A Review Of Mining Technologies For Space

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Abstract

It is a truism that if humanity wants to expand its horizons to Moon and other planets the area of mining in space has to go along. In the present paper a brief review of literature in terms of different mine unit operations is undertaken. The present paper gives a quick outlook as to where we stand in terms of technologies, which can be applied to space mining applications

Key words: technologies, mine-unit operations, space mining

1. Introduction:

"Earth is the cradle of mankind; but one cannot live in the cradle forever (Konstantin Tsiolkovsky)." It is well known that space offers abundant and unexplored resources which human race has never come across. The concept of mining in space has to go along if man is to advance to the frontiers of Moon and other planets and establish his presence in pursuit of knowledge and resources.

The process of mining on the terrestrial environment starts with prospecting the resources and exploration followed by development, exploitation and reclamation. Developing a space-mining scenario is also quite similar, but constrained by space logistics and economics along with environmental variables. Some of the mine unit operations like drilling, blasting, excavation and secondary breakage processes are common to different stages of mine development. In the present paper we review the different technologies in terms of these common mine unit operations as applicable to space environment. A more detailed review of different technologies and design issues pertaining to mining in space can be found in [1].

2. Drilling:

Drilling would be the most common and important operations for any kind of mining or explorative operation in space. Different methods of drilling would be required for the purposes of

anchorage, explosive emplacement, exploration and large-scale production during different stages of mine development. Below we review some of the important drilling technologies developed for space applications.

The idea of drilling on Moon dates back to Apollo mission times, Hughes tool co, USA in 1960 had developed a drilling system to collect samples of the Moon's surface for analysis. The drill system developed was a miniature drill that stood 5ft tall and weighed 60lb and capable of penetrating dust or granite like rock [2]. Other technical details pertaining to materials, capacity, cooling and flushing systems are not cited in the publication. NASA sponsored research team [3] developed a dry drill system for collecting Lunar rock core samples from depths in excess of 100ft with internal chip cooling and dry chip flushing. Diamond crystals (± 0.004 in tolerance) were used for the drill bits.

The Italian space agency (Galileo Avionica) has developed an integrated drill system under their ongoing deep drill program. This system consists of both single rod and multiple rod configurations and shows their ability to achieve performances in line with resources allowed by a Mars vehicle and feasibility of the drill tool to operate in different types of soils and rocks. This system is capable of retrieving cores samples 14mm in diameter and 25mm in length. Single rod design is suitable for 1m depth, weighing 7.32Kg and multirod design is suitable for 3m depth-weighing 8.3Kg [4]. Nasa has developed a low power (~60 W) and low mass (~20 Kg) drill that is capable of retrieving samples of diameter 20mm from the

permafrost regions of earth and Mars. The system can be operated without drilling fluids and takes the form of a down hole unit attached to a cable so that it can be scaled readily to reach significant depths. Hill et al (2003) [5] present the basic concept of tethered down hole motor drilling, as it might be developed to work with a broad range of available basic down hole drilling equipment. This system consists of a revolutionary new bit system that can drill a 80mm diameter hole in medium strength sandstone to a depth of 2m at a total power consumption that is five times less than the conventional drilling methods. Researchers from the jet propulsion laboratory have developed an

Ultrasonic driller corer that is based on an ultrasonic horn driven by a piezoelectric stack. This system weighs 450 g and requires low preload ($<5\text{N}$) and can be driven at low power (5W) [6].

Apart from the mechanical methods, alternatively penetration could also be achieved by actually melting the surrounding rock with electrically heated probes. This method obviates the need for any casing or drilling fluids making this method suitable for space applications. However this method has the disadvantage of contaminating the samples when used for exploration purposes, which needs further investigation[7].

Table 1 Applicability of various drilling methods in Lunar environment

Method	Basis	Advantages	Disadvantages	Applicability
Mechanical	Mechanical Breakage of Rock	Demonstrated application on earth, versatile, simple and ease of operation	Power intensive Bulky, wear of drill tools	Medium
High pressure fluid Drilling	Fluidized Breakage of Rock (fluid medium-water)	Demonstrated Applicability for soft rocks mining (coal mining)	Involves use of a fluid, cannot be used for very hard rocks, cannot be used in vacuum conditions and extremely low temperatures	Low
Thermal/Microwave drilling	Spalling of the rocks	Less bulky, demonstrated applicability, no fluids, no moving components, no wear	Power intensive, new technology, expensive	High
Nuclear drilling	Nuclear fission Nuclear fusion	Conceptual stage	Conceptual stage	Medium

2. Blasting

Blasting is the primary process of rock fragmentation when large-scale production operations have to be undertaken in terms of mining and construction. On terrestrial environments the predominant method of blasting employed is by chemical explosives, however electrical methods of blasting have been used sparingly for secondary breakage process.

When it comes to space environments the explosives used have to satisfy some requirements as stated below [8]:

1. Safe to handle and use
2. Maintain their stability at temperatures of -60°C to 127°C in an insulated package for atleast one year.
3. Exhibit low volatility in vacuum conditions
4. Capable being compacted to high densities and then machined to fit grandee case.

5. Capable of withstanding the shock and vibration during the launch and emplacement processes.
6. Develop explosive energy of TNT.
7. Maintain properties after exposure to high levels of radiations (> 100 times that on earth)
8. Initiate reliably with available initiation systems.

Following explosives were identified by Naval ordinance laboratory (NOL) for their use in space: DATB, HNS/Teflon, ALD, LX04, ALX, ALH, MFH and ALOX [8]. HNS/Teflon was used to conduct seismic experiments during the Apollo 16 flights to Moon, because of the fact that they were thermally very stable, capable of sustaining harsh Lunar environments and also had a detonation velocity comparable to that of TNT [7,8]. It is also important to note that most of the explosives selected for space applications are aluminized explosives, because they are denser and more energetic [9].

Apart from chemical explosives one other technology that holds promise for space applications is the plasma blasting method. Which is based on fast discharge of electrical energy in to an electrolyte located in the rock, there by facilitating its conversion to plasma, which in turn generates shock waves to accomplish rock fragmentation. This blasting technique-using electricity has tremendous advantage for space industry in reducing drastically the payload and eliminating transport and handling of potentially hazardous substances such as chemical explosives with detonating devices. However this has the drawback that a new electrode has to be used after each fragmentation process, rendering this process cost intensive [10].

3. Excavation

Space mining activities invariably needs excavation for resource utilization, anchorage and construction purposes. Over the years researchers have come up with some multitasking excavating machines and also

suggested methods of excavating Lunar regolith. The concentration in terms of developing and understanding excavation process has been more on the Lunar environment.

A NASA sponsored assessment of various Lunar mining surface mining equipment resulted in the conceptualization of Ripper excavator loader (REL) and haulage vehicle (HV) by US bureau of mines. The REL is a multipurpose machine capable of loosening compacted regolith. The vehicle is equipped with a 0.25m^3 bucket to excavate; self load and load other vehicles. It is designed to handle 1500 to 1800 Mt /year of ilmenite rich feedstock. HV is equipped with a 2m^3 rear dump bed and is capable of transporting feedstock from pit, liquid oxygen containers from the processing plant and materials during construction [11]. The radial axial splitter, which is used on terrestrial environments for secondary breakage is one of the most simple rock destruction technology that is well suited for space because of it low gravity dependence. The minimucker was developed by the US bureau of mines, capable of operating as a load haul dump vehicle. This machine is quite suitable for narrow vein underground mines, it loads muck at the front with a novel slide-bucket system and ejects the material with out turning around. All the machines developed by the bureau have the teleoperation capabilities and are powered by electricity [12].

Experiments of Bernold et al (1997) [13] indicate that it is extremely difficult to carry out excavation by traditional means below 20 cm due to the high density of Lunar regolith and the existence of large boulders might further complicate the problem. Apart from mechanical methods of fragmentation and excavation the US bureau of mines have conducted research on fragmenting basalts with the use of lasers, microwaves and solar energies. The results indicated that vacuum had a positive effect on rock fragmentation through these electromagnetic forms of energy [14]. Various under ground mining methods and their applicabilities on Lunar/Martian environments is shown in Table 2.

Table 2 Applicability of under ground mining methods to lunar and Martian Environment (Lewis et al 1993)[15]

Mining system	Operation	Advantages and disadvantages	Applicability
TBM's (Tunnel Boring Machines)	Developed for terrestrial applications requiring long straight tunnels such as railway tunnels. Machines are rather inflexible and massive	High Mass and inflexible	Low
Drum type continuous miners	Developed for mining coal, can mine soft to medium hard material (200-700mt/hr).	High power requirement and dependence on machine weight to counteract cutting forces.	Low
Road header	Originally intended to enlarge access headings in coalmines. The main attraction is the boom mounted cutter head.	Dependence on machine weight to counteract cutting forces	Medium
Hydraulic Rock Splitter	Used on Earth for secondary breakage, generates tensile breaking force by pulsing against its own anchoring system requiring no external thrust	Requires no external thrust, low power requirement	High
Novel methods	Such methods are mainly energy intensive, include thermal fragmentation with electromagnetic energy in the form microwaves /Lasers	High-energy requirement, low mass and less massive.	High

4. Comminution, Separation and Beneficiation

The lunar and Martian surface consists of granular loose fine-grained material called the regolith, which is the starting material for many processes (for eg: extraction of liquid oxygen from the Lunar regolith). But before regolith can be used for further processing it requires sizing, grinding and beneficiation.

Not much work has been done in terms of addressing this issue except for the work of Mason (1992) [16]. The applicability of terrestrial comminution (particle grinding and sizing) and beneficiation equipment for their use in Lunar environment is studied. Classification techniques (screening, settling, cyclonic and pneumatic), grinding operations (tumbling, fluid energy, impact and ultrasonic mills) and beneficiation techniques (magnetic and electrostatic) are assessed for the use in Lunar surface. Of the equipments surveyed, screens, ultrasonic grinding mills and magnetic and electrostatic separators are the most applicable for their use on Lunar surface.

5. Conclusions

It can be concluded that much of the work that has been done in terms of the different mine unit operations, is concentrated more on the Lunar environment. This is because of the fact that Lunar surface is better understood from a series of Apollo and Luna missions. Majority focus is on the exploration drilling part of the mine-unit operations, which is quite understandable because the surface and subsurface has to be characterized before large-scale production can be undertaken. Also a majority of researchers proposed mechanical methods of drilling and excavation for space because of its simplicity, versatility, ease of deployment and considerable amount of information available from decades of terrestrial use. Nevertheless novel energy methods (using electromagnetic energies) have also been advocated because of their non-mass intensive nature, making them very suitable for space

Explosives for space have been developed and explosives such as HNS/Teflon have already been used on harsh Lunar

environments. However, newer methods of blasting, such as plasma blasting have also been investigated for their use in space. Not much work has been done in terms of secondary breakage and processing part of the regolith.

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