Realtime Sensing while Drilling using the USDC and Integrated Sensors

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Summary: *The search for existing or past life in the Universe is one of the most important objectives of NASA's mission. In support of this objective, an ultrasonic based mechanism is being developed to allow probing and sampling of rocks and soil. The novel lightweight Ultrasonic/Sonic Driller/Corer (USDC) used in this study takes advantage of its ability to drill with low axial force and low power. These advantages overcome some of the major limitations of planetary sampling using conventional drills in low gravity environments. Sensors, such as thermocouple and fiberoptics, are integrated into the bit and used to perform real-time analysis while drilling.*

Keywords: *Ultrasonic drilling, piezoelectrics, sensors, fiberoptics*
Category: *10 (Applications)*

1 Introduction

Future NASA exploration missions to Mars, Europa, Titan, comets and asteroids are seeking to perform sampling, in-situ analysis and possibly the return of material to Earth for further tests. For this purpose effective instruments that can sample and conduct in-situ astrobiology analysis are being sought. As sampling devices, existing drilling techniques are limited by the need for large axial forces and torques, high power consumption and an inability to efficiently duty cycle. Lightweight robots and rovers have difficulties to accommodate the constraints of existing drills. To address these constraints and the challenges to the NASA objective of planetary in-situ sampling and analysis, an ultrasonic/sonic driller/corer (USDC) was developed [1 – 3].

1.1 The USDC as a piezoelectric based drill

The USDC consists of an actuator, free-mass and a bit. The actuator is a piezoelectric stack and a horn for the amplification of the displacement. The actuator is driven in resonance at 20kHz and a stress bolt holds it in compression to prevent fracture during operation. Unlike typical ultrasonic drill where the drill stem is acoustically coupled to the horn in the USDC the actuator drives a free flying mass (free-mass), which bounces between the horn tip and the drilling or coring bit at sonic frequencies. The impacts of the free-mass create stress pulses that propagate to the interface of the bit and the rock onto which the USDC is placed in contact. The rock fractures when its ultimate strain is exceeded at the rock/bit interface. Under a variety of conditions, this novel drilling mechanism has been shown to be more efficient and versatile than conventional ultrasonic drills. The low mass of a USDC device and the ability to operate with minimum axial load with near zero torque (see Figure 1) offers important capabilities for sample acquisition and in-situ analysis. Another important characteristic of the USDC is its ability to operate in the harsh environments of space, which include low or high temperature and/or pressure.

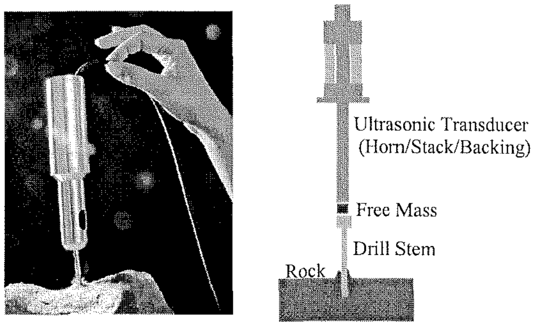


Fig. 1: The USDC is shown coring with minimum axial force and holding torque (left), and a schematic diagram of the USDC components (right).

1.2 Demonstrated characteristics

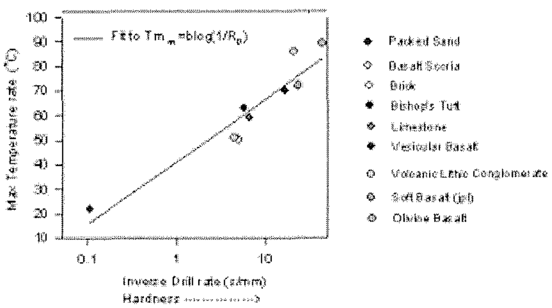
The USDC has been demonstrated to drill rocks that range in hardness from granite and basalt to sandstone and tuff. Other media that have been drilled include soil, ice and diorite, and limestone. This novel drill is capable of high-speed drilling (2 to 20-mm/Watt·hr for a 2.85mm diameter bit) in basalt and Bishop Tuff using low axial preload (<10N) and low average power (<12W). Drilling using average power levels as low as 5 Watts has been demonstrated. The USDC has drilled 25-mm deep, 6-mm diameter holes in basalt in a little over 2-hrs from a 4-kg platform using 10W average and 25W peak power. It has also drilled 15-cm deep, 5-mm diameter holes in sandstone in just over an hour using similar power as for the basalt drilling.

2 Lab-on-a-Drill

The USDC novel characteristics allow it to be used not only as a sampling tool where cores and dust can be acquired but also as a probing device. The sonic and ultrasonic hammering action on the bit allows using it as a sounder for probing the drilled medium. Further, the longitudinal displacement of the bit without rotation allows mounting of sensors for real-time analysis of the drilled medium. The combination of sampling probing and sensing allows the USDC to be used as a lab-on-a-drill system. In order to allow effective design of the USDC it was analytically modeled and predicted drilling rates and power levels were corroborated experimentally with a reasonable accuracy [1].

3 USDC with integrated sensor suite

Since the USDC bit does not turn and its vibration amplitude is relatively small one can easily mount sensors on the bit and conduct real-time tests during drilling or coring. Two types of sensors were successfully demonstrated todate: thermocouple and fiberoptic. The thermocouple was used to measure the rate and maximum rise of temperature and these values were found to correlate to the hardness of the rock being drilled. Even though these thermal variables are dependent on the heat conductivity and capacity of the drilled object, one can assume with a reasonable accuracy that most rocks have thermal properties within a comparatively narrow range. Compiling temperature rise rate and maxima as a function of time for variety of drilled materials has demonstrated the feasibility of using a thermocouple-on-the-bit as a means of assessing the drilled medium hardness (see Figure 2).



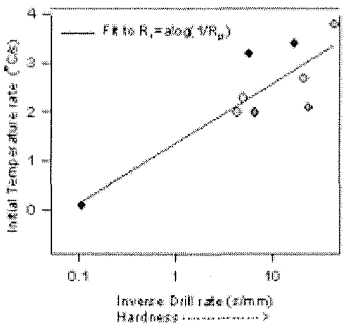


FIGURE 2: The measured temperature maxima and initial temperature rate as a function of hardness (inverse drilling rate) for variety of media.

Other tests using an optical fiber that was approximately 160 μm in diameter was imbedded into 10-mm diameter coring bit with a 1-mm wall thickness. Reflection data in the wavelength range of 400-1200 nm were recorded. The results of this study will be reported.

4 Summary

The USDC is being investigated for potential planetary applications as a Lab-on-a-drill. The capability to use it with integrated sensors was investigated and two type of sensors were examined including thermocouple and fiberoptics. The thermocouple was shown to assess the hardness of the drilled medium using the rate and maximum rise of the temperature. Further, reflection spectral data was examined using a imbedded optical fiber in a coring bit-. Other fibers using low wavelength UV excitation are being considered for detection of biological markers using biofluorescence.

Acknowledgement

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References

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