MEASURING THE PROPERTIES OF ASTEROID REGOLITH SUBSURFACE PARTICLES USING A PENETROMETER.

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Introduction: Even small asteroids can retain a blanket of loose debris generated from impacts, as observed by Hayabusa at Itokawa [1]. Penetrometers can provide a means to access the subsurface, investigate micro-scale structures and provide useful information for optical, thermal and mechanical modeling of asteroids. Here we demonstrate that a flight heritage penetrometer, using a piezoelectric sensor and minimal electronics, can measure the average particle size and mass, from a single point measurement, with reasonable accuracy. Modifications are suggested to the penetrometer, allowing even more accurate determination of particle size and mass distribution with depth. This is a measurement unobtainable or very difficult by other methods.

The Penetrometer: We used a copy of the ACC-E penetrometer, the original of which was used by the Huygens probe to successfully make subsurface measurements on Titan [2], for our tests. The penetrometer included a piezo-electric force sensor positioned behind a hemispherical tip and was housed between two vespel washers. It was kept under slight compression by a bolt passing through the middle of the sensor.

The sensor worked by producing a charge when compressed. It was converted into a voltage by a charge amplifier and logged via an analogue to digital convertor. The tip and sensor were mounted at the end of a cylindrical strut, about 8 cm in length. The other end of the strut had a weight attached, to maintain constant speed during penetration, and a plate to stop it from burying itself in the target.

When dropped, at low speed, into a granular material, the penetrometer produced data with many peaks whose frequency were thought to correlate with particle size and whose magnitude were thought to correlate with particle mass [3].

Laboratory Tests: Particles of different masses were individually dropped onto the centre of the tip, at the same speed, to determine the response of the sensor. A monodisperse target (sili-beads) was then used to investigate how the curved surface of the tip affected the measurements. This information was used to construct a model of how the penetrometer responded to impacts across the whole tip.

Asteroid regolith analogues (gravel), with known properties, were used as targets to assess how accurately the size and mass of the particles could be determined in a realistic situation.

Results: The numbers of peaks in the data were found to be linearly proportional to the number of particles excavated by the penetrometer. However there was a large offset, possible due to bit-flip noise from the analogue to digital convertor. The average peak height, in the data, was found to be linearly proportional with average particle mass. For targets with larger particles (and larger peaks) there was a leveling off because smaller noise peaks became more dominant. Bit-flip noise was removed but this trend remained. Closer inspection of the data revealed that mechanical oscillations (i.e. ringing) played an important role in generating peaks in the data. The average size and mass could be recovered from the data. The accuracy of these measurements was found to decrease with decreasing number of particles excavated.

Tip Shape Effects: While a cone tip will produce ambiguous results in depth (the location of impact along the length of the tip is not known) a hemispherical tip will produce ambiguous results in both depth and width. A particle striking the centre of the tip will produce the greatest output while the same particle striking the edge will produce the least. The particle mass cannot then be determined from voltage output unless its impact location on the tip is known. This has important implications if the particle mass distribution, in the entire volume of material excavated, is desired.

A model of the target material was developed and used together with the penetrometer model to investigate these effects. Sensitivity effects due to tip shape and angles of attack were also investigated.

Summary: The unmodified penetrometer can measure particle size accurately with a sufficiently large sample size. It is possible to determine the average mass of the particles (and hence the density) with detailed knowledge of the penetrometer properties. A large sample size is required to overcome ambiguity problems of the hemispherical tip. Also electronic and mechanical noise is significant, when penetrating some of the targets, and needs to be accounted for.

Tip shape appears to be a very important element of the penetrometer, controlling the depth resolution of particle size and mass measurements. A conical tip with a large half angle (perhaps even flat) is favored. A prototype asteroid penetrometer, with a cone tip, is introduced for further investigating asteroid regolith properties.

References: [1] Yano et al. (2006), Science, 312, 1350-1353. [2] Zarnecki et al. (2005), Nature, 90, 1151-1154. [3] Lorenz et al. (1994) *Meas. Sci. Technol.*, 5, 1033-1044.