THE ADAPTATION OF TERRESTRIAL MINING EXPLORATION DRILLING TECHNOLOGY TO SPACE.

Dale S. Boucher[1], Northern Centre for Advanced Technology Inc. (NORCAT), 1400 Barrydowne Rd., Sudbury, Ontario, Canada, P3A 3V8, e-mail: dboucher@norcat.org.

Introduction: NORCAT has formed a coalition with a group of mining equipment manufacturers located in Sudbury, Ontario, Canada, to develop an autonomous mining exploration tool for the purpose of drilling and sample core retrieval. This group intends to develop a unit that can be readily adapted to both terrestrial and extra-terrestrial applications.

The approach is to develop a terrestrial unit first, followed closely by a "standard" unit for space based applications such as Asteroid prospecting, Mars and Lunar sample returns, etc. This paper provides an update as to project progress and raises some specific issues related to further development work.

Background: Exploration style drilling is used in the mining industry for the purposes of determining ore reserves and the delineation of new and existing ore bodies. It is based on core sample extraction and retrieval from various depth bore holes. This project focuses on medium depth (500 metre) core drilling.

The initial system design and much of the initial work was performed using a standard Size A diamond drill system. Operational specifications [1] are:

Parameter	Value (nom.)	Units
Hole Depth (up or down)	600	metre
Hole Diameter	48	mm
Core diameter	27	mm
Bit Rotation Torque	1,750	joules
Bit Rotation Velocity	1,300	RPM
Axial Thrust at bit	35,500	Newton
Axial Rate of Penetration	250	mm/min.

Base Technology: The base technology for this project was selected as the result of two primary points of consideration; first, the Background Intellectual Property (BIP) representative in the coalition partners, and second, the potential for application in BOTH space and terrestrial commercial sectors. Terrestrial commercialization requires the use of COTS products wherever possible, to facilitate design and improve margins. This quickly became a guiding principle to design efforts by the coalition.

Hole Propagation: Earlier work [2], [3] established diamond drilling technology as the technology of choice. The decision was primarily based upon a few salient points: 1) energy conversion is one of the highest in the industry, 2) post propagation hole stabilization and core sampling are inherent in the technology, 3) hole diameters can be tightly controlled, 4) the technology is readily and dynamically adaptable to varying ground conditions, 5) reactive forces are among the lowest of the contact drilling methods, and 6) the makeup of the coalition, within which a vast wealth of experience and BIP in diamond drilling was represented.

Prime Mover: Existing diamond drill units utilize electro-hydraulic or mechanical hydraulic drives. Since the coalition has vast experience in harsh environment electric DC drives, and MIL spec communications and control packages, it was determined early on that the new drill would use only electrical power for set-up, deployment, and operation.

The decision was also based upon the experiences gained by the coalition as relates to the maintenance requirements of underground hydraulic systems and their poor MTBF. Hydraulics systems generally require the use of cooling systems to remove waste heat. This required the installation and maintenance of significant infrastructure and logistic support. It was essential that any unit developed exhibit high reliability, require low maintenance, exhibit long operation life times and be capable of operation in hypo-baric conditions. This precluded the use of hydraulics.

Mechanical Stabilization: Existing exploration drill systems require careful alignment and set-up to ensure proper drill hole propagation. Although existing terrestrial exploration drills can weigh in excess of 5 tonnes, they still require the use of a manual anchoring procedure to ensure the unit is stationary and stable during drilling operations. This is normally accomplished via the placement of a resin activated anchor or a rock bolt to hold the drill firmly in place during the drilling operation. The operator must then re-align the drill to the proper azimuth and dip, and begin to drill, allowing the anchor to absorb reaction forces.

Work was started on a self deploying anchor system capable of withstanding drilling reaction forces. DMC Drilling Supplies has a patent pending for such a device for use in terrestrial mining applications.

System Control : Control of drill parameters during the drilling phase is paramount to the extension of drill bit and rod life as well as to the prevention of unwanted excursions of the drill, especially during drilling media transitions.

Work was performed by NORCAT and DMC Drilling to develop and refine the appropriate parameter control algorithms. DMC Drilling is now marketing the system under the product name Smart Drill as a retro-fit kit for existing hydraulic exploration drills.

Rod and Core Handling: To date, fully autonomous drilling has been limited to approximately 10 metres; the limiting factors being rod handling, and core handling.

Standard mining automation techniques have been used to develop an automated rod handler system, capable of tripping rods autonomously. Such a device is presently in pre-market testing.

Core retrieval methods are actively being worked at by a number of equipment suppliers in the Sudbury region, as well as by some major mining companies, as part of overall mining automation programs.

The Next Steps: The coalition has identified key steps in this development program and has organized them into a planned approach. Each step has been shown to have potential commercialization activities in terrestrial mining and exploration

Electric Drill: The coalition is not aware of any production scale exploration drill available on the market that is fully electric. The first effort is to develop and prove a commercially viable all electric drill capable of drilling and coring to a depth of 500 metres in various types of ground..

Efforts are underway to develop an A size compatible unit capable of matching the specifications of existing hydraulic units [1]. Once completed, the unit will be installed at NORCAT facilities for comparative testing with the existing A-size unit.

Control algorithms developed for the hydraulic unit will be migrated to the electric drill and the control package simplified and miniaturized.

Anchoring System: The existing self-deploying anchor system will be used as the final stage anchor for all terrestrial and extra-terrestrial units. Work is already planned to develop primary anchoring [3] technology for micro-gravity environs.

Drill Bit: Existing diamond drill bits require water flushing to remove balings, lubricate the diamond matrix/rock interface, and dissipate heat. Efforts are underway to develop a diamond drill bit capable of drilling dry and enabling mechanical removal of balings during drilling.

The miniaturization of the drill unit would require a redesign of the drill bit itself, so that maximum penetration could be realized while reducing balings production. Since in-situ analysis is not yet a reality on a commercial scale, adequately sized core samples must be produced that are of use to geologists and others interested in using this technology for sample analysis. These criteria will drive the final configuration and design of the drill bit. Work has already been started on specialty drill bit design by coalition members.

Rod Handling: Standard length drill rods (A size) are 1.5 metres long, hollow to allow core retrieval without drill bit removal, and can be joined together with simple threading algorithms. During drilling operations, the drill rod is used to transfer rotational energy as well as thrust to the drill bit. The drill rod serves to stabilize the drill hole post propagation and can be used as a guide for later analyses such as in-situ geophysical testing, or resource extraction [3], [4].

The vagaries of autonomous drilling operations have shown that rod coupling is the weakest point of the system. In addition, shipping and storage of drill rods is a significant issue. Work is well under way to address the issue of autonomous rod handling and storage.

Sample Core Handling and Recovery: Core samples are presently recovered once every 10 metres maximum. Nominally, they are recovered once per 1.5 metres, or upon operator intervention. The criteria for core recovery are excessive system loading on the drive components of the drill (rotational or thrust) such that a potential stall occurs, or the bit ceases penetration. Core recovery is presently handled semi-autonomously and cores are catalogued and stored by an operator for later analysis. An autonomous unit must be capable of performing these tasks efficiently, accurately and repetitively. No work has been performed in this area as yet.

Space Drilling: Preliminary performance specifications for the "Space Drill" are for an all-electric drill capable of autonomously deploying and anchoring in a micro-gravity, airless environment and extracting core samples 10 mm diameter to depths of 100 metres. The technology is intended as "Throw Away", using COTS products where possible. It is also intended as a dynamically reconfigurable system to allow piggy back science missions to ride along, such as in hole seismic sensors, radio beacons, analysis, etc. The coalition has developed some conceptual models based upon the SpaceDev Micro-NEAP project. The system will be prototyped at NORCAT facilities and then integrated and tested at the NORCAT mine in hard rock under 2-D micro-gravity simulation and extreme temperatures.

Acknowledgements: Coalition: NORCAT, DMC Drilling Supplies Ltd., Electric Vehicle Controllers Ltd., Falter Engineering Inc, Sudbury; SpaceDev, California

References: [1] Longyear Australia Pty Ltd., *Longyear LM 75 Operations and Service Manual*. [2]D.S. Boucher (1997) *Alternative Exploration Drilling Technologies, Laser and Water Based Drills for DMC Drilling Supplies Ltd.*. [3] Mark J. Sonter (1997) *The Technical and Economic Feasibility of Mining the Near Earth Asteroids*. [4] D.L. Kuck (1992) *In-Situ Recovery of Water from Dormant Comet Cores and Carbonaceous Chondrites, Space '92*