Assessment of excavation technologies for a small-scale mining robot and development of future concepts

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INTRODUCTION

Future challenges in mining due to sustainability and ecological aspects require additional efforts in research and development. With the help of fully automated machines and/or autonomous robots, new deposits can be accessed, or abandoned mines can be re-opened and operated economically. Possible tasks for robots in mining are the maintenance of machinery, exploration (e.g. of abandoned mines) and excavation (especially in difficult to access areas). Depending on mine layout, mining method and numerous other parameters, the design of autonomous robots can be drastically different compared to the current machinery. Outdated paths may have to be left to create room for thinking outside the box and to develop innovative solutions, which assist making future mining more sustainable and economical. The future scenarios require novel approaches and adaption of existing technologies. In particular, current excavation technologies must be assessed with new standards in order to fulfill the upcoming criteria. (Robert Hiltz 2020; Khatib & Siciliano 2016)

Several research and development projects are dealing with the development of robots for mining and exploration purposes. The comparatively small weight and low available power are the most limiting factors and therefore require – in addition to adaptions to commercial off-the-shelf (COTS) products - new approaches. The interaction between an excavation tool and rock creates reaction forces, which the machine needs to be capable of handling. Excavation methods can be separated into drill and blast, mechanical, alternative and combined excavation technologies, whereas the first two listed are the most commonly applied in standard excavation engineering. In order to ensure an efficient and economic application, the excavation tool needs to fulfill a number of requirements such as reasonable advance and excavation rates as well as flexible and mobile handling to adapt to the in-situ conditions. A developed methodology is used to compare the most promising excavation methods by defining certain parameters (specific energy, reaction forces, etc.) and to assess their application for different rock strengths. Based on those studies, the feasibility and applicability of certain excavation tools for different scenarios and rock strengths are analysed.

ASSESSMENT

To assess the applicability of the eligible excavation methods, a classification and rough analysis of them are done. Generally, excavation systems can be divided into: drill and blast, mechanical excavation systems, alternative excavation systems and combined excavation systems (see Figure 1). (Bilgin 2013; Vogt 2016)

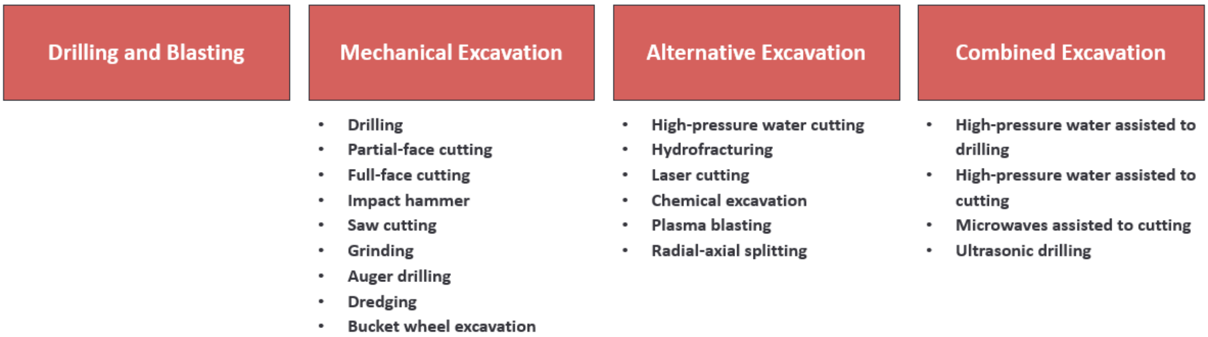

Figure 1: Classification of excavation systems

In the first step, these technologies are examined, analysed and evaluated according to selected criteria. Many of these methods are used for the extraction of raw materials or for tunnelling, but not all are economically viable on such a small scale. Firstly, the following features are assessed, which are mandatory for future production tools of small-scale, mobile mining robots:

- Ability to continuously excavate material.
- The capability to excavate tunnels for the robot's own locomotion.
- Limitations (maximum compressive strength and abrasivity of rock to be excavated, etc.)

Drill and blast is one of the most used excavation technologies due to the generic applicability in mining and tunnelling and it's high production rate. Mechanical excavation systems are at least equally popular compared to drill and blast and exhibit some benefits, such as a safer operation, a better ability for selective mining and the continuous material excavation. Alternative excavation systems cover non-conventional excavation methods apart from mechanical excavation and drill and blast. The main application areas are precision tasks, pre-weakening of the rock to be excavated (used in combined excavation systems) and tasks for which the ambient conditions do not allow conventional methods. Combined excavation systems unite the advantages of mechanical excavation systems with alternative, auxiliary methods. Auxiliary tools provide an additional energy input to pre-fracture the rock or to amplify the effect of the mechanical excavation system. (Bilgin 2013; *Drilling and excavation technologies for the future* 1994; Sifferlinger, Hartlieb & Moser 2017)

The tools most commonly applied in practice, include in some way a mechanical excavation tool. Because of this, it is inevitable to examine those systems in great detail. The high masses of the mechanical tools in relation to the mass of the robot pose an additional challenge. Therefore, even if they are irrefutably marked by high specific energies, alternative excavation technologies are also taken into account, because the required forces provided by the robot to penetrate the rock are comparatively low.

In the detailed investigations, the applicability of the technologies is assessed in terms of the following parameters:

- Specific energy
- Production rate
- Excavation force / Reaction force

Power, mass and capability of handling the reaction forces are determined as the most crucial parameters influencing the ability of designing a small-scale excavation tool. In this case, the power and mass of the robot are assumed to be 40 kW and 1500 kg. The nature and strength of the rock to be excavated define the efficiency of the excavation process greatly and most importantly set strict boundary conditions for each mining system. In theory, for many excavation methods, the obtained results for specific energies and production rates sound reasonable and suggest a potential feasibility of a certain technology. However, these results do not provide any information about the practical feasibility. In reality, the machine/robot has to generate the required forces for penetrating the rock – or other way around – needs to handle the reaction forces exerted on it. Usually, the reaction forces are countered by the high mass of the machine and, depending on application and design, additional anchoring mechanisms. This issue constitutes the most fundamental consideration regarding the development of a small-scale production tool.

The minimum thrust forces of full-face cutting for excavating very soft rock already exceed the robot's capabilities. Partial-face cutting appears to be viable for soft rock material. Hydrofracturing can tackle stronger rocks, whereby alternative methods demand higher specific energies. High-pressure water jets assisted to cutting do lower the cutting forces of partial-face methods, but on the other hand also require a greater energy input. In this scale, drill and blast is the only remaining option for excavation of hard rock material, due to the low drilling forces and high efficiency of blasting rock. In this step, the technical feasibility is of lesser importance and will be covered in prospective activities.

Based on this premises, minimum requirements for each excavation method are defined, including the minimum mass of the robot and the minimum supplied power, to excavate rock with a defined strength.

Eventually, the results of the previous studies will be used for developing excavation tool concepts to be integrated in small-scale mining robots.

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