Rock Sampling using the Ultrasonic/Sonic Driller/Corer (USDC) for In-situ Planetary Exploration

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Ultrasonic/Sonic Driller/Corer (USDC)

- Backing
- Stack
- Horn
- Powder cuttings
- Rock
- Drill bit
- Ultrasonic Actuator (Backing/Stack/Horn)
- Free-Mass

2000 R&D 100 award
Applications of the USDC

**Quiet concrete drill**

**Powdered cuttings sampler**

**Lab-on-a-drill:** perform probing and sampling (dust and cores) using sensors integrated on the bit (fiberoptics, thermocouple, etc.)

Simple feasibility tests were made operating the USDC from the Sojourner and the FIDO robotic arm.

**2000 R&D 100 award**

**Proto-flight unit**

**Ultrasonic Gopher** for deep drilling

**Ultrasonic Rock Abrasion Tool (URAT)**

Imparted elastic waves are investigated for screening sampled media.
Drilling rate for different maximum power

The average power is maintained at 10 watts by duty cycling the power supply.

Note: The range described by the error bar was determined experimentally from a variety of rock samples.
Soil penetrator and test bed

- Using 7 lb preload at ~70W and 20% duty cycled power, we reached a depth of 3-ft (~90-cm) in 30-40min.
- Since we used duty cycling the net drilling time is only about 6-8 minutes.
The Ultrasonic/Sonic Driller/Corer (USDC) as a probing, sampling and sensing system

• The USDC was demonstrated to core samples from rocks that range in hardness from soft to very hard using very low axial force and with no need for bit sharpening.

• Effective sampling of cores, gases and powdered cuttings is being developed.

• The capability to probe the sampled medium and the ability to equipped it with sensors are being established.

Imparted elastic waves are investigated for screening sampled media

USDC equipped with sensors on the bit and tubing for acquisition of powdered cuttings

Surface wave receivers
Bit Temperature measurements

A thermocouple was integrated into the USDC bit to allow real-time monitoring of the temperature during drilling.

Temperature rate of rise and maxima as a function of time for drilling variety of media

- Power < 40 watts
- Bit diameter = 3.6 mm
Integrated fiberoptics and measured reflectivity

Preliminary study jointly with Research International, Inc

Differential response in the range of 545nm and 700nm
Coring basalt via the USDC
USDC Core Breaking/Holding/Extracting

All-in-one bit using an internal wedge and side springs

Retaining spring and a grabbed core

Two created cores (out of two attempts)
Powdered Cuttings

USDC crusher

- The USDC is used as a rock crushing, milling, and powdering device.
- Its actuator harmonic motion creates a series of low frequency impacts that grind the sample into powder within a short time period.
- A crushing chamber confines the free-mass to movement in one direction only leading to a very efficient milling.
- The grinding effect can be enhanced by making a free-mass with teeth on its interface with the sample.
Dimensions reduction

- Using a folded horn the length of the powdered cuttings sampler was significantly reduced.
Powdered Cuttings Sampler

A view of the bit cutting edge

Sampled powder

The sampler in action drilling limestone and accumulating powdered cuttings inside the bit
LANL’s Lab XRD patterns of the <45 μm USDC powder (blue) compared to the Retsch milled <5 μm powder (red).

Note: The patterns compared extremely well.
Dog-bone horn

The dog-bone horn offers in addition to the performance enhancement also design benefits as a mounting fixture.

Neck Diam: 7.5 mm, Length: 75.5 mm, Freq.: 19.3 KHz
Operation in extreme environments
Comparison of various Piezoceramics with BiScO$_3$–PbTiO$_3$

<table>
<thead>
<tr>
<th>Material</th>
<th>Structure</th>
<th>$T_c$ (°C)</th>
<th>$P_r$</th>
<th>$E_c$ (kV/cm)</th>
<th>$d_{33}$ (pC/N)</th>
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<tbody>
<tr>
<td>PZT-5A (soft)</td>
<td>Perovskite (MPB)</td>
<td>330</td>
<td>36</td>
<td>~ 10–12</td>
<td>~ 400</td>
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<tr>
<td>PZT-8 (hard)</td>
<td>Perovskite (MPB)</td>
<td>330</td>
<td>25</td>
<td>&gt; 15</td>
<td>~ 225</td>
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<tr>
<td>PbNb$_2$O$_6$ (modified)</td>
<td>Tungsten Bronze</td>
<td>~ 500</td>
<td>—</td>
<td>—</td>
<td>~ 85</td>
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<tr>
<td>Na$<em>{0.5}$Bi$</em>{4.5}$Ti$<em>4$O$</em>{15}$</td>
<td>Bismuth Layered</td>
<td>~ 600</td>
<td>—</td>
<td>—</td>
<td>18</td>
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<td>BiScO$_3$–xPbTiO$_3$ x=62</td>
<td>Perovskite (rhombohedral)</td>
<td>420</td>
<td>28</td>
<td>17</td>
<td>290</td>
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<td>BiScO$_3$–xPbTiO$_3$ x=64</td>
<td>Perovskite (MPB)</td>
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<td>Perovskite (tetragonal)</td>
<td>460</td>
<td>23</td>
<td>25</td>
<td>260</td>
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</table>

Ref: T. Shrout, Penn State U.
Demonstrated drilling cold ice including: -40°C crashed ice, crashed ice with water and solid ice as well as -140°C in crashed ice and solid ice.

- **Crashed ice at -40°C and 140°C** - At both -40°C and 140°C no problem drilling and the speed was too fast to measure.
- **-40°C slush ice with water** - Drilled 7mm deep using 6-mm diameter drill in 1-minute.
- **-40°C solid ice** - About 1-cm in about 30-sec.
- **-140°C solid ice** - Cored about 3-mm deep using a 10-mm diameter
- **-40°C and -60°C** - Environmental testing for 160 hours

Tests were done at the JPL’s Extraterrestrial Materials Simulation Laboratory.
A total of 1.25-m was accomplished in a total drilling of 5 hours with an average drilling of 0.25 m/hr.
Field test in Lake Vida, Antarctica

A total depth of 176cm was reached

Lake Vida test site.

Inside the drilling tent.

The gopher in the drilled hole
SUMMARY

The USDC has been studied as a probing device that can sample cores, powdered cuttings as well as operate as a platform for sensors.

Noninvasive probing
- The reflection and transmission of imparted elastic waves (bulk and surface) were measured to establish means of rocks characterization. Also, the effect of loading the actuator by the sample were monitored by measuring the change in impedance and resonance frequency.
- Surface wave velocity measurements were the only reliable quantitative data that was obtained.

Sampling techniques
- Methods of operating the bit as an all-in-one unit for extraction of cored rocks (including basalt) with maximum integrity were developed.
- Devices for the acquisition of powdered cutting and cores of various materials were developed and being studied including powder sampler, gopher and many others.

Integrated sensors
- An integrated thermocouple showed great potential in determining the hardness of drilled rocks using the heating rate and maximum temperature rise. Assuming relatively similar heat transfer to rocks, this should provide an effective sensing technique. It can also help protecting cored samples from thermal damage.
- We demonstrated the integration of an optical-fiber into a bit and the measurement of reflectance and fluorescence levels in the wavelength range of 400 – 1150 nm.