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Application of Pneumatics to Sample Acquisition and Delivery for Planetary Surface Missions

Kris Zacny, **Stephen Indyk**, Fredrik Rehnmark, Tighe Costa, Joseph Sparta,Vishnu Sanigepalli, Bernice Yen, David Yu, Jameil Bailey, Dean Bergman and Will Hovik.
Honeybee Robotics Exploration Technologies Group, Pasadena CA, USA (sjindyk@honeybeerobotics.com)

Abstract

Traditional sample acquisition, transfer and capture approaches depend on mechanical methods (e.g. drill or a scoop) to acquire a sample, mechanical methods (e.g. robotic arm) to transfer the sample and gravity to capture the sample inside an instrument or a sample return container. This approach has some limitations: because of reliance on gravity, it is best suited to materials with no or little cohesion. Because of the sample transfer requiring mechanical system, the instrument or sample return container need to be easily accessible. Pneumatic based systems solve these problems because the pneumatic force can exceed the gravitational force and the sample delivery tubing can be routed around other spacecraft elements, making instrument or sample return container placement irrelevant to the sampling system. Background is presented on pneumatic systems applied to planetary missions and provides examples how this could be accomplished on planetary bodies with significant atmosphere and on airless bodies.

1. Introduction

Future planetary surface missions seek to capture surface and subsurface samples and deliver them to in-situ instruments for analysis. Pneumatic systems are used extensively on Earth to move drill cuttings out of the hole during a drilling process as well as to transfer powders. Pneumatic systems have been well characterized and both fundamental equations as well as empirical data can be used to size tanks, valves, and hose diameters. The main benefit of pneumatics is that they are extremely well suited for handling unstructured material such as powder or rock cuttings. In the most basic design, sample to be transported is placed on one side of a tube and sometime later it appears on the other side of a tube with the help of a carrier gas. Even sticky material can be moved with increased gas pressures and flow rates. For almost twenty years, Honeybee Robotics has been developing pneumatic-based systems for planetary surface missions requiring samples for the in-situ instruments, sample return, or for deployment of instruments at some depth [3-5]. Reduced gravity flights (lunar g) in vacuum conditions (5 torr) revealed that with 1 gram of gas at 60 kPa pressure, up to 6000 g of gas can be lofted at high speeds [3]. This high mass ratio efficiency is mainly attributed to vacuum, with secondary effect being lower gravity.

2. Pneumatic Sample Acquisition Methods

On Mars, the Moon, and Europa, sample acquisition can be achieved using compressed air that accelerates particles into a transfer tube or a container. There are many variations of how this can be achieved. For example, gas can be injected into the regolith and later 'escape' into vacuum while accelerating regolith particles (Figure 1). This is also observed when spacecraft propulsive lands on a planetary surface covered with regolith. During landing, gas from rocket thruster penetrates regolith underneath the thruster. Once the engine shuts off, the gas pressure inside the regolith is no longer sustained by the gas pressure from the engine thrust, and the gas escapes upwards, carrying regolith with it.

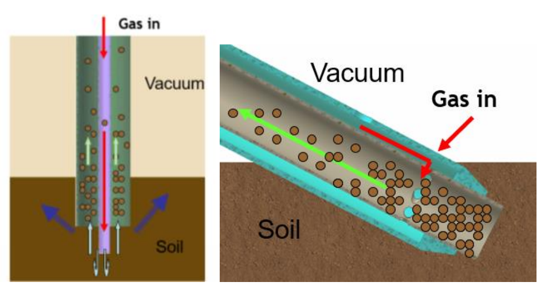

Figure 1: Options for pneumatic sample acquisition.

If particles are captured inside a sampling tube, gas could be injected at the bottom of the tube and move the sample directly into a container (Figure 2). The sampling tube could be either pushed into the surface during landing (passive option) or pushed into the surface after landing (e.g. using a preloaded spring).

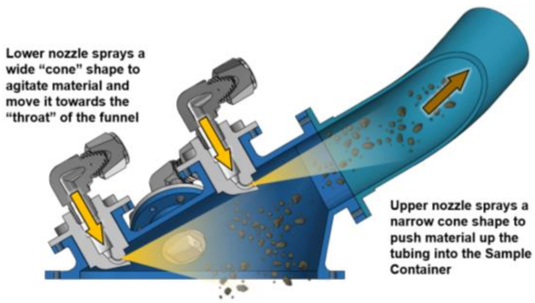

Figure 2: PlanetVac style sample acquisition.

Compressed gas could also be used as a "broom" to sweep particles from the planetary surface or the scoop into a container or a transfer tube (Figure 8). For this to happen, gas jets need to be at a relatively shallow angle to the horizontal and pointed towards the collection container [1]. Several nozzles could be placed in strategic locations to enable more efficient transfer; some could be pointed towards the surface and some towards the sample container. The firing of the gas jets would need to be synchronized; the jets pointed towards the ground would fire up first to stir up the sample and the jets pointed towards the container would fire some fraction of a second later to move the loosened-up regolith into the container.

3. Applications

Numerous approaches to pneumatic sample acquisition, transfer, and capture are possible. Pneumatics offers significant benefits over traditional gravity driven approaches and in turn is well suited on planetary missions, where material to be sampled is of unknown cohesion. Pneumatics also offers ability to place the instrument or sample return container at some distance from the sample acquisition hardware since transfer tubing can be routed around potential obstacles. Gas can be used to clean up transfer hoses and in turn minimize cross contamination. Currently, pneumatic based approaches have been implemented on CAESAR [1] and Dragonfly [2] New Frontiers candidate missions, the P-Sampler on Mars Moon eXplorer, Lunar Heat Flow Probe [6], and PlanetVac [7].

Acknowledgements

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