

Machine performance and Acoustic fingerprints of cutting and drilling

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ABSTRACT:

‘It is always dark ahead of the pick!’ This centuries-old miners’ expression still reveals the uncertainty about the upcoming rock properties during exploration and extraction processes. It is still tough to predict what a drill rig or a cutting machine will experience during operation. However, in terms of safety, energy consumption and the performance of the whole machine it would be beneficial to be able to monitor such an extraction process. Hence, different sensors or sensor combinations are tested during cutting and drilling processes within RealTime Mining project. First aim is to depict the machine performance of the machine at any time. In a second step sensor information is also used to conclude on mechanical rock properties during the process.

Measuring the machine performance for cutting and drilling is quite similar and has been condensed under the terms Monitoring-While-Cutting (MWC) respectively Monitoring-While-Drilling (MWD). Both monitoring systems contain a bundle of sensors to depict the whole process. As an example, the energy demand of such a machine can be determined by measuring the power consumption of the engines constantly. Furthermore, the process parameters like advance rates and drilling or cutting speed have to be evaluated as well to be able to depict the whole extraction machine.

To conclude on mechanical rock properties several other sensor solutions have been tested and finally integrated into those monitoring systems. One of the most important rock properties for drilling and cutting is the rock strength. Increasing rock strength during an extraction process leads to increasing forces that are needed to break a certain amount of rock. Hence, e.g. measuring the torque of a drill string or the cutting forces can be an indicator on rock resistance or rock strength. Not minor important, is the characteristic rock breakage behavior which can be classified by the use of ‘acoustic’ sensors. Dependent on the rock properties that currently is drilled or cut through a characteristic fracture occurs in front of the tool. This results in audible and also inaudible characteristic acoustic waves that propagate through the machine body and can be gathered on the machine by piezo-electric sensors. The interpretation of these signals could lead to a material classification already during the extraction process.

Several tests of these sensor technologies have been conducted in laboratory environment as well in field tests. The most promising results are going to be presented.

1 Introduction/State of the Art

Since the beginning of human mining activities, miners face the challenge that rock properties in mining operations are almost unpredictable. As a result, a centuries old miners' expression arose: 'It is always dark ahead of the pick!' The meaning of this expression is still valid. However, in terms of safety, energy consumption and the performance of the whole machine it would be beneficial to be able to gain more knowledge about the surrounding rock in real-time.

Monitoring systems to monitor cutting or drilling processes could be used to gain more information about the extraction process. It is plausible that an increasing rock strength during extraction will lead to also increasing energy demand of the machine. Hence, it is helpful to monitor the energy demand in real time. To gain even more information about other rock properties or even the characteristic cracking behaviour different other sensor solutions are conceivable. State of the art in most rock cutting and drilling operations is still an operator standing on or close to the machine guiding it by using his natural senses. Basically, he listens to the cracking behaviour of the rock or also senses the machine vibrations as a reaction of the rock being extracted. Hence, it could be useful to measure these kind of emissions by the use of appropriate 'acoustic' sensors. [1]

'Acoustic' measuring systems are wide-spread in the industry for condition monitoring and machine diagnoses. Structure-borne-sound is evaluated to detect damages in machine components. If cracks already shall be detected when they arise high-frequent Acoustic Emissions can be recorded. Hence, it appears that acoustics could also be measured during cutting and drilling where crack initiation and rock damages are planned. Within the RealTime Mining project a monitoring system has been developed to monitor both structure-borne-sound as well as Acoustic Emissions and has been tested in two field tests. Measuring the 'acoustics' during cutting and drilling has been named 'Acoustic Fingerprints'.

2 Short introduction into 'Acoustics' during cutting and drilling

Mentally, reducing a cutting or a drilling process to tools that are in an interaction with rock, two acoustic effects can occur.

- Vibrations (Frequency range: 1 Hz – 16 kHz)
- Acoustic emission (Frequency range: 20 kHz – 1MHz)

Vibrations occur due to the rock tool interaction. During the extraction process, the tool penetrates the rock and creates tensions in front of the tool. Further movement of the tool leads to crack initiation and finally chipping out of rock pieces. Especially, the sudden release of a rock chip could lead an elastic vibration of the tool. These vibrations propagate from the tool through the entire machine body. Simply put, these vibrations can be sensed by an operator standing on or next to the machine. It is plausible that extracting soft rock will lead to comparably less vibrations than extracting hard rock. Appropriate vibrations sensors installed on the machine body can gather those vibrations. [2]

In contrast, the idea of gathering high frequent Acoustic Emissions is that those Emissions particularly occur due to the crack initiation. During the tool penetration cracks will occur in the rock in front of the tool. The crack initiation leads to sudden release of a very small amount of energy. This energy results in a very high frequent elastic wave which also propagates through the machine

body. Appropriate Acoustic Emission sensors could gain such high frequent waves as a so-called burst which have a duration of only a few milliseconds. The quantity as well as the shape of these burst can give an indication of the cracking behavior of the extracted rock. [3-8]

The combination of both sensors allows to build up ‘Acoustic Fingerprints’ for drilling and cutting processes. For analyzing the measured Acoustic Emission bursts and the vibration data, different data processing tools have been developed utilizing the time and frequency spectrum. Main work within RealTime Mining project (H2020 Grant Agreement 641989) was conducted in laboratory environment but could tested on a real sized cutting test bench as well on a drill rig. The main findings shall be summarized in the following.

3 Acoustic Fingerprints for cutting and drilling

3.1 Acoustic Fingerprints for cutting

A real dimensioned rock cutting test bench has been found at the mining equipment supplier T-Machinery in Czech Republic. The test bench is equipped with a cutting drum of 1.1 m which is hung up on a cutting arm with a length of about 1.4 m. The test bench is powered with a 250 kW drive that allows a cutting velocity of 3.6 m/s (see Fig. 1).



Fig. 1: Rock cutting test bench in Czech Republic

Main aim was to monitor the machine performance of the test bench by the use of Acoustic Emission and vibration sensors. For determining the machine performance also the electrical power consumption has been recorded during the cutting process. The comparison of those data can be seen in Figure 2. The sketch on the left of figure helps to describe the cutting process. Starting with a rotation above the block with no tool intrusions the cutting drum was moved clockwise. This led to an increasing tool intrusion during the cut until a maximum of 60 mm.

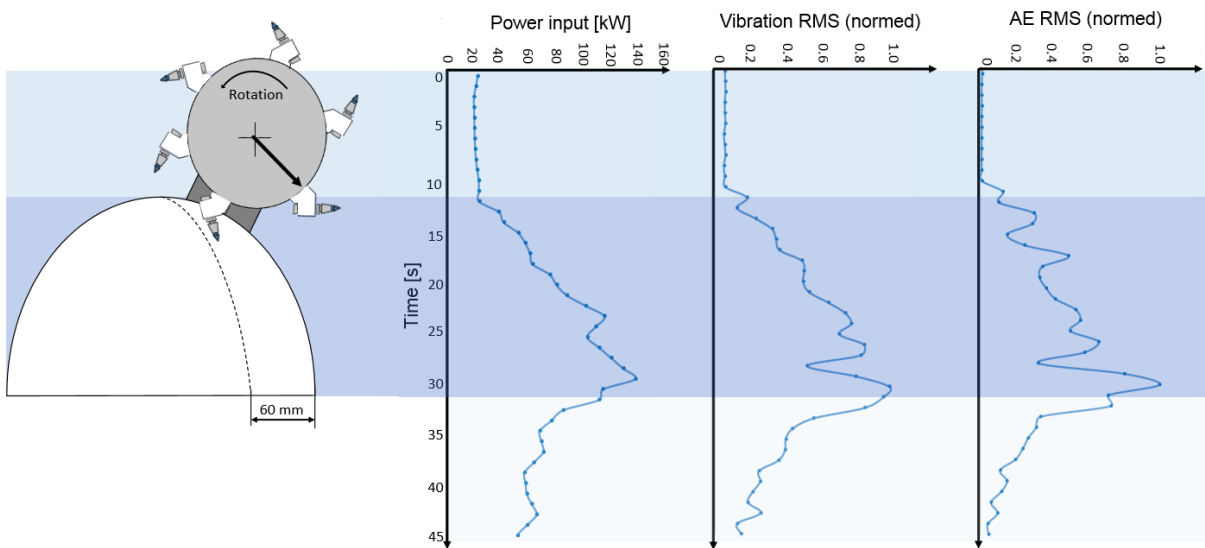


Fig. 2: Acoustic Fingerprint of rock cutting test [9]

It can clearly be seen that an increasing intrusion of the tools leads to an increasing energy demand of the test bench. The evaluated sensor data of the vibration as well as the from the acoustic emission sensors clearly follows the power consumption. This is a confirmation of the expectations from cutting tests on a smaller cutting test bench.

3.2 Acoustic Fingerprints for drilling

The field test was conducted in cooperation with Eijkelkamp SonicSampDrill in Giesbeek Netherland. Unfortunately, no MWD-System was on the tractor type drill rig. Further tests with the MWD system are scheduled for September 2017.

Fig. 3 shows the tractor mounted drill rig setup. Furthermore, they prepared a field in Giesbeek with granite and concrete samples. Thus, rectangular granite and concrete probes have been embedded into the ground. The concrete plate with a thickness of 200 mm served as a foundation on the bottom of the hole. Afterwards, two granite blocks with a total thickness of 1400 mm were installed above the concrete plate. This setup allowed to drill from the top through three different materials granite, concrete and clay.

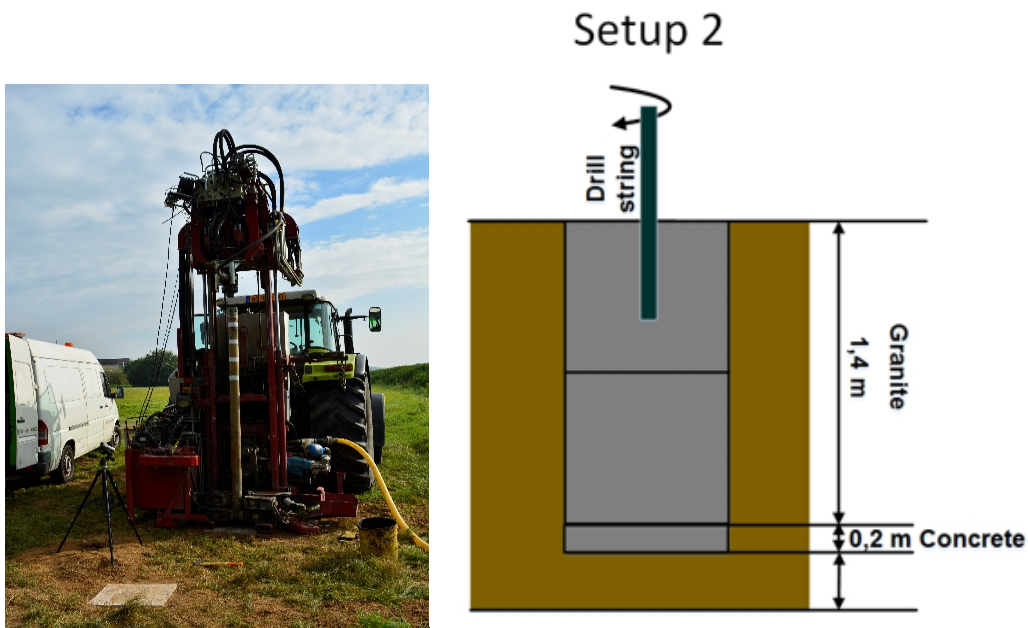


Fig. 3: Drill test setup [10]

For determining the acoustic fingerprint during drilling acoustic emission sensors have been mounted on the drill head. Fig. 4 shows the results of one borehole. The different materials induce varying levels of amplitudes on the acoustic emission sensors. It shows that granite stimulates higher amplitudes compared with the concrete and the following clay ground. But it also exists differences between concrete and clay. Since, the clay layer induces the lowest amplitudes in this test series.

The field test confirms the assumption that it is able to recognize differences in the acoustic emission signal between different materials at drilling processes as well as cutting processes. In both cases it was possible to generate an acoustic fingerprint of the used materials.

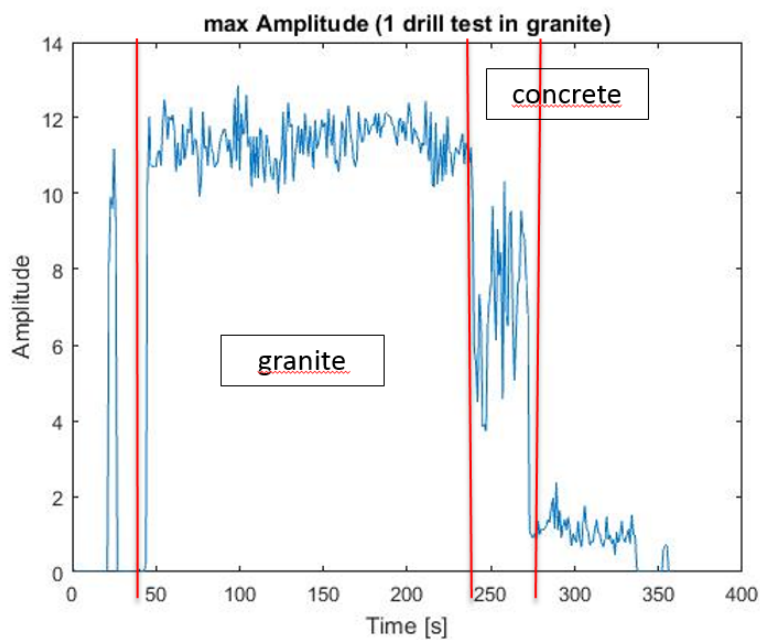


Fig. 4: Acoustic Fingerprint of the drill tests [10]

4 Conclusion

The researches have been shown that Monitoring Machine Performance is possible by using acoustic methods. The used methods describe not only the machine performance but include also additional information. It has been shown that the energy demand can be monitored by acoustic sensors. Furthermore, the analysis of Acoustic Emission signals allows to distinguish different cracking behavior of different materials in real time. Especially, the specific energy demand signalizes a high significance due to more precise depiction of cutting and drilling processes.

The additional information, which can be measured by the acoustic methods, leads to possible rock classifications. Perhaps, it will be possible to determine the different cut and drilled rocks on the basis of the cracking behaviour. There is a chance that this knowledge induces to a boundary layer detection for cutting processes. That would be the first step for automation systems for cutting as well as drilling processes. A visualization of these methods is planned in work package 6.

Further drill tests are planned for September 2017 since the lack on the MWD at the last drilling test series. The results will be compared with the results of the cutting test series.

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