ACCESSING MARS CLIMATE RECORD THROUGH DEEP-SUBSURFACE PULSED PLASMA DISCHARGE DRILLING

Research and Technology Development Annual Report

JPL Task #R20113

Fernando Mier Hicks (PI), Mobility & Robotic Systems Section (347)
Benjamin J. Hockman, Mobility & Robotic Systems Section (347)

A. OBJECTIVES

Plasma drilling is a deep drilling technology which leverages electrical discharges to fracture rocks and sediments. Plasma drilling is investigated as a performance enhancer for existing thermal-probe technology for use in planetary sub-glacial exploration missions. The hypothesis is that the cracking of ice induced by the plasma discharges results in a local reduction of thermal conductivity capable of decreasing the conductive thermal losses that make up the majority of a thermal probe's power budget in cryogenic ice conditions.

B. STRATEGIC FOCUS AREA

Topics:

[X] Localization and Mobility

C. BRIEF BACKGROUND

Subsurface samples are imperative for determining the composition of planetary objects such as Mars and Europa. Analysis of these samples provide insight regarding both the structure of these bodies, their climate history, as well as searching for life. Drilling into these extreme environments, however, presents a challenge due to the low pressure and low temperature environments as well as the power limitations of the available equipment. The two predominant methods involve either mechanically breaking or thermally melting down the material.

Melt probes require a substantial amount of power, so boosting their efficiency is necessary before they can be used on other planets. Current melt probe designs experience a low-level efficiency due to the dissipation of thermal energy to the surrounding ice. A plasma drill capable of pulsed plasma discharges can create shockwaves that crack the surrounding ice reducing its equivalent thermal conductivity. After cracks have been formed, a traditional hot-tip melt probe can be used to melt the ice surface with a decreased loss of thermal energy.

In addition, it is noted that the shockwaves produced by plasma discharges are capable of yielding seismic data of the surrounding subsurface area.

D. APPROACH AND RESULTS

The single objective for Y3 was to validate the power efficiencies of the plasma drilling concept. The thermal probe constructed on Y2 would descend through the testbed ice also developed during Y2 with and without performing plasma discharges. By comparing both modes, the performance gains of a plasma-aided probe will be experimentally quantified against a baseline.

The only additional piece of hardware to enable this objective was a functioning plasma discharge module.

Plasma discharge module

The integral component of this task, several revisions of a high-voltage module capable of delivering pulsed-plasma discharges were designed and tested. Four new revisions were explored bringing the latest revision to version 16, Fig1-A/B. Note that twelve revisions of this component were iterated during FY21.

The large number of revisions were due to the peculiar challenges in realizing a compact, mechanically robust, self-heating, plasma discharge module. Versions from FY21 did not survive plasma discharges as they would break apart. Intermediary versions were able to sustain dozens of plasma discharges but ultimately ended up breaking apart as well. Two conflicting properties make the design of the plasma module challenging:

the need for it to be electrically insulative up to 40kV, which limited materials to epoxy/resins and plastics.

The need to be thermally conductive. Since the module sits on top of the melt head of the probe, it needs to generate some heat to avoid getting frozen in. The electrical heaters on the module need to be sufficiently isolated from the high voltage portion to avoid shorts. The fact that the main material of the module is epoxy/resin makes transferring the heat from the heater to the external surface an inefficient process.

The latest version generated at the end of FY21, relied on a relatively thin aluminum shell that encapsulates the plastic and epoxy filing of the module. The metal shell provides excellent mechanical robustness and allows heat to effectively transfer to the ice. The drawback is that due to the small dimensions of the test probe, there is no possibility to sufficiently isolate the high voltage components of the module to this aluminum shell. In order to avoid shorts, the metal chassis of the probe, connected to the aluminum shell of the discharge module, will be temporarily disconnected from ground when performing discharges. This electrical configuration, although easier to work with in laboratory environment, is not realistic for a flight probe. This design was the first one tested in FY22.

All the modules pursued in FY22 had three spark gap locations on the outer diameter of the module, Fig1-B. The key points of consideration in the design were (1) to avoid having electrical arcing occur anywhere in the module, aside from the intentional discharging at the three spark gaps, and (2) to have the discharge module's outer surface heat up enough so it doesn't get frozen in ice. To achieve the first point, a strong and electrically insulative epoxy was used as the main body material of the module. To achieve the second

E. SIGNIFICANCE OF RESULTS/BENEFITS TO NASA/JPL

From FY20, the preliminary findings of the thermal model, when coupled with the thermal conductivity experimental data, shows that a 25% reduction in thermal conductivity from the plasma discharges generate 10-20% savings on consumed power for constant probe geometry and descend velocity. These power savings could enable a thermal probe mission to Mars that employs solar power as opposed to a significantly more expensive RTG mission. Furthermore, these efficiencies could be applied to any thermal probe on any planetary system, including Ocean Worlds. Even a radioisotope-powered thermal probe on Europa on Enceladus could benefit from the reduction on thermal conductivity and increase descend velocity without incurring penalties on power.

That being said, the engineering challenges discovered during FY21 and FY22 will make any gains on power efficiency a difficult trade with respect to considerable complexity the plasma module adds. The design, assembly and operation of a compact, heated, plasma discharge module is challenging under laboratory conditions which indicates that designing a flight version would be a non-trivial task.

The new fluid-based RPS powered probe prototype will be used as leverage for future, external and internal, funding opportunities calls that look to develop technologies related to melt probes. Such

F. NEW TECHNOLOGY

List relevant NTR numbers: 51627.

None

G. FINANCIAL STATUS

The total funding for this task was $50,000, all of which has been expended.

H. ACKNOWLEDGEMENTS

None

I. PUBLICATIONS

[A] Guglielmo Daddi, Fernando Mier-Hicks.Thermal Probe Enhanced with Pulsed Plasma Discharges for Efficient Ice Penetration. Journal of Thermophysics and Heat Transfer 0 0:0, 1-8

J. REFERENCES

None

K. APPENDIX

None

L. FIGURES

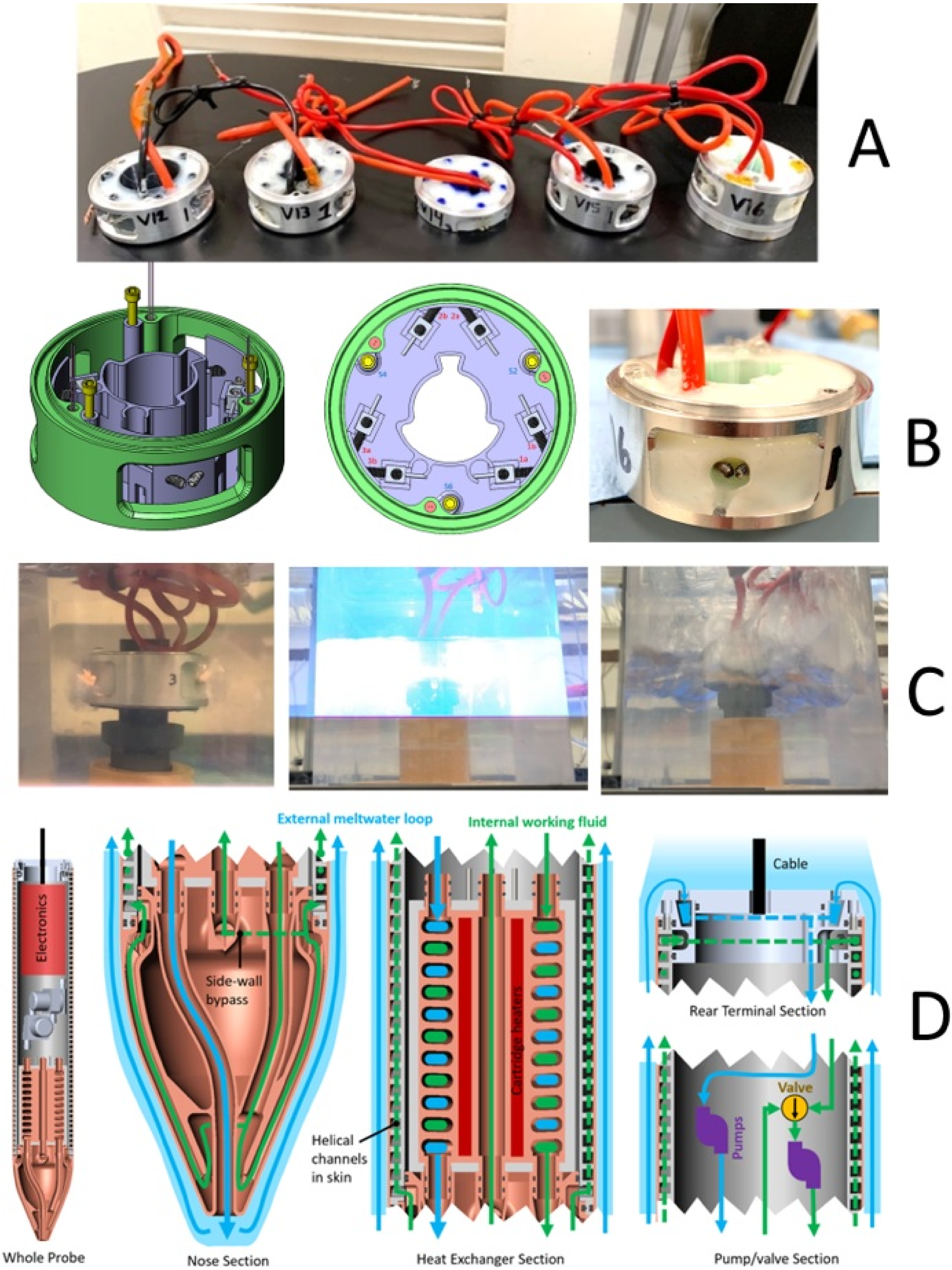

Figure 1. Figure 1 A) Four revisions of the plasma discharge module pursued in FY22. B- Version 16, Survived over 1500 discharges in water. C Version 16 discharging in water

M. COPYRIGHT STATEMENT