THE IN SITU AUTOMATED ROCK THIN SECTION INSTRUMENT (IS-ARTS).  C. B. Dreyer\textsuperscript{1}, K. Zacny\textsuperscript{2}, R. C. Anderson\textsuperscript{2}, G. K. Paulsen\textsuperscript{2}, J. Skok\textsuperscript{3}, J. P. H. Steele\textsuperscript{1}, J. Schwendeman\textsuperscript{1}, \textsuperscript{1}Colorado School of Mines (cdreyer@mines.edu), \textsuperscript{2}Honeybee Robotics Spacecraft Mechanisms Corporation, New York, NY, (zacny@honeybeerobotics.com), \textsuperscript{3}Jet Propulsion Laboratory, Pasadena, CA.

Introduction: The technical challenge of creating a thin section device compatible with the spacecraft environment is formidable and often has been thought too technically difficult to be practical. Terrestrial thin section preparation requires a skilled petrographist, several preparation instruments that individually exceed typical spacecraft mass and power limits, and consumable materials that are not easily compatible with spaceflight. By focusing on essential thin section production elements, careful consideration of requirements, and considering only dry grinding and cutting we have produced an instrument design for preparing rock thin sections in space. The In Situ Automated Rock Thin Section Instrument (IS-ARTS) conceptual design demonstrates that the in situ production of thin sections on a planetary body is a plausible instrument capability \cite{1}.

Thin section analysis provides a perspective to understanding planetary surfaces that will be uniquely different from the viewpoint obtainable from any previous orbital or surface missions. Mineralogical and petrological evidence for the presence or absence of past water, secondary alteration such as weathering and metamorphism (shock and heat), and local habitat identification can not be determined with a high degree of certainty using data sets currently available for planetary surfaces. On Earth, the main tool used by a geologist to gather this type of information is to identify the optical properties of the minerals by making thin-sections of the rocks/soils and examination using a petrographic microscope.

IS-ARTS Design: The In Situ Automated Rock Thin Section instrument (IS-ARTS) was designed to be capable of preparing thin sections of a variety of samples, including: rocks of $<3$ cm characteristic dimension and low aspect ratio, cores of $\sim 1$ cm diameter, rock fragments, regolith, and dust. The total number of thin sections produced is highly dependent on sample physical properties (hardness, texture), and initial shape and the size of the tablet produced. The design target was set at 50 thin sections assuming worst case wear rates and cutting rates for the diamond wire cutter and GRITS.

Fig. 1 shows a schematic of the IS-ARTS design concept consisting of 6 major subsystems. The Rock Gripper (item 6) moves along the Linear Rail (item 5). The Linear Rail provides a long axis of translation ($\sim 17$ cm) so that the sample can be presented to several stations to perform the processing steps needed to make a thin section. The Linear Rail delivers the sample to the grinding and polishing station, GRITS (item 1), a petrographic microscope (item 2), slide and epoxy application (item 3), Diamond Wire Cutter (DWC) (item 4), and receiving station (the Rock Gripper at the far right end of the Linear Rail). A precision vertical translation stage integrated into the Rock Gripper provides the motive force to drive the sample into the GRITS grind/polish wheel, position the sample in focus for the microscope, receive a slide and epoxy, and create vertical cuts with the wire. Passive mechanisms activated by the position of the Linear Rail and vertical translation of the gripper are used for several functions such as: open/close gripper, and to flip the sample or slide. A set of engineering sensing devices, i.e. contact switches, strain gauge, engineering camera, motor current sensing and encoders, could be used to verify sample progress through the system.

Based on breadboarding tests it was concluded that a thin section can be made with only four actuators (motors): (1) Linear Rail, (2) Vertical Translation on the Gripper, (3) GRITS motor, and (4) DWC motor. The Linear Rail requires a long length of travel ($\sim 17$ cm) but low precision ($\sim 0.5$ mm). Vertical Translation can be accomplished with $\sim 1$ cm of travel but requires high precision ($\sim 2$ micron) as this axis drives the sample into the GRITS grinder to make the section thin.

Grinding Rocks into Thin Sections (GRITS) Breadboard: Grinding Rocks Into Thin Sections

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig1.png}
\caption{Schematic design concept of IS-ARTS. Six major subsystems as annotated. 3: Slide/Epoxy Application. Four independent motorized degrees of freedom: Linear Rail, Rock Gripper Vertical Translation, GRITS and the Diamond Wire Cutter. Gripper open/close and slide/epoxy application will be engaged by passive mechanisms via Linear Rail and Vertical Translation. Rock receiving at the Right end of Linear Rail.}
\end{figure}
(GRITS) is the dry grinding/polishing system developed by Honeybee Robotics [2]. The GRITS breadboard configuration was similar to the IS-ARTS design shown in Fig. 1. It was designed so that the grind station could be oriented to grind with either a cup or straight type grinding wheel. The sample holder was mounted to a load cell to provide information on the force with which the wheel is pressing against the rock and in turn the grind pressure and was mounted to a precision linear lift stage with a resolution of 0.2 microns.

Using autonomous grinding the GRITS system successfully completed grinding of a tablet to a thickness of ~33 microns and to a surface finish that is adequate for petrographic analysis using a polarizing microscope. In Fig. 2 micrographs of an Anorthosite sample are shown. While the traditionally prepared thin section is clearly superior to the GRITS prepared thin section, the GRITS prepared thin section was deemed adequate for petrographic analysis by a petrographic expert.

**Diamond Wire Cutter Breadboard:** A breadboard diamond wire cutter was developed at the Colorado School of Mines [3,4]. The breadboard was instrumented to measure cutting forces, wire speed, and sample advancement rate. The diamond cutter requires less energy, reduces over-cutting waste (kerf), produces less dust, has the capability to cut in multiple directions, and reduces system weight and volume relative to other cutting devices. Tests of wire performance, wear rate, specific energy used, and viability of different configurations were conducted. Rock grippers using a pin array were breadboarded and found to be adequate for gripping of samples for cutting using diamond wire.

**Microscope:** The microscope shown in Fig. 1 would include a color camera and optics to operate at fixed magnification. A linearly polarized white light source below the linear rail transmits light through the thin section. The microscope would contain an analyzing linear polarization filter crossed to the transmitted polarization. Similar focal plane arrays and microscope optics have already been developed for space missions. For example, the MArS HandLens Imager (MAHLI) instrument developed for the MSL mission is a good example of spaceflight instrument that could be adapted to a petrographic analysis application [5].

**Flight System Estimates:** Based on a hypothetical 2-year mid-latitude Mars mission, and a requirement to produce 50 thin sections of rocks having varying hardness, a flight system is estimated to have a mass of less than 15 kg and maximum sustained average power 23 W. These estimates are based on breadboard testing, experience with the MER RAT instrument [6], and the performance of flight microscopes [5]. Time to produce a thin section is highly dependent on rock physical characteristics, primarily hardness and porosity. Total time required to produce a thin section from a hard igneous sample is on the order of 30 hours. Most of this time would be spent grinding the sample. Thin section preparation would proceed in stages spread out over several days depending on mission priorities.

**Conclusions:** The development of an automated rock thin section device for space exploration is a challenging endeavor. The IS-ARTS conceptual design shows that although challenging the *in situ* production of thin sections on planetary science missions is possible.

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