Acoustic Analysis of Rock Cutting Process for Impregnated Diamond Drilling

by

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To my beloved parents, Jose Gregorio and Adriana Patricia, for their endless support

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Abstract

The rock cutting industry has experienced important changes with the introduction of diamond-based drilling tools in the last few decades. Impregnated diamond (ID) bits are part of that introduction and their main use is to drill hard and abrasive rock formations. ID core drilling has emerged as the most commonly used technology employed in the advanced stages of mineral exploration. Through this technology, existing resources - mineral and energy - are expanded and greenfield exploration is carried out. As near-surface deposits are depleted, there is a global trend towards targeting deeper for exploration. Currently, in near-surface drilling, bit wear condition is determined by the experience of drilling operators –trial and error–. Although it makes the evaluation very subjective and prone to errors, it is an accepted practice. Conversely, in deep drilling, direct assessment of the bit wear condition is difficult and time consuming. Therefore, alternative techniques must be developed in order to evaluate, in real time, the wear condition of the bit and properties of the drilling medium. In this thesis, Acoustic Emission (AE) along with Measuring While Drilling (MWD) parameters are considered as an alternative technique to remotely monitor the ID bit wear condition (sharp and blunt) and rock properties (abrasivity). A series of rigorous and specialized drilling and abrasivity tests are utilised to generate the acoustic signatures with (topologically variant) and without (topologically invariant) changes in the topology of the tool cutting face.

Main findings of this work are as follows: firstly, based on the step test results, linear relationships were developed that make it possible to estimate the depth of cut, weight on the bit (WOB) and torque on the bit (TOB) by simply using the time domain parameters of the AE signals. Wear tests also showed that AE amplitudes start to trend down as wear begins to accelerate. Secondly, acceptable pattern recognition rates are obtained for the majority of tool condition monitoring systems developed for predicting sharpness or bluntness of ID bits. In particular, the system composed by AE_{rms} and TOB excels due to the high classification performance rates and the fewer input variables compared to other tool condition monitoring systems.

Lastly, AE parameters, such as total number of events and root mean square of AE, in addition to testing parameters are found to accurately predict rock abrasivity measured via Cerchar Abrasivity Index (CAI). The importance of this index lies on: (i) the fact that ID drilling is commonly used in abrasive rock formations, and (ii) the way CAI has been defined (length of wear flat exerted on a steel pin after being scratched on one centimetre of rock surface), which intrinsically relates it to wear condition of the tool. The insights presented in this thesis open up a new promising field of study, impregnated diamond drilling using AE as an indirect technique to evaluate tool condition.

Statement of Originality

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Abbreviations and Symbols

AE	Acoustic Emission
AI	Artificial Intelligence
ANN	Artificial Neural Network
ASTM	American Society for Testing and Materials
BSE	Back-Scattered Electrons
BT	Boosted Trees
CAI	Cerchar Abrasivity Index
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
C_{qtz}	Quartz Content
D	Depth of cut
DAQ	Data Acquisition Card
DET CRC	Deep Exploration Technologies Cooperative Research Centre
E_{tan}	Young's Modulus
FN	False Negative
FP	False Positive
FFT	Fast Fourier Transform

GMDH	Group Method Data Handling
h_p	Pin Hardness
HRC	Rockwell Hardness C
ID	Impregnated Diamond
IEEE	Institute of Electrical and Electronics Engineering
ISRM	International Society of Rock Mechanics
KNN	K-Nearest Neighbours
LCPC	Laboratoire des Ponts et Chaussées
MAE	Mean Absolute Error
MLP	Multi Layered Perceptron
MWD	Measuring While Drilling
NTNU	Norwegian University of Science and Technology
PDC	Polycrystalline Diamond Compact
QCAT	Queensland Centre for Advanced Technologies
RPM	Revolutions Per Minute
SE	Specific Energy
SEl	Secondary Electrons
SEM	Scanning Electron Microscopy
ST	Simple Trees
SVM	Support Vector Machines
TCM	Tool Condition Monitoring
TN	True Negative

TOB	Torque On Bit
TP	True Positive
UCS (σ_c)	Uniaxial Compressive Strength
ROP (V)	Rate of Penetration
VAF	Variance Account For
WOB	Weight On Bit
Ω	Rotary Speed