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Conceptual Study of a Combined Hammering/Melting Drill Device for Investigations of Icy Planetary Subsurfaces – The 'Cryo-Mole'

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Abstract

We will provide details on the concept development of a combined hammering and melting probe for icy planetary subsurfaces as can be found on the Moon, Mars, Titan, and Europa and also for terrestrial purposes. By means of numerical simulation using a mechanical soil intrusion model combined with a thermal melting model, basic parameters such as penetrator length, diameter, hammering energy and heating power have been estimated for the combined system.

1. Introduction

The Jovian moon Europa gains more and more interest in the planetary community, since it is not only geologically of particular interest with its earth-like internal structure, but also from the astrobiological point of view of special importance. This is due to past discoveries, which have proven the existence of a liquid water ocean under Europa's thick icy crust, one of the ingredients for having life on a planetary body.

A joint-venture exploration mission between NASA and ESA is currently under investigation, which has this interesting moon as one of its targets. Planned for launch in 2020, the EJSM/Laplace mission will send an orbiter there, which will investigate the body more in detail [1].

Ultimately, considering Europa's astrobiological potential, the best way to explore its mysteries is to send a vehicle for the in-situ investigation of the chemical and biological properties of the ice crust. At the moment, such a lander is being studied by the Russian Academy of Sciences and Roscosmos. The lander would have the capability of including roughly 60 kg of payload to be operated during a lifetime of a few days [2]. Also, in the past, several concepts of melting probes, so called 'Cryobots' have been proposed for assessing the ice layer of Europa and it has proven that essentially revolutionary technologies will be needed to cope with the highly demanding constraints imposed on such a system, i.e. considering mass, volume and power budgets, but also environmental and planetary protection requirements. Ultimately, new technology will be needed to access the ice layer, either for inclusion as an instrument to be deployed by the lander and to penetrate only a few meters of the upper layer, or as a complete separate vehicle which can go even deeper into the subsurface.

A research of conventional technologies for subsurface access has proven that each existing technology has its advantages and limitations, as shown in Tab. 1. A promising, yet not investigated possibility is the development of a combined device using the mole principle (e.g. of the PLUTO-mole) and the melting process of so called 'Cryobots'.

2. Technology Description

2.1 The 'Mole'

At the German Aerospace Center DLR, a hammering drill ('mole'), called PLanetary Underground TOol (PLUTO) has been developed for the Beagle-2 lander, to represent a new and promising direction for subsurface sampling and in-situ measurements of planetary soils.

Tab. 1: Comparison of Subsurface Penetration Concepts

Criteria	Depth	Mass	Size	Power	Dealing with Obstacles / Dust Layers	Sampling Issues
Mechanical / Rotary Drilling	Restricted by drilling rods	high: motor and drilling rods	moderate	high	no problem	Difficult
Melting Probe	restricted by length of cable	small: heater	small	small: heating; losses through tether	problem in case of soil layers and rocks	only frozen samples
Rotating Drillhead + Melting	restricted by length of cable	moderate: heater + drilling gear and motor	moderate	medium: heating + drilling motor; losses through tether	Dealing with soil layers is feasible, but risks of blockage remains	probably only frozen samples; eventually cuttings

The PLUTO-mole uses an internal electro-mechanical hammering mechanism for forward movement into the soil, thereby reaching depths of a meter and more. Compared to conventional rotary drilling this method provides an innovative lightweight and low power solution not only for collecting subsurface samples, but also for carrying sensors to perform in-situ investigations of the subsurface. Investigations have been performed for the optimal configuration of mole and instrument compartment, where a two-body mole configuration with a trailing mole and a trailed payload compartment has found to be the best solution for intrusion into the Martian soil [4].

As this tool has originally been developed for the application on Mars, it is currently under investigation for utilization in the lunar environment and likewise we propose its utilization at the Jovian moon Europa and other planetary bodies such as Titan.

2.2 Melting Probes and ‘Cryobots’

Melting probes or ‚Cryobots’ have first been proposed by Philbert and Aamot [5] to penetrate glacial ice up to a thickness of a few hundred meters. These probes were equipped with a heated tip, which allowed, given a high enough energy input, the melting of the ice ahead, thereby realizing the forward motion. They worked well under terrestrial environment, where a sufficient pressure sustained a liquid phase in front of the probe. However, recent investigations on adapting this technology for planetary bodies (e.g. Europa), where pressures are very low (down to vacuum), aroused some new questions dealing with sublimation and heat transfer under vacuum conditions and in very cold ice [6].

3. Research Overview

This paper will give an overview over a deeper concept investigation of the combined system. We will identify requirements for different solar system bodies, with Europa as basic application, but also for Mars, Moon, Titan and terrestrial investigations. To find out about the necessary adaptations of the existing system for such an application, we will also have to define basic constraints, such as penetrator length, diameter, hammering energy and heating power. These parameters will be assessed by combining the existing numerical models of the two mechanisms, e.g. the soil intrusion model of the mole and the melting model of the ‘Cryobots’.

Based on the parameter study, a first baseline-design will be presented, which will include for instance the design of a pressure vessel for the mole housing to prevent the mechanisms and electronics from intruding water, the implementation of a tip-heating to facilitate movement in the ice-soil mixture and the general heating concept of the system.

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