EXPERIMENTAL INVESTIGATION OF BUCKET EXCAVATION TORQUE REDUCTION WITH AN ULTRASONIC LEADING EDGE

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INTRODUCTION

Lunar regolith excavation is critical to the development of a sustainable human presence on the Moon. Lunar gravity, jagged particle shapes including agglutinates and glasses, and very small average particle sizes (~70μm) pose a challenging excavation problem [1]. The vehicle mass needed to excavate lunar regolith could become prohibitively large to achieve large forces or risk tipping if not massive enough. Ultrasonic probes in granular material have proven useful for force reduction [2,3]. Tools with ultrasonic leading edges can reduce required excavation forces and eliminate the need for massive vehicles for large-scale regolith extraction on the Moon.

OBJECTIVE

The primary goal of this study is to quantify force and torque differences between digging with and without vibration in the leading edge of the Ultrasonic Bucket. Preliminary studies in a uniaxial test setup indicated that large reductions of axial force (upwards of 70%) are possible with the introduction of 20 kHz vibration into a tool [4]. The test matrix for this study seeks to understand the impacts of tool leading edge speed and depth on the measured forces and torques with and without the use of vibration in the leading edge.

METHODS

The Advanced Planetary Excavator (APEX) allows repeatable, planar toolpaths to be tested with a 6-axis force transducer to measure forces and torques at the wrist-tool interface of the test stand. APEX is driven by all electric actuators, allowing for power measurements and torque estimates at each joint. The digging environment is controlled to ambient humidity and temperature as an indoor facility with GRC-3b lunar regolith simulant in the soil bin. A three-segment toolpath was investigated such that data could be collected as the leading edge moves through soil shear planes normally as well as along them horizontally. This study investigated the effects three velocities of the leading edge (1 cm/s, 2 cm/s, 3 cm/s) as well as the use of active 20 kHz vibration at the tip.

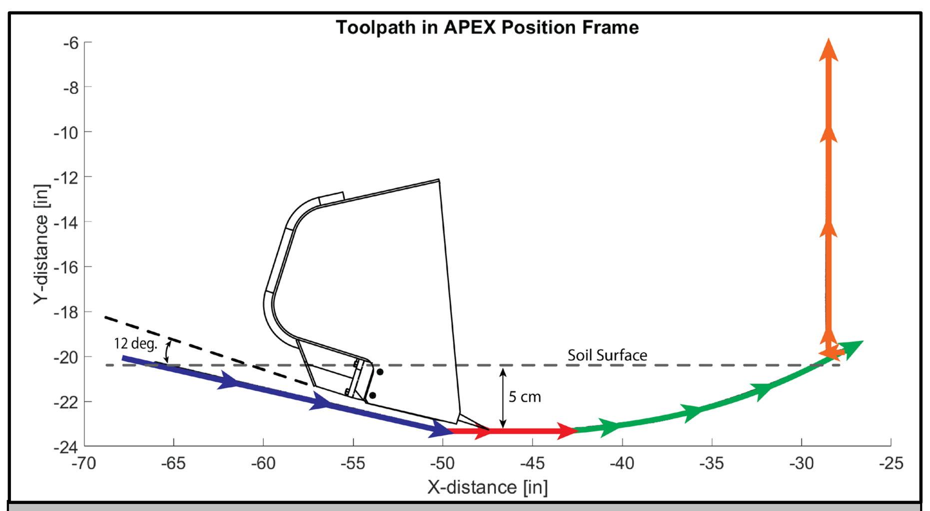

Figure 1: Three-segment tool path with designated sections. The blue section is linear and angled, the red section is linear and horizontal, the green section is a circular arc out with a rake angle of 12° maintained.

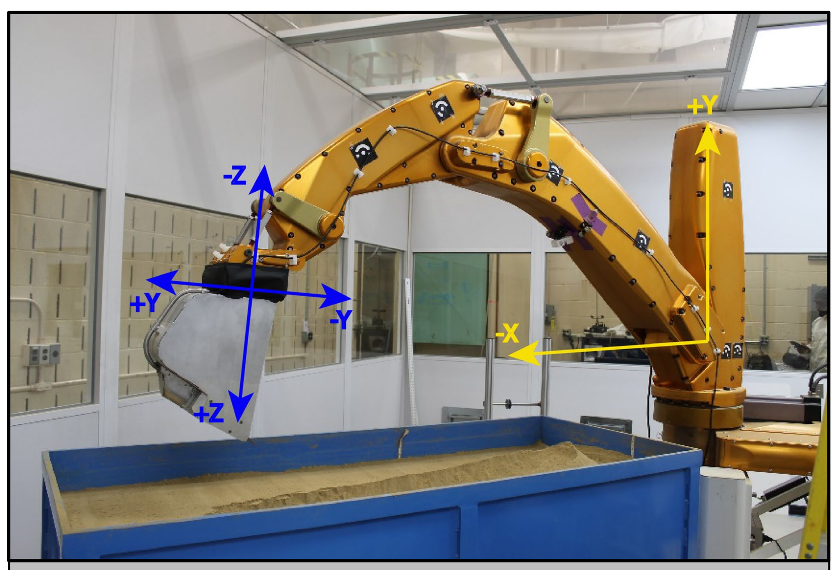

Figure 2: APEX in the Excavation Lab with the Ultrasonic Bucket. Yellow axes represent the tip position frame, blue axes represent force/torque transducer frame.

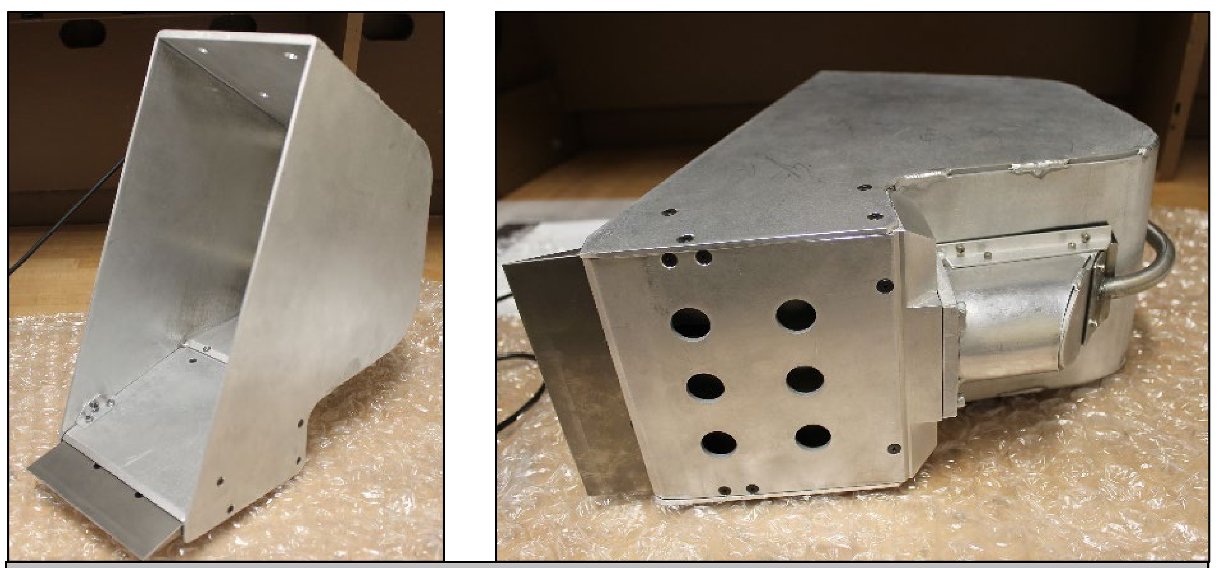

Figure 3: Ultrasonic bucket with integrated 20 kHz vibrating leading edge.

RESULTS AND DISCUSSION

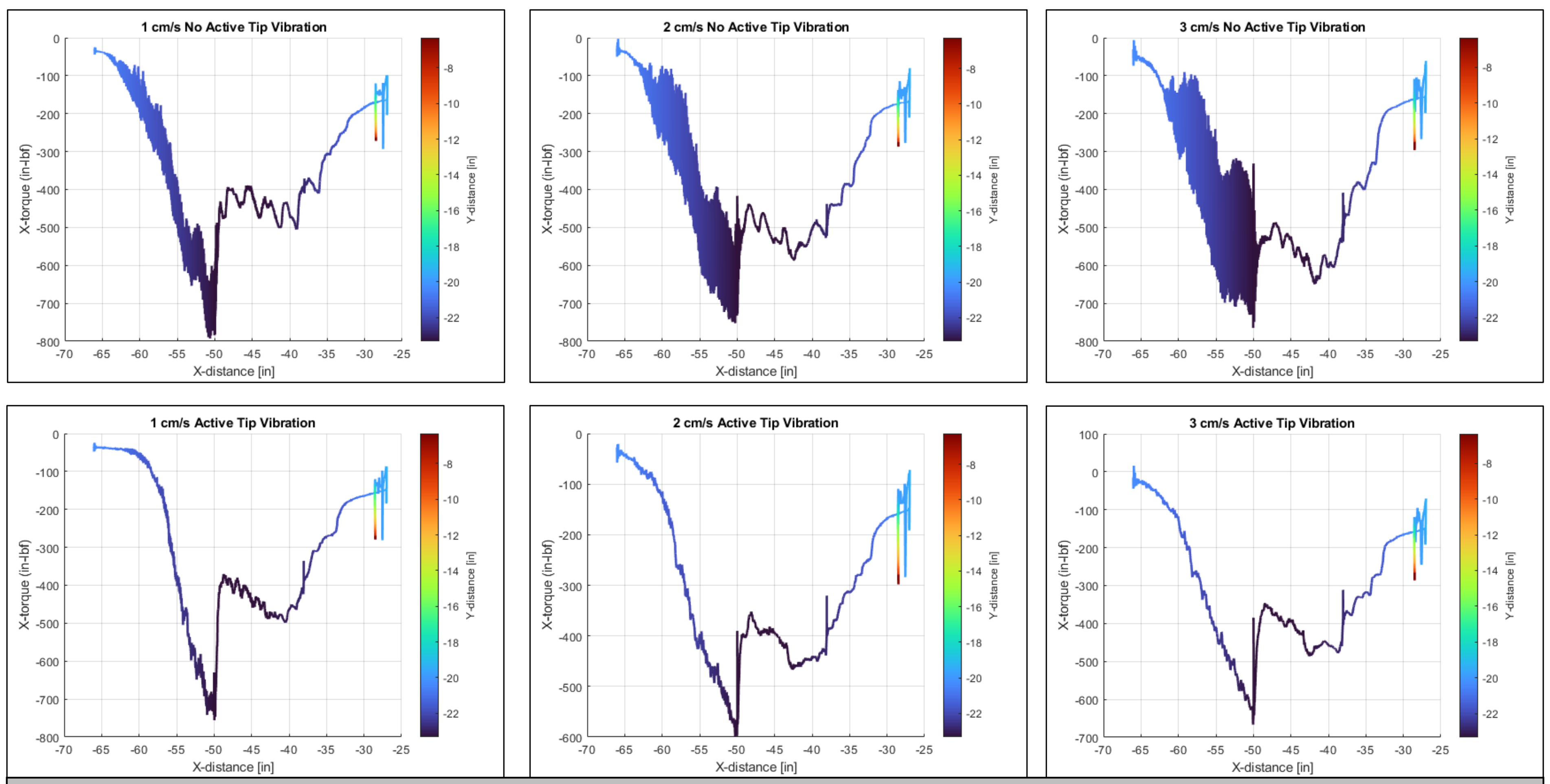

Figure 4: The measured X-torque at the center of the force transducer plotted against the x-distance traversal in the APEX position frame for various tip speeds with and without active vibration in the leading edge.

A sampling of the x-axis torque results are presented for the three tested tip speeds with and without active tip vibration. Actual dig depth for these tests was uncertain due to preparation methods and could range from about 5 – 10 cm in a single trial, thereby making it difficult to correlate force or torque magnitudes with the presence of tip vibration. Positive effects due to the use of tip vibration are still observed in that vibration significantly reduces noise in the torque response which is hypothesized to be present due to stick-slip events during the cut. The vibration is believed to fluidize the soil around the tip, allowing the tool to move through dynamic rather than static soil which would support the observed differences. Even with uncertainty in the tested soil conditions, these results support excavation benefits from the use of a vibrating tool tip.

BROADER IMPACT AND BENEFIT

The actual results presented here represent a first step towards developing ultrasonic vibration assisted regolith excavation tools. These results show that there could be force/torque control benefits to utilizing an ultrasonic tooling tip with a significantly cleaner torque response observed with the use of vibration, a use case not previously envisioned.

The state of the technology offers a high level of design flexibility and can be integrated into many excavation tool form factors including but not limited to buckets, rippers, and blades. Unlike percussive tools, this concept of an isolated, vibrating leading edge offers the opportunity for targeted vibration parameters like frequency and amplitude to maximize force reduction efficiency. While the use of vibration requires some additional input power, the goal of this broader research effort is to assess whether there could be mass reduction benefits for excavation systems if lower excavation forces can be achieved.

REFERENCES

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