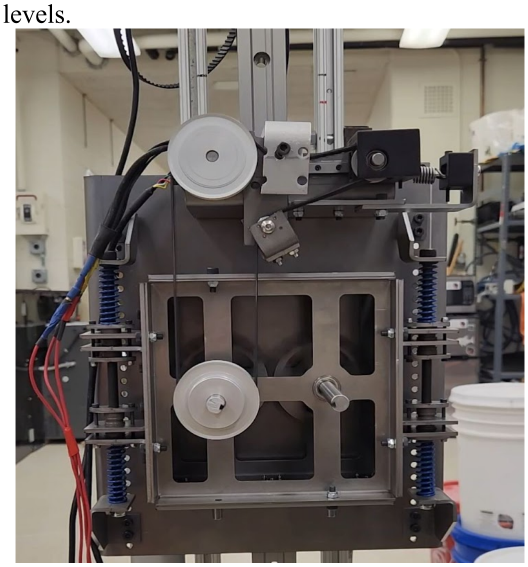

Figure 2: Vibration unit of testing prototype

Figure 3: Test box, pin and pressure plate of test setup

Results:

The primary goal of testing was to achieve 90% relative density to a depth of 30 cm as specified by the grant. An initial test series was conducted as a fractional factorial design investigating: frequency, eccentric mass, spring isolation stiffness, and pressure plate duty cycle. The results indicated that frequency, excentric mass, and their interaction were the only significant effects. With this testing completed further testing efforts were committed to investigating appropriate dwell periods with the optimized frequency and eccentric mass, varied the time the pin spent in regolith. The results, shown in figure 4, indicated that time-in-regolith improves compaction to a point, then reduces the compaction, which supports expectations of compacting dry granular materials. Very low starting compaction however did not allow for 90% compaction to be achieved in one pass and such loose starting compaction level is unrealistic of the lunar environment that increases in relative density (compaction level) rapidly with depth. Further testing was conducted with precompacted regolith (figure 5), showing a similar pattern after exploring varying dwell time at a higher starting compaction level. The highest relative density achieved to date is 86% with this method and refining the method and control strategies will likely allow us to achieve the desired 90% relative density over the compacted column.

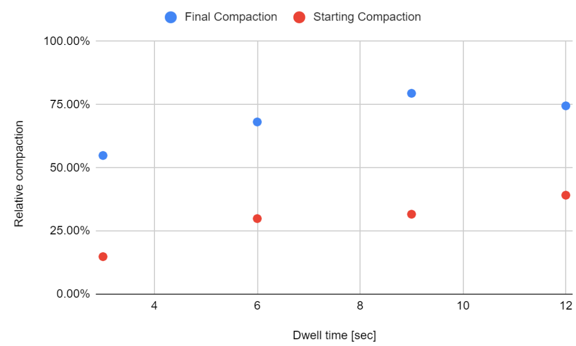

Figure 4: Achived compaction compared to dwell time in regolith

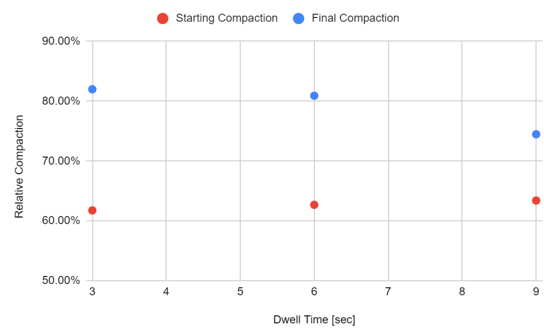

Figure 5: Achived compaction compared to dwell time in regolith

Path Forward:

Test results are informing the design of a rover mounted compactor which will demonstrate site preparation on a 10 m platorm. Testing will continue in an effort to optimize performance, and better characterize vibration dynamics compared to achieved compaction. Further testing is also planned for vacuum conditions.

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References:

[1] van Susante, P. and Carey, C. (2022) *Michigan Technological Universities' Lunar Highland Simulant MTU-LHT-1A.*