Low Mass Method for Lunar Regolith Surface Compaction. C. L. Carey[1], R. D. Austerberry[2], P. S. Parker[3], and P. J. van Susante[4], [1,2,3,4]Dept. of Mechanical Engineering-Engineering Mechanics, Michigan Technological University 1800 Townsend Drive, Houghton, MI 49931 (contact: pjvansus@mtu.edu).

Introduction: As human space exploration expands to include lunar bases, and resource collection, the development of infrastructure on the moon becomes imperative. Terrestrial construction informs us of the basics necessary to build roads, foundations, launch pads and more. The equipment used on earth however is too massive and requires too much energy for use on moon or other extraterrestrial bodies. Construction vehicles are designed to be very large to leverage high reactive forces in Eartht's gravity 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 in terms of mass to launch. Additionally, many planetary bodies of interest have lower gravity than Earth. These differences are especially challenging for achieving soil compaction which typically uses large masses to compress and vibrate at the surface to compact sufficiently at required depths. Michigan Technological University's (MTU) Planetary Surface Technology Development Lab (PSTDL) has been investigating a novel compaction method to address these issues. Instead of massive surface loading, the design uses vibrating pins that are inserted into the regolith and vibrated at depth, greatly reducing the required mass and energy required to compact to desired depths by delivering energy directly down to the location of compaction. This abstract includes details regarding the optimization of this design to compact a simulated 10 m launch pad surface down to 30 cm depth with the goal of achieving 90% relative density as a part of NASA's 2021 LuSTR grant.

Methods: The design consists of an array of rods, covering an area limited by the vehicle's maximum downward force. Each individual pin will be attached to the structure by spring which will allow for the pin to deflect after reaching the target compaction level or in the event of a buried obstacle (figure 1). The primary requirements for optimization are minimizing mass, energy, and time to compact, while achieving a specified compaction level. As a novel compaction system there are many variables to be considered and optimal values determined; pin spacing, vibration frequency and amplitude, pin tip geometry, and feed rates and dwell times.

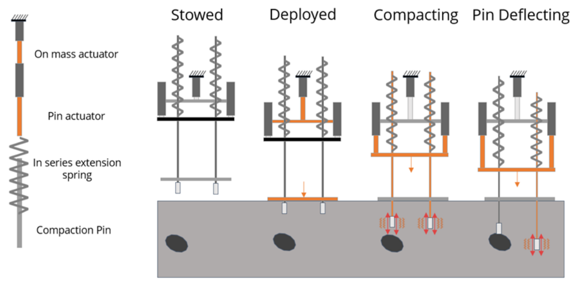

Figure 1: Compaction mechanism

To investigate the independent pin mechanism, a singular pin prototype will be used as shown in figure 2. This rig will allow investigation of the effective radius of compaction, and optimization of vibration parameters. For effective radius a pin solution will be tested in a series of polycarbonate tubes of increasing size filled with regolith simulant. The bulk density will be measured, relative density determined and compared to the requirement. The largest tube compacted will represent the effective range of the given settings. Vibration parameters within a set tube radius, where vibration method, frequency, and amplitude will be varied to determine the best configuration.


Figure 2: Single pin prototype [left] and Pin array test set-up [right].

A second testing rig will allow for testing of different pin arrays and pin tips, and duty cycles (figure 2). This test set-up can place varied on mass loads of up to 800 ± 50 N simulating the mass of the rover; it can test a variety of pin arrays with an interchangeable plate; and it can test a variety of possible duty cycles. This system can compact down to 30 cm depth and will be used to closely approximate the use case of the landing pad construction task as specified by NASA LuSTR21, and will be used to fine tune most final details.

Preliminary Results: Vibratory compaction down to 30 cm depth has been achieved in initial testing using the vibratory pin method. Compaction level was increased from 20-70% relative compaction with initial testing. Many variable still need dialing in and tweaking to achieve optimum compaction efficiency and performance. This will occur over the next few months.

Optimization: Using this test equipment the ideal parameters are being determined through testing. The expected results of testing will primarily focus on the vibration, operation, and individual pin geometries.

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