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Technical Note

Simulation of the chain saw cutting process with a linear cutting machine

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1. Introduction

The use of new machines for quarrying dimension stones, especially the diamond wire saw, chain saw, air and hydro bags, has resulted changes to the of technology used for the excavation of dimension stones. An effective way to obtain stone blocks is achieved by combining chain saw and diamond wire saw because of the advantages of both machines. Chain saws are used for vertical and horizontal cuts in surface and underground quarrying in less to medium abrasive and soft to medium hard rocks. The use of chain saws meets the prerequisites for underground quarrying of dimension stones.

Chain saw performance in quarrying dimension stone depends on the right choice of machine's constructional and operational parameters, cutting elements as well as the conditions and methods of quarrying in the certain type of rock. The key operational parameters controlled by chain saw operator are cart movement and chain speed. The optimum values of operational parameters are based on manufacturer's recommendations and/or chain saw operator's experience.

In addition to constructional and operational parameters, chain saw performance also depends on physical and mechanical properties and compactness of the rock mass. Properties with the largest influence on chain saw performance and the wear of cutting elements are: uniaxial compressive strength, Shore scleroscope hardness and Cerchar abrasivity index.[1–3]

The operational element of a chain saw is an arm on which a continuous chain slides with cutting tools attached on tool holders. The length of cut can theoretically be infinite whereas the depth and the thickness of cut depend on constructional parameters of chain saw arm. Since rocks differ according to their properties it is unrealistic to expect that the same cutting chain construction can be used for all types of rock.[4] There are therefore different cutting chain constructions in order to achieve the most favourable ratio between the performance and the wear of cutting tools.

Even though chain saws are technologically more advanced today, primarily in terms of arm length, they still operate with certain deficiencies. Based on previous research, despite the low number of published papers on chain saw performance, it can be concluded that chain saws do not operate with optimum operational parameters.

Field experiments showed that the cutting tools depth of cutting is rather low and what in the end results with the larger consumption of energy.[1] This happens because the specific cutting energy decreases with the increase of the depth of cutting.[5,6] It was also established that the available chain constructions are not optimum enough in terms of energy consumption and the wear of cutting tools. By changing the arrangement and the number of cutting tools within the existing cutting sequences it is possible to

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increase the performance and reduce the wear of tools.[7]

Chain saw performance can be analysed on the basis of cutting energy and cutting force. Forces on cutting tools can be determined by using analytical and numerical models as well as in laboratory experiments. Merchant, Evans and Nishimatsu's models are analytical models mostly used to calculate cutting forces.[8–10] The key parameters in calculating cutting forces by using the above models are the depth of cut, material strength, shear zone angle and rake angle.

The main deficiency of all analytical models is in the fact that they perceive the interaction of cutting tools and rocks as two-dimensional whereas in reality this interaction is three-dimensional. Furthermore, all models rely solely on the rake angle neglecting thus the sideway angle and the sideway rake angle of cutting tool which also influence cutting forces. Mancini et al. proposed the method for calculating chain pull force based on geostatic modelling of cutting chain motion.[11] Dagrain[12] analysed the cutting mechanism with a linear rock cutting machine by using different cutting sequences and different shapes of cutting tools. Based on specific cutting energy he found that certain constructions of cutting sequences are more efficient than the others so that the obtained results could be used to optimise cutting chain construction.

Copur et al.[13] also conducted experiments on linear rock cutting machines by using specially shaped tools which simulate different sideway angles. Based on the extensive study of the influence the cutting conditions and cutting tools geometric quantities have on cutting forces and cutting energy, the authors proposed a model for predicting chain saw performance which was verified in laboratory and field experiments. The results of experimental studies and in-situ investigations indicate that the cutting action of chain saw machines can be successfully simulated by linear cutting experiments, even though there was a certain deviation when comparing specific cutting energy. According to the authors, the main reason for the deviation is the difference in the value of sideway angels during measurements. Furthermore, the measurements did not consider the different height of individual tool holders determined by chain construction.

This was the reason to conduct laboratory experiments on a linear rock cutting machine with full sized cutting elements, so that the conditions during experiments are equal to conditions in the process of chain saw cutting. For the purpose of experiments a triaxial transducer was constructed which enables the recording of all three components of cutting force. In order to verify the possibility of using the linear rock cutting machine in simulating cutting process, field experiments were conducted which included the measurement of chain saw cutting energy under field conditions.

2. Laboratory studies

Given that currently there is no standard for rock cuttability, the experiments were conducted on a linear rock cutting machine. The linear cutting machine is a modified shaping machine equipped with a triaxial force transducer attached to the cutter head and connected to a data acquisition device. The force transducer is constructed in the way to enable the installation of chain saw tool holder and it enables the measurement of three force components while cutting. Transducer elements are octagonal rings fixed between two solid plates. The force on the ring is measured indirectly by measuring deformations using strain gauges on the ring. Four rings were used altogether, each ring with four strain gauges. Strain gauges were connected to full Wheatstone bridge in the way to enable the measurement of all three force components independently.[14] Each measurement bridge was connected with a cable to one channel of the data acquisition device. The autonomous measurement system "Hbm Spider 8" was used for these measurements. The device has four measurement channels and it enables the excitation of the bridge and the measurement of output voltage of the bridge, i.e. output voltage to excitation voltage ratio in mV/V. Excitation is an alternating voltage source and it is the carrier frequency device.[15] Output voltage is amplified, filtered and then the measurement quantity is converted into a digital data. The communication with the computer is done via a parallel port. "Catman" software installed on the computer enables the operation with the "Hbm Spider 8" device as well as the display and recording of the data. The detailed description of transducer structure and of the measurement system is given in another work.[16]

The simulation of cutting process was conducted on the linear rock cutting machine with full sized chain saw tool holders and cutting tools in actual size. The chain saw cutting sequence used in these experiments consists of eight tool holders and thirteen cutting tools. The first three tool holders have one cutting tool and are used for opening the cut whereas the other tool holders have two cutting tools and are used to widen the cut. Cutting tools are rectangular and made of tungsten carbide. The first tool holder within the sequence is marked with No. 1 and the last with No. 8. The length of the cutting sequence is 730.0 mm, width 44.6 mm and the difference in height between the first and the last cutting tool is 13.5 mm. The dimensions and the lacing design of cutting tools are given in Fig. 1b.

2.1. Simulation of rock cutting process

Samples used for laboratory experiments were obtained from the dimension stone exploitation field "Redi" near Trogir, Croatia. The samples were sawn at an open pit, to a of size 150 mm × 150 mm × 70 mm. Sample dimensions were selected

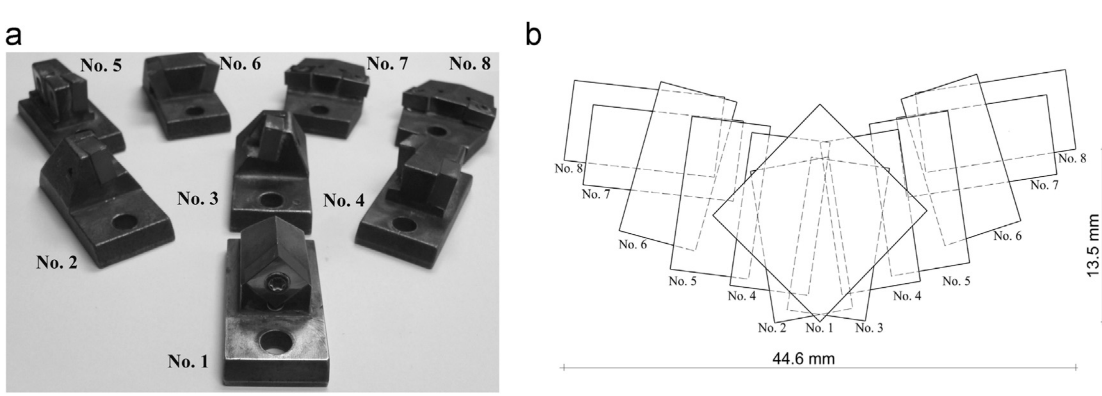

Fig. 1. (a) Tool holders and cutting tools of the cutting sequence, (b) cutting tools lacing design.