# Rotary Percussive Sample Acquisition Tool

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## ABSTRACT

As part of a potential Mars Sample Return campaign NASA is studying a sample caching mission to Mars, with a possible 2018 launch opportunity. As such, a Sample Acquisition Tool (SAT) has been developed in support of the Integrated Mars Sample Acquisition and Handling (IMSAH) architecture as it relates to the proposed Mars Sample Return (MSR) campaign. The tool allows for core generation and capture directly into a sample tube. In doing so, the sample tube becomes the fundamental handling element within the IMSAH sample chain reducing the risk associated with sample contamination as well as the need to handle a sample of unknown geometry. The tool's functionality was verified utilizing a proposed rock test suite that encompasses a series of rock types that have been utilized in the past to qualify Martian surface sampling hardware. The corresponding results have shown the tool can effectively generate, fracture, and capture rock cores while maintaining torque margins of no less than 50% with an average power consumption of no greater than 90W and a tool mass of less than 6kg.

## INTRODUCTION

As expressed in the planetary science decadal survey, the highest priority Flagship mission should be a Mars surface science and sample caching mission in support of the NASA-ESA Mars Sample Return campaign [1]. Therefore, if a future goal of the Mars exploration program is to return planetary samples to Earth for analysis it is foreseen that a Sample Acquisition and Caching (SAC) subsystem would be necessary to perform core and soil acquisition, sample caching, and sample canister placement on the Martian surface. In support of this, the Integrated Mars Sample Acquisition and Handling (IMSAH) architecture was developed in order to advance the key elements necessary for end-to-end sample generation and containerization. The IMSAH architecture has been presented in depth in previous publications [2, 3, 4, 5] and is characterized by the following three sub-elements and shown in Figure1:

(1) Tool Deployment Device (TDD)
(2) Sample Acquisition Tool (SAT)
(3) Sample Handling Encapsulation and Containerization (SHEC).

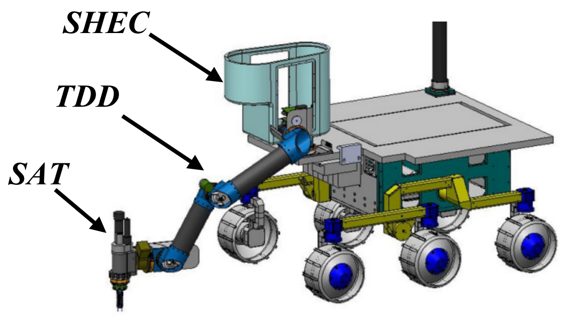


**Figure 1. Integrated Mars Sample Acquisition and Handling (IMSAH)**

In addition, the IMSAH architecture is defined by the following operational needs [2], [5]:

- Bit change-out would be utilized to perform the sample transfer from the coring tool to the caching subsystem.

- Each sample would be acquired into its own sample tube in order to prevent the risk of sample contamination as well as handling cores of unknown geometry.

- A rotary percussion mechanism would be utilized for coring in order to keep subsystem mass to a minimum and maximize efficiency. The rotary percussive tool results in successful coring with less weight on bit (i.e. lower arm preload), does not induce bit walk, and would allow for robust hole start when compared with rotary only alternatives.

- The coring tool deployment, alignment, and feed would be performed utilizing a five degree-of-freedom robotic arm. In using the specified deployment arm the system has enough DOFs to provide tool alignment and accommodate modest rover slip.

Of the three IMSAH sub-elements this paper will focus on the development and testing associated with the Sample Acquisition Tool.

## SAMPLE ACQUISITION TOOL OVERVIEW

**SAT Description.** The SAT was developed to provide for autonomous core generation, fracture, capture, as well as bit change-out. Since the IMSAH architecture utilizes a 5-DOF TDD for tool deployment, alignment, and feed; a less complex coring tool can be utilized than what has been proposed in the past for autonomous coring tools. As such, the required weight on bit is provided by the TDD through a lightly sprung linear compliance stage between the turret and the coring tool [2].

**SAT Requirements**. The necessary functions required to provide the operations listed above are satisfied by the following SAT design requirements:

- Acquire rock cores with dimensions approximately 1 cm in diameter by 5 cm in length

- Acquire at least 20 rock cores for return.

- Acquire samples from Kaolinite, Limestone, Siltstone, Saddleback Basalt, and Volcanic Breccia.

- Be able to eject a bit that inadvertently is stuck in a rock.

- Be robust to anomalous cores that may be broken in the bit and/or at the bit opening.

- Account for catastrophic slip conditions where it is presumed the rover would experience a significant shift in position while the SAT tool is in use.

- Cores need to be of appropriate quality and suitable for caching.

**Core Quality.** Core quality is evaluated qualitatively and binned into three categories :

- Good – full length cores or in a few large segments
- Acceptable – mostly segments, discs, and/or pucks
- Bad – Powder and/or small chunks, stratigraphy not maintained

## SAMPLE ACQUISITION TOOL DEVELOPMENT

**Assembly Overview.** The Sample Acquisition Tool prototype is comprised of the following four mechanisms, shown in Figure 2, which provide the necessary functions for performing core generation, fracture, and capture:

(1) Spindle Percussion Assembly (SPA)
(2) Core Breakoff Assembly (CBO)
(3) Magnetic Chuck Assembly (MCA)

(4) Core Bit Assembly (CBA).

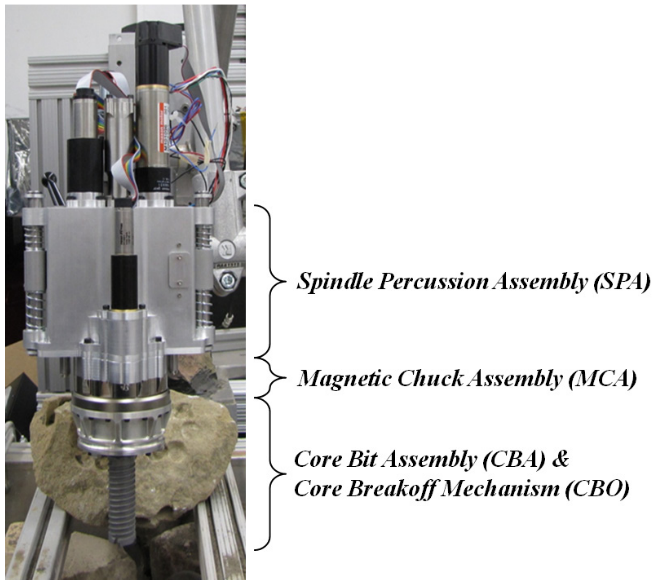


**Figure2. Sample Acquisition Tool (SAT)**

As mentioned previously, a key enabling feature of the tool is the ability to core and acquire the sample directly into the sample tube allowing for the tube to become the handling component within the sample chain. In order to allow for ease of integration and testing, the four mechanisms were designed to allow for independent operation and actuation to facilitate subassembly functional verification and validation.

**Spindle Percussion Assembly (SPA)**. The SPA provides the impact energy necessary to facilitate rock fracture thru the use of a CAM/lever which drives a striker mass and is actuated thru the rotation DOF provided by the spindle drivetrain. This rotation DOF is also utilized to provide the necessary CBA actuation as well. In addition, the SPA also provides the means for actuating and interfacing with the CBO thru a secondary drivetrain.

**Magnetic Chuck Assembly (MCA).** The MCA utilizes two permanent magnets who's magnetic poles can either be aligned (chuck engaged) or misaligned (chuck disengaged) by rotating one of the permanent magnets relative to the other. The implementation of a magnetic chuck was selected in order to accommodate a passive breakaway of the bit from the tool in the event of a gross rover slip condition during operation.

**Core Bit Assembly (CBA).** The CBA interfaces with the SPA and transmits the generated impact energy to the rock surface as well as accept the rotation DOF from the spindle drivetrain. In addition the CBA is utilized as the mechanical constraint for the CBO during core break-off. The major component of the CBA is the custom coring bit which is free to not only rotate but translate axially thus ensuring maximum transmission of the impact energy to the rock.

**Core Breakoff Mechanism (CBO).** A cleaving approach was selected for the CBO in order to provide a well-controlled and predictable fracture plan. As such, the core is fractured by utilizing two opposing sharp edges symmetrically split about the bit axis. As previously mentioned the CBO is actuated through the CBO drivetrain located within the SPA and is designed to fracture cores that range in diameter from 9 mm to 10 mm. In addition, the CBO is designed to fully retain the fractured core until the sample is transferred to the SHEC.

## UNIT LEVEL VERIFICATION

The tool's unit level functional verification was performed utilizing a non-actuated 5-DOF arm with a stiffness that is equivalent with existing tool deployment devices. The non-actuated arm was utilized for not only positioning the tool adjacent to the rock samples but to also provide realistic boundary constraints during testing. In addition, in order to simplify the test setup a linear z-stage was utilized at the turret interface to provide the feed motion which would nominally be provided by the TDD within the IMSAH architecture. The testing was performed utilizing the proposed rock suite provided in the SAT requirements list. The rocks included within the test suite were selected based on their wide range of properties that are analogous to Martian rocks and have been used previously to qualify Martian surface sampling hardware.

Since the tool mechanisms were designed to be modular, the first series of verification tests were performed at the mechanism level in order to characterize individual mechanism torque capabilities and losses. Once the individual mechanisms were appropriately characterized the SAT unit level testing was completed with an emphasis on verifying:

- impact energy generation
- rate of progression (drilling)
- end-to-end core generation, fracture and capture.

For the purpose of brevity the individual mechanism test results related to torque margin as well as the unit level test results associated with impact energy will not be discussed.

**Rate of Penetration.** Two bit sizes were utilized during the unit level testing in order to get an assessment of the variability of penetration rate as it relates to bit diameter. As may be expected, the rate of penetration (ROP) is highly dependent on the wear of the bit teeth as well as the volume of material that needs to be removed in order to expose the "fresh" rock surface. Due to the limited resources available an indepth characterization of bit diameter vs. ROP could not be investigated however two bounded cases were selected:

(1) Min Bit OD – 22.56 mm

(2) Max Bit OD – 24.36 mm

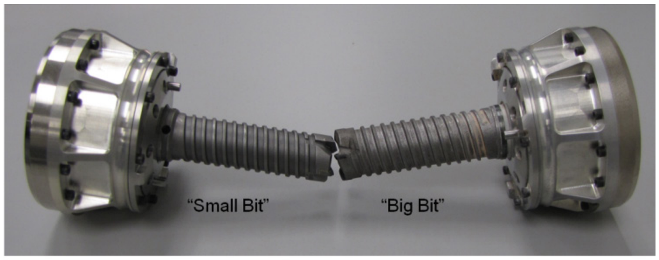


**Figure 3. Comparison of 22.56 mm bit vs the 24.36 mm inch bit utilized during the rate of penetration (ROP) investigation.**

For the purpose of the investigation relatively unworn bits were utilized in order to limit the number of test variables. The results of the testing are shown in Table 1 where it can be seen that even a small reduction in bit size, on the order of 30%, can improve ROP by greater than a factor of 2.

**Table 1. As measured rate of penetration (ROP) of coring tool vs. bit diameter.**

| | Average Drilling Rate (mm/min) | | Total Drilled Depth (mm) | |
|---|---|---|---|---|
| | 7/8" Bit | 3/4" Bit | 7/8" Bit | 3/4" Bit |
| **Limestone** | 26.2 | 59.6 | 640 | 178 |
| **Kaolinite** | 49.3 | 162 | 214 | 70 |
| **Siltstone** | 6.3 | 27.9 | 472 | 110 |
| **S. Basalt** | 2.4 | 7.9 | 231 | 166 |
| **V. Breccia** | 1.3 | 2.7 | 204 | 67 |

**End-to-End Core Generation, Fracture, and Capture.** In all cases, the CBO successfully fractured and retained the cores within the sample tube. In addition, the core quality based on the metric defined above and the images shown in Figures 4 through 5 below were determined to either be good or acceptable. It is important to note that it was observed that the generated cores were not of uniform cross-section. It is believed this is the result of the minor instability of the drill observed during hole start, due to the low arm stiffness, which produced a slightly smaller diameter at the top of the core when compared to its base.


**Figure 4. Generated cores in Kaolinite (left), Siltstone (middle), and Volcanic Breccia (right).**

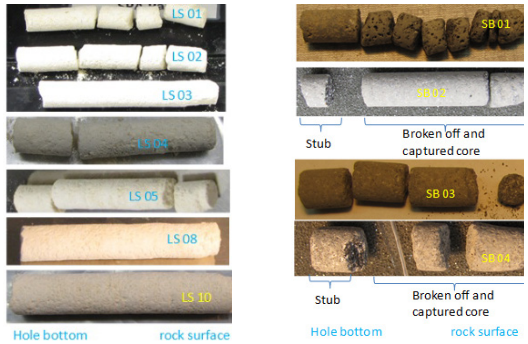


**Figure 5. Generated cores in Limestone (left) and Saddleback Basalt (right)**

## CONCLUSSION

It has been shown that a low mass Sample Acquisition Tool (SAT) has been produced that can be utilized to succesfully generate cores, fracture and separate the core from the parent rock, and retain the cores within a sample tube. The tool was developed in support of demonstrating coring tool functionality necessary for the Integrated Mars Sample Acquisition and Handling (IMSAH) architecture. A key element of the tool is the ability to core and capture samples directly within a sample tube allowing for a significant reduction in risk associated with sample contamiantion. Furthermore, the sample tube becomes the main handling element within the sampling chain reducing uncertainity and additional risk associated with having to handle cores of unknown geometry. Although not specifically identified above, the unit level verification and validation testing has shown the tool provides the necessary capability across the proposed test suite while maintianing the necessary torque margins and low average power consumption while retaining a tool mass of less than 6kg.

## ACKNOWLEDGEMENTS

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