Mechanizing Extraterrestial Excavation – Transfer Potentials from the TBM Industry.

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Introduction: Tunnel Boring Machine (TBM) technology greatly advanced over the course of the past few decades. A number of technologies has been crucial for the development of todays capabilities in the industry. Several of them are of potential use for extraterrestrial excavation. Most excavator concepts for lunar construction or mining focus on moving regolith. However humans will have to go beyond the thin layer of regolith to establish a long term presence on the moon. Technological principles adapted from tunnel boring and mining can improve construction in regolith as well as enable venturing into harder and deeper formations. Two lunar habitat concepts are mainly pursued: "buried tin cans" and "furnished lava tubes" [1]. Both require digging and / or drilling.

TBM Principles: TBMs have led to a significant increase in operator safety by allowing concurrent excavation and lining construction. Personnel is only exposed to the environment for maintenance on the machines cutting tools. The cutting tools, a mix of disc cutters and scrapers are adaptable to any geology. The force necessary to excavate is applied by pushing the machine ahead from the section of lining which has been last completed. This allows high excavation forces without relying on gravity or ground support. In hard rock, gripping mechanisms may transfer loads to the geology. Design for non-exposure maintenance and remote inspection and monitoring have further reduced operators risk in aggressive environments such as high water pressure or unstable ground. Integrated muck handling systems also protect people from dust or gas from the excavated ground.

The mining industry has adopted several excavation methods from mechanized tunneling. Shaft sinking machines and different types of directional boring machines for diameters up to several meters are able to safely excavate defined geometries in varying ground conditions. While mechanized tunneling relies on highly specialized machinery, the developments in the mining industry often target towards more variable application for example for variable excavation cross sections or drilling directions. These are among the most promising for extraterrestrial application.

Demand for lunar drilling: Lunar exploration is envisioned to take place in 3-4 phases which are characterized by the type of deployed technology and the extend of human presence [2]. Phase 1 consists of robotic exploration. Phase 2 includes human activities but is restricted to using structures brought from earth. Phase 3 is characterized by making extensive use of ISRU to create permanent habitat and operation structures. In order to create protection from cosmic radiation and micrometeorites, any habitat designed for long term occupation needs appropriate protection covers. Two to five meters of regolith cover fulfill this requirement. While in early exploration stages the easiest way to reach this might be covering structures with loose or bagged regolith, later stages require underground construction. If the existence of lava tubes can be proven, these form natural enclosures. However after evolving past initial settlements, methods for rock excavation will be necessary to extend, connect and modify the natural caves and their access openings. Generally the further lunar development advances, the higher will the need for drilling and excavation of defined cross sections and shapes become.

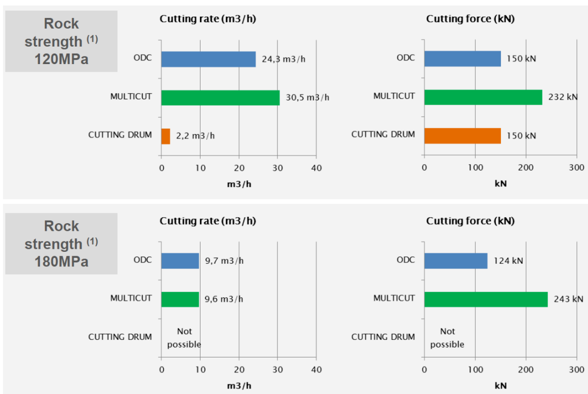
Operation Conditions: Operation conditions for lunar drilling are extremely difficult. Large temperature gradients, near vacuum, radiation, low gravity and dust are among the main concerns. Another issue is the high abrasivity of lunar soil due to the particle shapes of regolith [3]. Maintenance and repair opportunities are extremely restricted and call for simplified and rugged design. High shipping cost dictate the use of low mass technologies.

Potentials for Technology Transfer: Several technical principles are used in mechanized excavation which appear promising for adaption to space exploration.

Concurrent excavation and lining construction allows operators to line the excavated cavity while permanently being protected inside the atmospheric pressure TBM. This can either be done by assembling prefabricated concrete segments or by extruding concrete from a gliding formwork. This principle is not limited to circular cross sections and can be applied to construct covered trenches as well. Similar to common double layer structures on earth, a sintered primary lining which provides mechanical support could be complemented by a secondary lining which acts as a sealing.

Integrated Mucking Systems facilitate the continuous transfer of muck from the excavation face to dump site. Belt conveyors, bucket ladders, pipelines or vacuum systems are successfully applied in tunneling and shaft sinking. This prevents additional traffic for mucking and creates a well defined material flow.

Fully meachanized rock excavation leads to full control of all excavation parameters. Opposed to drill and blast excavation as proposed means to loosen rock sections in lunar excavation, mechanical excavation ensures permanent and precise control, limits dust production and can be performed in small scale physical enclosures. Different techniques such as disc cutters, undercutters and oscillating disc cutters lead to increased ability to cut very hard rock with reduced cutting forces and equipment size. Earth experiences in rock cutting in rock cutting are vital for achieving cutters able to work with minimal energy supply.



Force Comparison for different Excavation Technologies

Minimal Exposure Maintenance is a key target in the tunneling industry. Cutting tools being exchangeable without the need of exposing personnel to the outside conditions has allowed venturing into higher pressures and achieving low accident rates at the same time. Individual tool monitoring with wireless sensor systems allows reducing inspection and maintenance further.

References: [1] Benaroya, H. (2010) Lunar Settlements, CRC Press. [2] Jablonski, A. and Ogden, K. (2008) A Review of Technical Requirements for Lunar Structures, Journal of Aerospace Engineering, Vol21, No2 pp72-90. [3] Zacny, K. Lunar Drilling, Excavation and Mining in Support of Science, Exploration, and In Situ Resource Utilization (ISRU), in Badescu, V. (2012), Moon, Springer