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Use of digital image processing techniques for evaluating wear of cemented carbide bits in rotary drilling

Omid Saeidi [a,*], Jamal Rostami [b], Mohammad Ataei [a], Seyed Rahman Torabi [a]

[a] Department of Mining Engineering, Geophysics & Petroleum, Shahrood University of Technology, Shahrood, Iran
[b] Department of Energy & Mineral Engineering, Pennsylvania State University, University Park, PA 16802-5000, USA

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ABSTRACT

This paper presents the use of image processing techniques in monitoring of bit wear, especially, WC/Co cemented carbide bits that are commonly used in rotary drilling in mining, civil and petroleum engineering. Image of the bits was acquired using a CCD camera. The background was subtracted from the image to reduce noise effects. A Laplacian filter has been used to enhance edge contrasts. Structural elements have been applied to dilate, erode and close boundary edges. Edge detecting was conducted using a canny edge detector. Image processing approaches; first order surface metrics, gray level co-occurrence matrix (GLCM) based texture analysis and minimum distance based classifiers have been used to estimate wear of tricone drill bits in rock drilling. A digital balance was used to obtain weight loss of the bits and also wear of their heel row and gage row (dimension loss) was measured using a micrometer in different directions. Results showed that, of the surface metrics, bit area and major length axis could be good measures for bit wear estimation. The entropy and contrast features of the GLCM method showed good correlations with bit weight loss. Of the minimum distance based classifiers just Euclidean, City block and Chebychev distances had reliable correlations with weight loss and heel row wear rather than other features.

1. Introduction

Improving drilling efficiency and optimized use of drill bits have become crucial issues in various underground and surface operations, due to the increased demand for drilling as part of excavation of rock masses in mining, petroleum and civil engineering. In large surface mining projects, tricone rotary drill bit which is a cemented carbide material (consists of tungsten carbide (WC) grains inserted or sintered into a steel cone and bonded together with a cobalt binder) is the most popular drilling tool for deep holes with large diameter. The penetration rate of rotary drills has increased over time due to the use of higher powered drills and better control of the operational parameters, which leads to an increase in mining production and reduction in drilling costs. To decrease downtime related to drilling, it is inevitable to use tool condition monitoring (TCM) methods. Excessive wear and frequent breakage of the drilling bit are two of the major causes of downtime.

Technically, the tool wear monitoring methods can be classified into two groups, a) direct methods, and b) indirect methods. In direct methods, fractured and torn WC inserts and crushed binders are measured directly either with observation under microscope, 3D surface profilers, optical microscope or scanning electron microscope (off-line method) or with a couple-charged device (CCD) camera (real time method). In indirect methods, the measured parameters or signals (viz. sound, acoustic emission, vibration, torque, etc.) of the drilling process allow for drawing conclusions upon the degree of tool wear [1,2]. However, direct methods usually using image and video processing are better for accuracy and reliability points of view.

In rock drilling, the common wear types of tools are heel row wear (when bit lateral inserts erodes in contact with earth materials), gage row wear (in which cone binder matrix erodes in contact with earth materials) and WC insert breakage. Wear measurements of bits in this study consist of two procedures, weight loss using a digital balance with precision of 0.1 g and dimension loss using a micrometer with a precision of 0.02 mm.

Currently, no universal process is available to assess wear of bits in rock drilling especially in mining tasks. Most of the works are based on the measurement of rock abrasivity indices; abrasive mineral content (AMC), equivalent quartz content (EQC), Cerchar abrasivity index (CAI), rock abrasivity index (RAI), F-abrasivity, bit wear index (BWI), cutter life index (CLI), etc. [3–6]. Further works are related to indirect methods such as measurement of drill system torque, vibration, thrust and their relationship with bit wear. However, all of the mentioned methods have interaction with bit wear rate, i.e. both could affect each other too. Hitherto neither abrasivity of rock minerals has given reliable correlation nor have indirect methods provided a comprehensive

* Corresponding author at. Department of Mining Engineering, Geophysics and Petroleum, Shahrood University of Technology, University Ave., Hafte-Tir Square, Shahrood, Iran. Tel.: + 98 9149804239.
E-mail address: osaeidi914@gmail.com (O. Saeidi).

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procedure for bit wear evaluation. Thus, on-line monitoring of wear level might enhance the management process involved in drill bit replacement, by means of taking advantage of a fact based approach instead of relying on the individual criteria of the drilling operator. Use of image processing for drilling tools monitoring could lead to development of a procedure, where bits could be quickly cleaned and photographed at regular time intervals and the amount of wear recorded for subsequent analysis. The quick turnaround time in this procedure allows for minimizing the interruptions and thus downtime of the drill, as compared to making limited measurements with the conventional measuring devices.

There are many studies that have tried to use the image processing in tool wear monitoring and measurement [7–17]. Su et al. measured flank wear of microdrills using machine vision. They captured images of worn-out microdrills after the hole-drilling tests on a 10-layered printed circuit board. By analyzing images they calculated flank wear area, average flank wear height, and maximum wear height to evaluate the tool life [18]. Nickel et al. presented the machining performance of HSS twist drills, evaluated and compared it with that of commercially TiN-coated drills. The optical methods were essentially off-line and involved the examination of geometry using a specially adapted toolmaker's microscope for the digital processing of the tool tip image [19].

Gray level co-occurrence matrix (GLCM), one of the most important texture analysis methods has been widely used in image processing in many applications. The GLCM matrices are the measurement of an image's statistical properties, visual characteristics, information theory measures and correlation based information. The GLCM is sometimes called spatial grey level dependency matrix. It has been widely used for texture analysis in tool wear monitoring [20–24]. Minimum distance classifiers calculate distance between an unknown feature and centroid of a class. Jeyapoovan and Murugan used two minimum distance based classifiers, i.e. Euclidean distance and Hamming distance to characterize surface roughness of machined surfaces. They found that the Euclidean distance and Hamming distance were very low for surfaces with similar surface roughness values. Therefore, this technique is ideal for online surface characterization of machined surfaces [25].

According to above review, several researches done on tool wear monitoring are related to machining process where up to now no study has been done regarding application of image processing in monitoring wear of rock drilling bits. The objective of this work is to find an algorithm for evaluation of the bit performance and hence generating relevant information for the operator that allows for proper decision making on the schedule of the bit replacement. For this purpose, WC/Co cemented carbide drilling bits are studied by different image processing techniques. It is tried to define appropriate correlations between bit weight loss percentages, heel and gage row wears and extracted image analysis features.

2. Field measurements and procedures

The study was carried out on the WC/Co cemented carbide bits at Sarcheshmeh copper mine located in southern Iran. Fig. 1 shows a tricone rotary drill bit mounted on the drill rig during drilling a borehole. The bits are API-RR321 standard type with a diameter of 25.09 cm manufactured by Sandvik Co. They are mounted on a DMH Ingersoll–Rand drill rig to penetrate rock masses. The system involves maximum 20.68 MPa feed pressure on the string, 2.75 MPa air pressure to drag out rock and soil detritus, 200 rpm and 34.47 MPa rotation pressure.

The bits are investigated before drilling and after their useful life is completed. However, no standard way is available to find useful life of a bit. It regularly depends on the experience of operator who decides to change the bit according to the condition of drill bit and reduction of its efficiency.

In this work, worn bits were transferred to the warehouse. Firstly the bits are washed to remove penetrated dust and rock material from their surfaces. They are weighted before and after drilling the rock masses to obtain weight loss of tricone bits. This represents eroded material because of contact with abrasive minerals of drilled rocks during the process.

A CCD camera was used to capture images with 10 Megapixel resolutions. Images were captured with the arrangement of the camera at 45° to the bit surface with constant settings. All images were captured with the same setting and arrangement of the camera. ISO sensitivity (standard set that represents sensitivity to light as a numerical value, where a higher number indicates a higher sensitivity, faster shutter speed, narrower aperture and a greater ability to capture light) and LED flash light were adjusted to take pictures with 4× magnifications (digital zoom) and a shutter speed of 1/5000 s. However, the camera resolution was 10 MP and the images captured have dimensions of 2071 × 1974 pixels. As they were too large to be processed in the Matlab environment they were resized to 400 × 400 pixels. The images were then processed to identify the variations in bit configuration (Fig. 2).

3. Theoretical background

The whole procedure to get the correlations between image processing features and real wear measurements is illustrated in Fig. 3. To extract the surface metrics, a Laplacian filter with $\alpha = 1$ has been used to enhance edge contrasts. Structural elements have been applied to dilate, erode and close boundary edges, clearly. In addition, to compute distance classifiers a set of 1D intensity signals were generated for characterizing the most important information of the original 2D image.

The detailed descriptions of methods are given as follow.

Fig. 1. Close up view of a drill bit during drilling the hole into the rockmass.