Dynamic Systems Group

dsg

Drill Wear Monitoring using Instantaneous Angular Speed

A comparison with Conventional Technologies used in Drill Monitoring Systems

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Contents

Introduction

- Machining remains very important in the manufacturing
- The cost of machining is estimated to more than 15% of all manufactured products in industrialized countries
- Between machining operations encountered in industry, we have: Turning, Drilling, Milling, Grinding and Boring
- It is estimated that 40% of machining operations in aerospace for instance are done by drilling.
- Drilling operations generate more income than any of the other machining processes individually
- During drilling operations, drill insert often wears during its time life
- This wear hampers the reliability and complete automation of machining processes
- Since insignificant levels of wear may cause defects of machined components, a conservative approach is often taken to recycle the drill insert non-optimally

Introduction

- Optimal machining requires constant awareness of the extent of the current tool condition to avoid financial loss due to non-optimal use of tool inserts and scrapping of expensive parts that may occur due to drill tool wear
- In manufacturing environment where drilled holes are required with small tolerance less then 0.5 mm, drill wear monitoring becomes inevitable for the following reasons:
  - Improvement of both quality and production
  - Reduce shut down time due to replacement of drill failure
  - Prevention of tool damage and parts
  - Use of the insert at its optimal by means of Tool Condition Monitoring (TCM) and diagnosis systems to identify defects and their locations
  - Overall there is an economic gain in terms of costs reduction
- Thus TCM and diagnosis systems are the key factors for unmanned machining processes

Literature Survey

- Prevalence of commercial sensors or custom-made sensors in machining operations with straight edge cutters such turning and milling.
- Theses applications are shown in the works of the following authors:
  - Byrne, G. et al.
  - Jemielniak K.
  - Dimla, D.E.
  - Scheffer, C. and Heyns, P.S.

Literature Survey

- The state-of-the-art in methods applied to TCM in machining operations has been reviewed by the following authors:
    - Jantunen, E.: summary of methods applied to Drill Condition Monitoring comprising conventional monitoring methods:
        - ✓ He concludes that conventional methods were successful in laboratories but still yet to find his way in unmanned industry environment

Literature Survey

- Rehorn, A.G. et al.: review the state-of-art of methods and results in TCM. He focuses on the following:
  - ✓ TCM development and technologies used in drilling, turning, end milling and face milling.
  - ✓ The state of the direction of TCM research
  - ✓ Lack of custom-made sensors in drilling operations
  - ✓ Suggest research in developing instrumented drill tool
  - ✓ With focus effort on innovative use of available sensor technology

Literature Survey

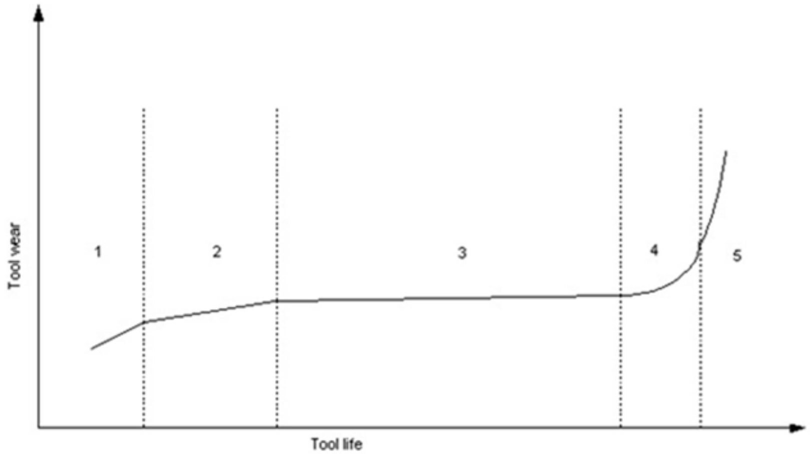
- Botsaris, P.N. and Tsakaras, J.A.: review conventional monitoring methods tested and reported in literature
  - He concludes that the TCM is of increasing importance but stresses that only few implementations have been achieved.
  - Consequently, all available techniques present drawbacks and limitations.

Scope of research

- Conventional methods have attracted most researches in drilling operations and successful tested in laboratories with less implementations achieved in industry due to techniques drawbacks and limitations
- Conventional methods use force that is affected by the drill wear. The assumption is therefore made that the spindle rotational speed will also be affected
- This work investigates the use of Angular Speed (AS) as an indirect monitoring parameter for drill wear compared to conventional measurands during artificially accelerated testing
- The sensitivity of the rotational speed to drill wear was tested and compared to torque and vibration measurements
- The root mean square (rms) and the Fast Fourier Transform (FFT) were used for signals analysis
- Regression Analysis (RA) was used for the decision making

Drill wear

- Drill wear stages
  - First stage: Initial stage of wear
  - Second stage: Slight wear or regular stage of wear
  - Third stage: Moderate wear or micro breakage stage of wear
  - Fourth stage: Severe wear or fast wear stage
  - Fifth stage: Worn-out or tool breakage



Drill wear states function of tool life (Ayesh et al., 2002)

Drill wear

- No mathematical model is available: drill life differs from one tool to another
- Drill life or tool life: represents the useful life of a tool expressed as function of time or number of components produced
- In term of tool replacement, it can be defined as the total time to failure or number of components produced to failure

Monitoring methods

- Direct methods: off-line system of drill monitoring, often used to understand and visualize different modes of wear when the drill is worn
- Indirect methods: on-line drill wear monitoring system. Widely used for on-line monitoring and automatic drilling operations. Suitable to prevent sudden failure or incipient mechanical failure, and fracture or breakage failure

Signal processing

- Time domain – Statistical parameters
  - Signal average
  - Peak
  - Root mean square
  - Variance
  - Crest factor
  - Kurtosis

Signal processing

- Frequency domain or spectral analysis
  - Use of Discrete Fourier Transform (DFT) of digitized data to generate the Power Spectral Density (PSD)
- Time Frequency domain
  - Describe how the spectral content of the data evolves with time

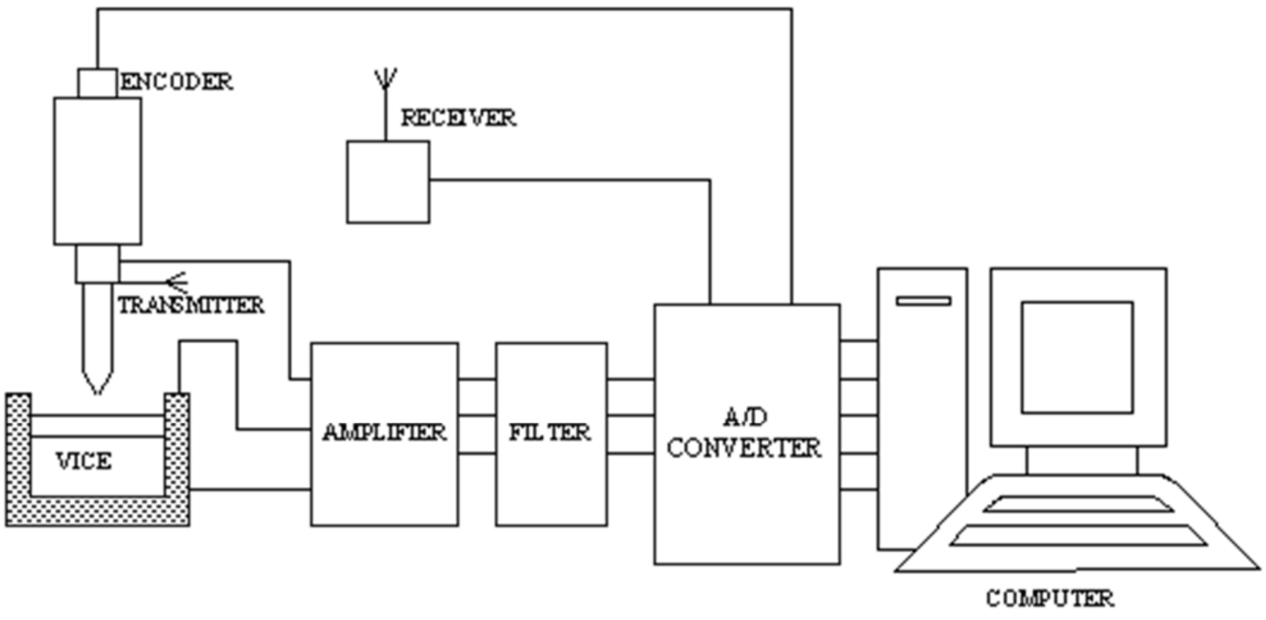
Decision making

Different ways of making decisions on drill tool:

- Decision based on an absolute threshold being exceeded
- Decision based on a trend
- Artificial neural networks

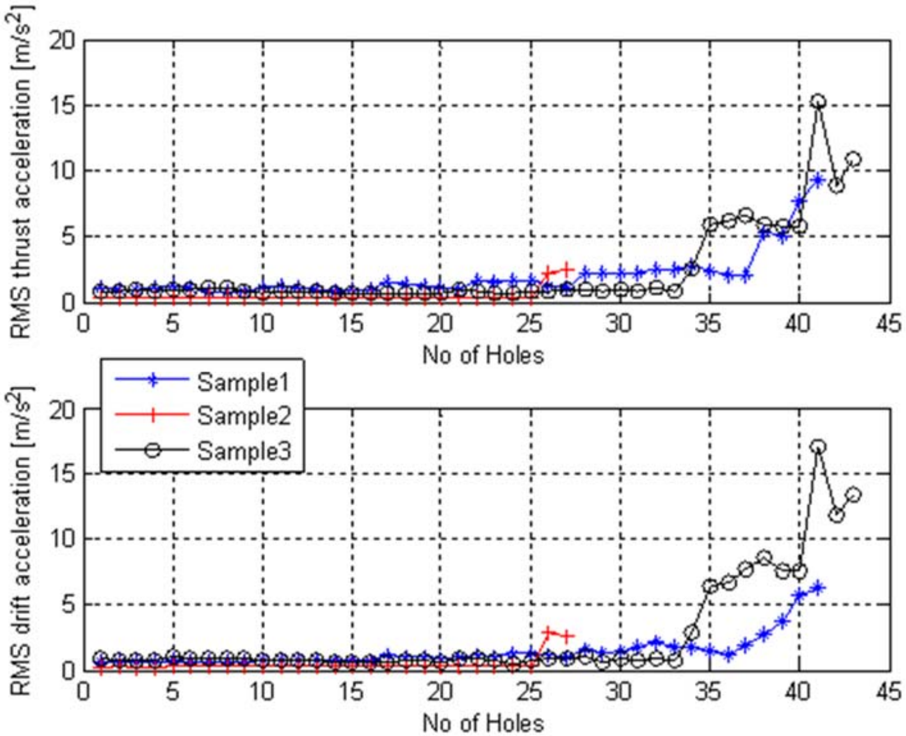
Experimental set-up

The schematic diagram of the experimental set-up



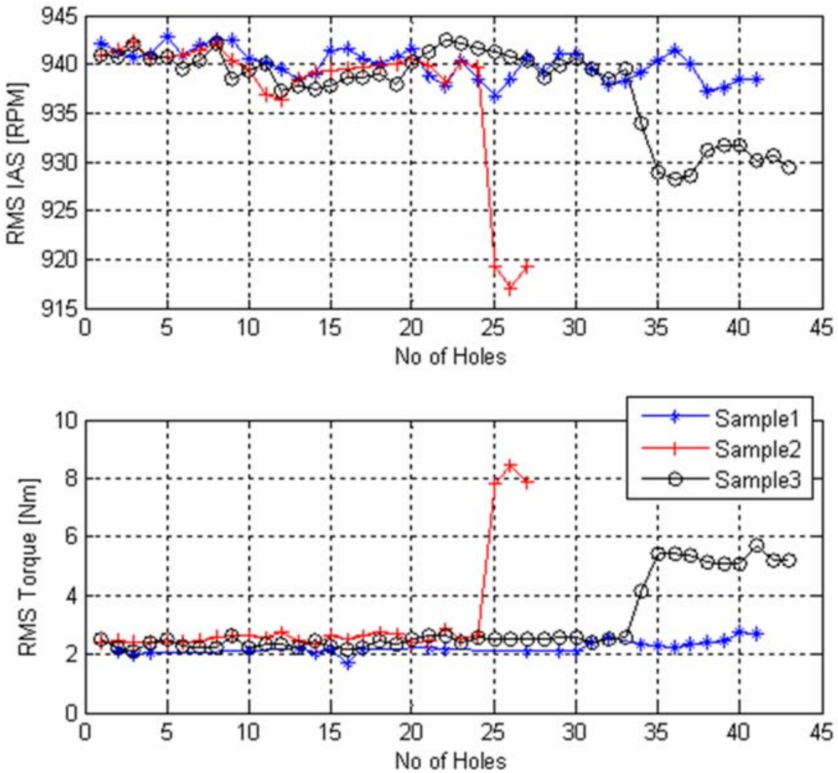
Results: conventional technologies vs AS

- Drill wear in time domain



Different rates of drill wear using vibration measurements

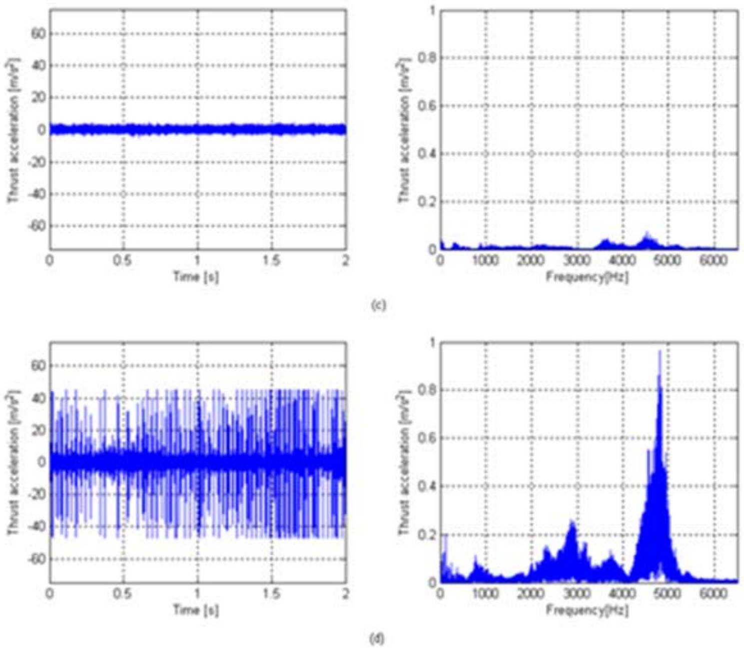
Results: conventional technologies vs AS



Different rates of drill wear using angular speed and torque measurements

Results: conventional technologies vs AS

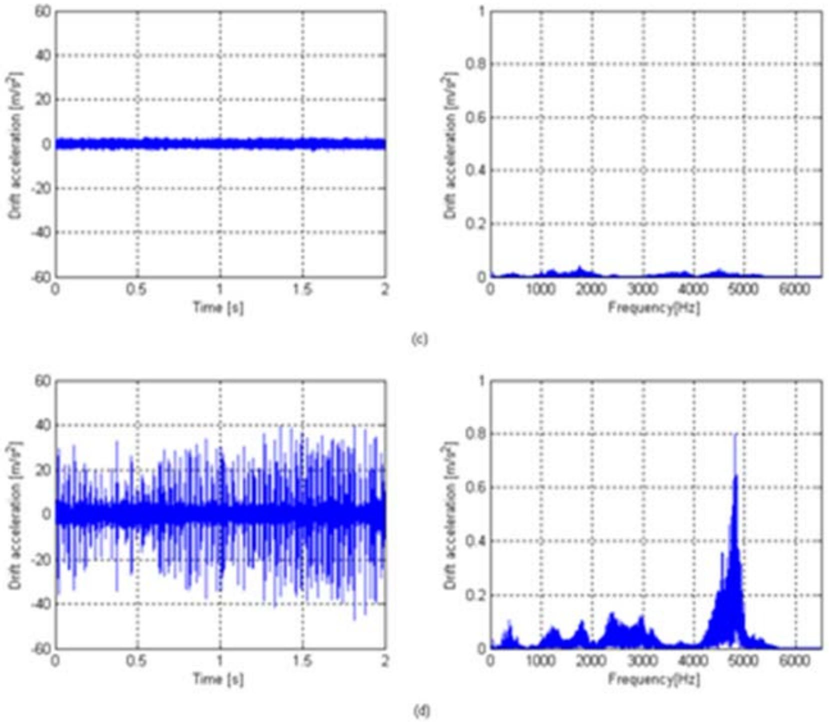
- Drill wear in frequency domain
  - Signal frequency response using vibration measurements in the thrust direction



Time domain response and frequency domain response of sharp and a worn drill

Results: conventional technologies vs AS

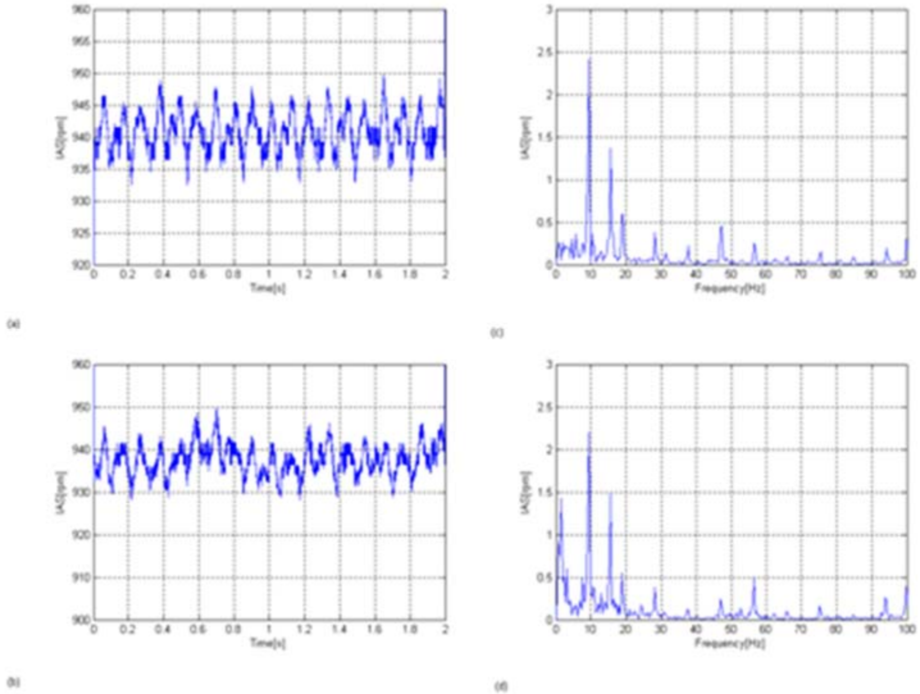
- Signal frequency response using vibration measurement in the drift direction



Time domain response and frequency domain response of sharp and a worn drill

Results: conventional technologies vs AS

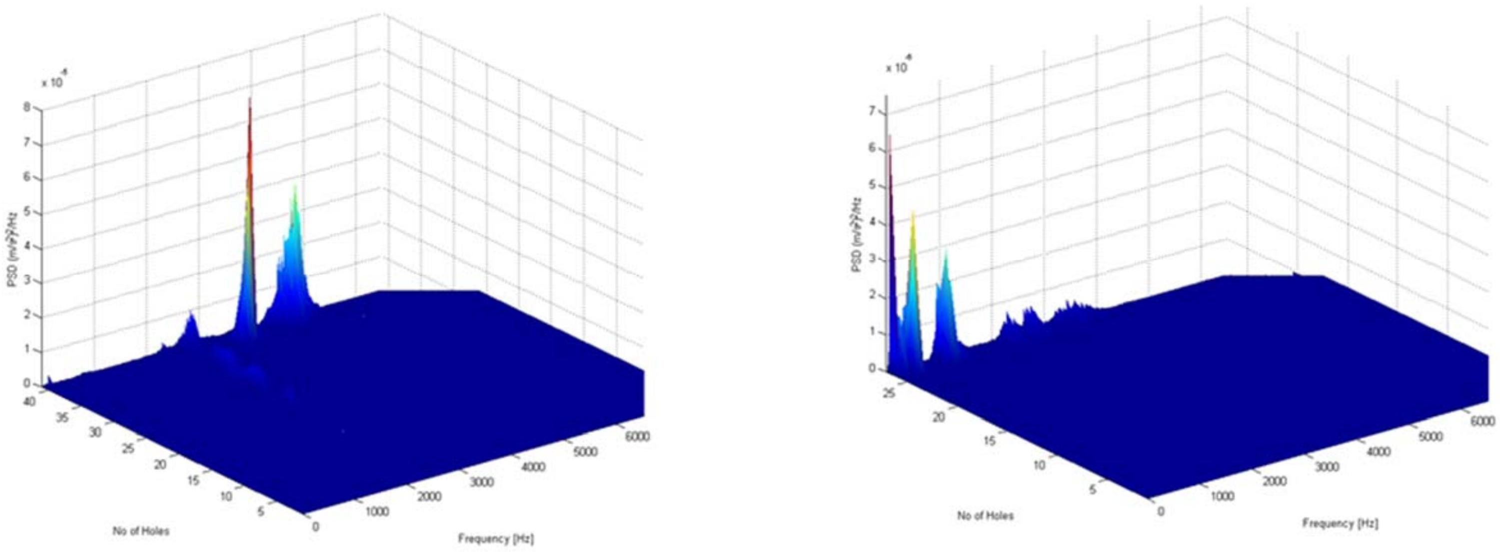
- Signal frequency response using angular speed measurements



Time domain response and frequency domain response of sharp and a worn drill

Results: conventional technologies vs AS

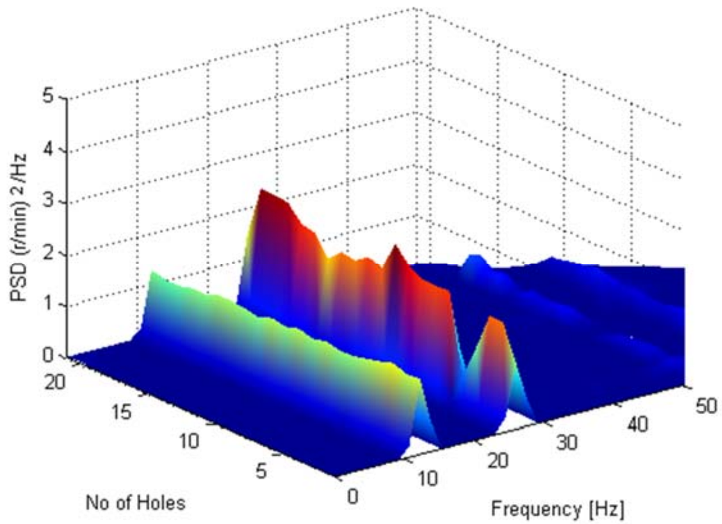
- Spectral analysis using vibration in the thrust direction



Waterfall plots – PSDs for drills D1 and D2

Results: conventional technologies vs AS

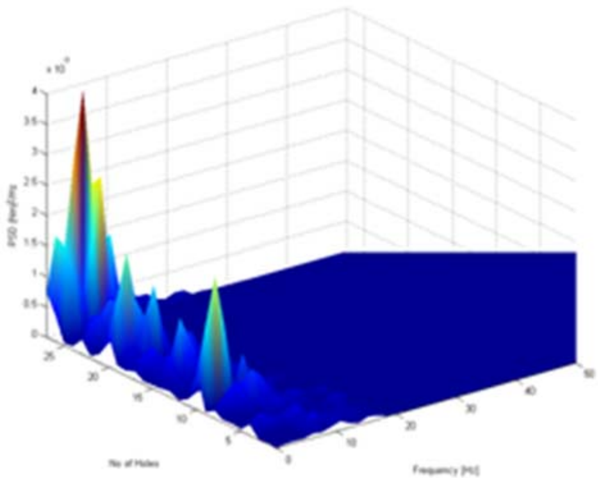
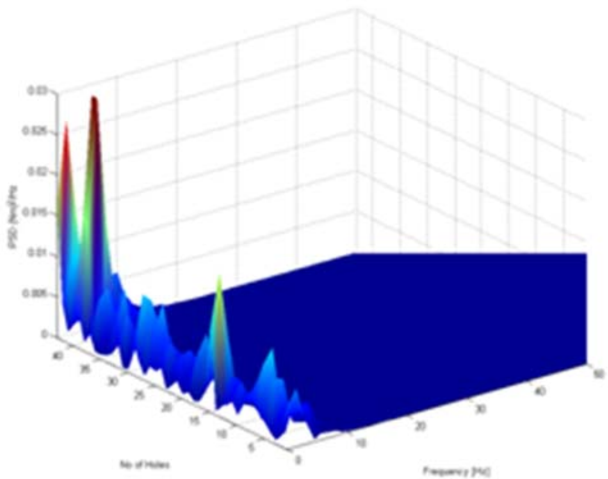
❖ Spectral analysis using angular speed



Waterfall plots – PSD for drill D2

Results: conventional technologies vs AS

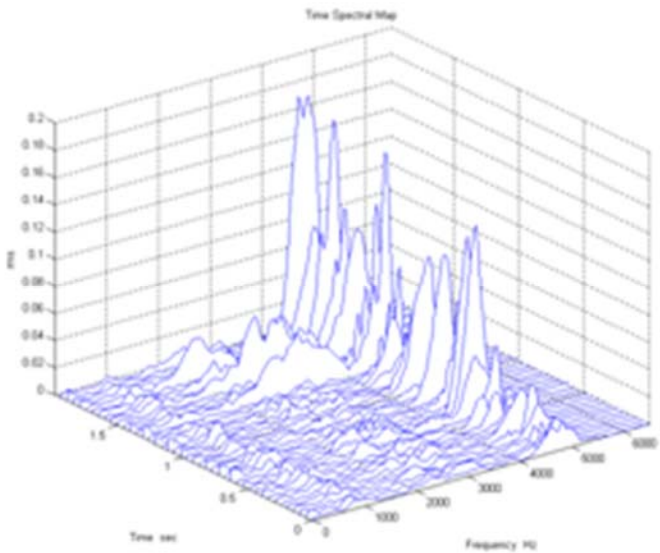
❖ Spectral analysis using torque measurements

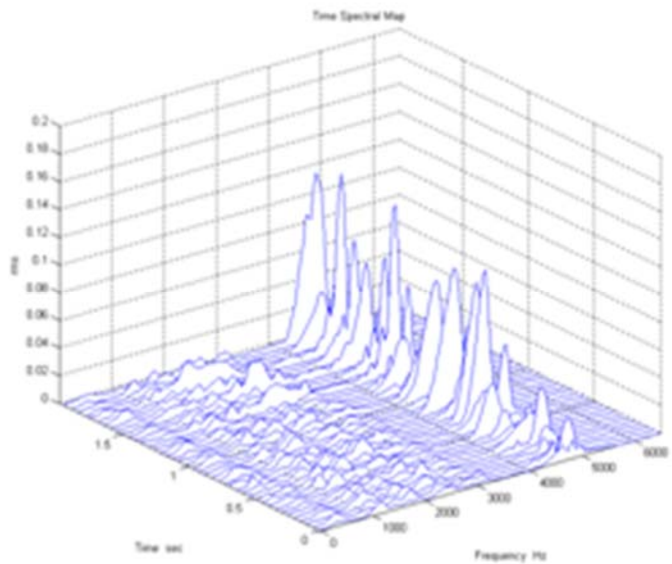



Waterfall plots – PSDs for drills D2 and D3

Results: conventional technologies vs AS

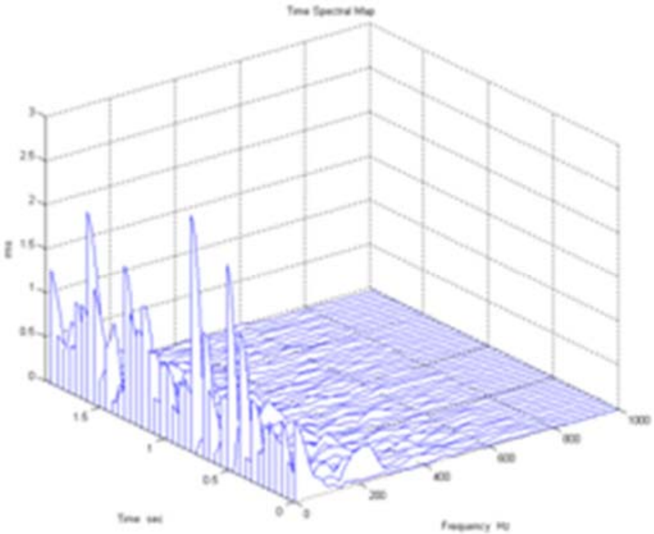
- Drill wear in time frequency domain

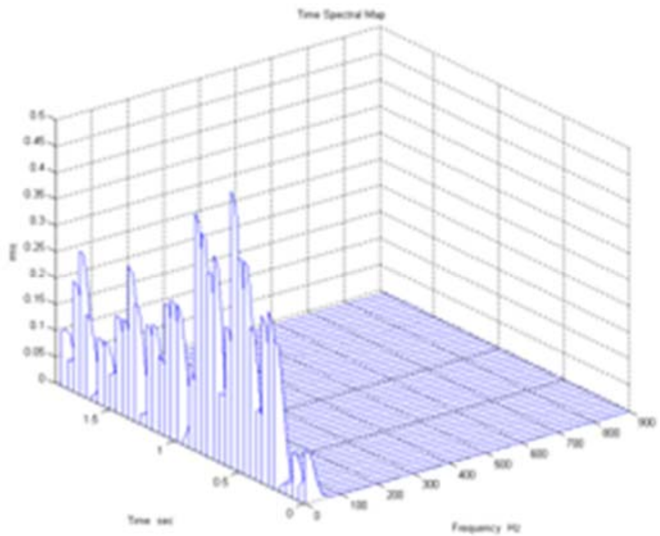




Waterfall plots – Time spectral for drill D3 using vibration in the thrust and drift directions

Results: conventional technologies vs AS





Waterfall plots – Time spectral for drill D3 using angular speed and torque measurements

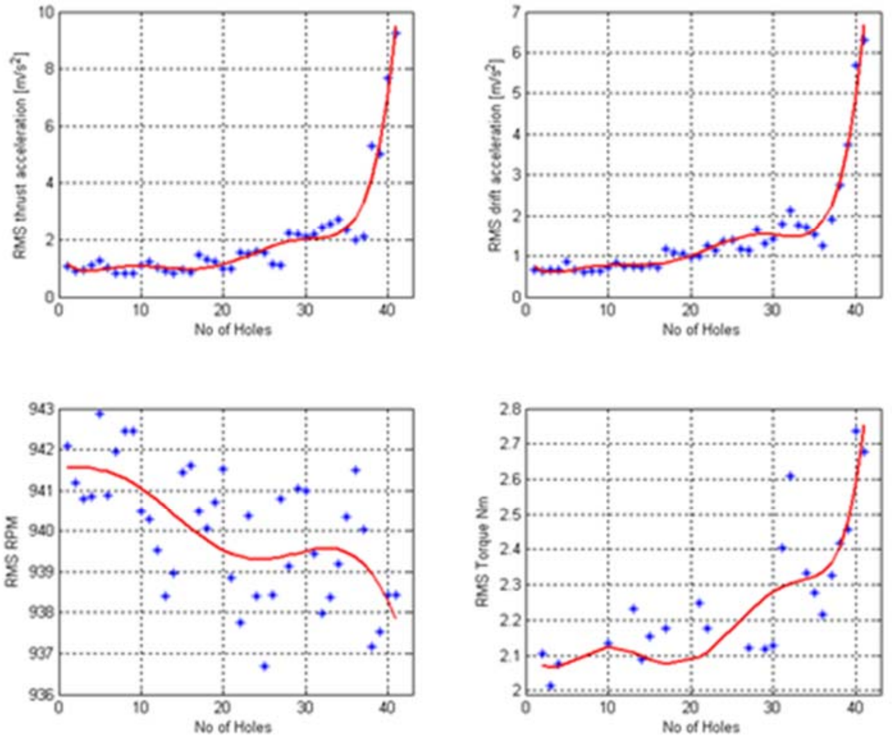
Diagnosis – Regression analysis

The use of a higher order regression analysis in the decision making of the drill condition presents some significant advantages:

- The ability for quick fault detection at the end of drill life
- When compared to conventional processing that used large amounts of data, there is reduction of time in terms of signal processing
- Reduce the variation of noisy data by smoothing sudden individual peaks and keep the trend of the analysed signal stable
- It mimics the shape of the wear development enabling prognosis of the monitor signal with a minimal risk of damaging parts

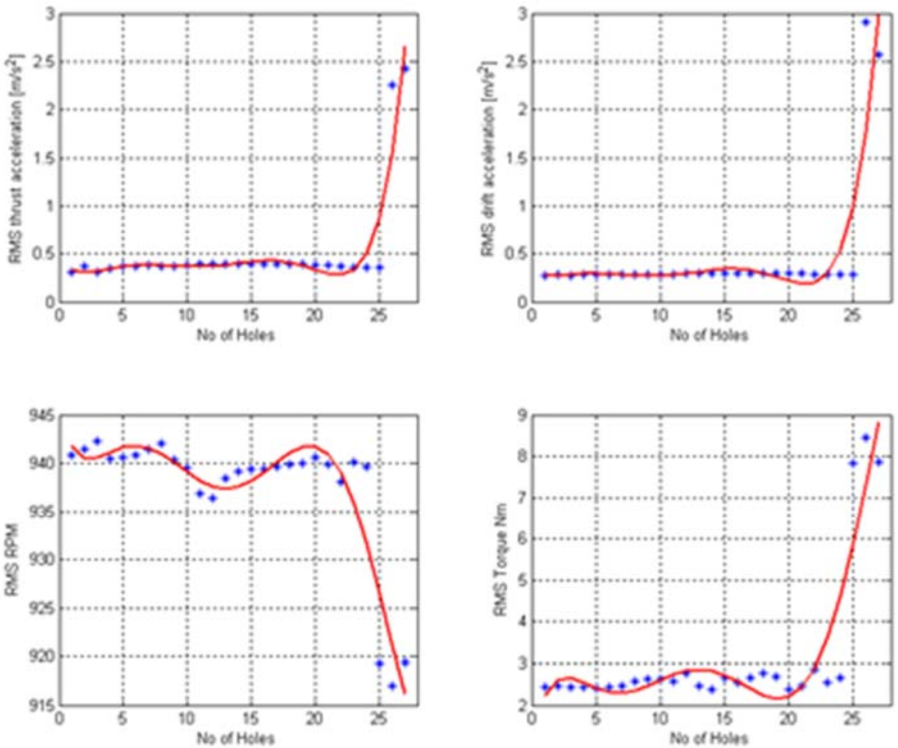
Diagnosis – Regression analysis

- Regression analysis – Time domain



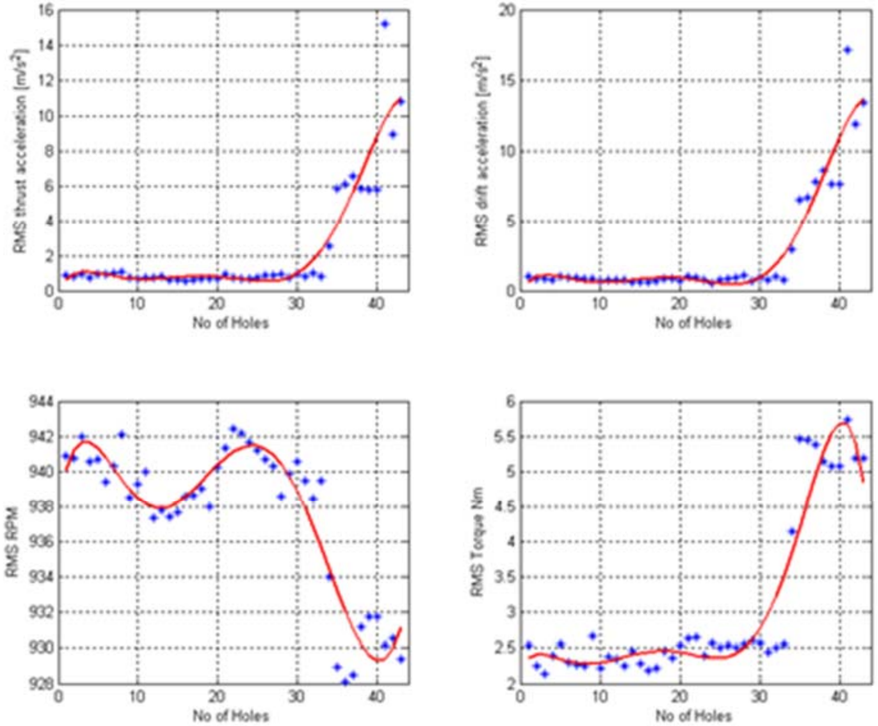
Regression analysis for drill D1: vibrations in thrust and drift direction; angular speed and torque

Diagnosis – Regression analysis



Regression analysis for drill D2: vibrations in thrust and drift direction; angular speed and torque

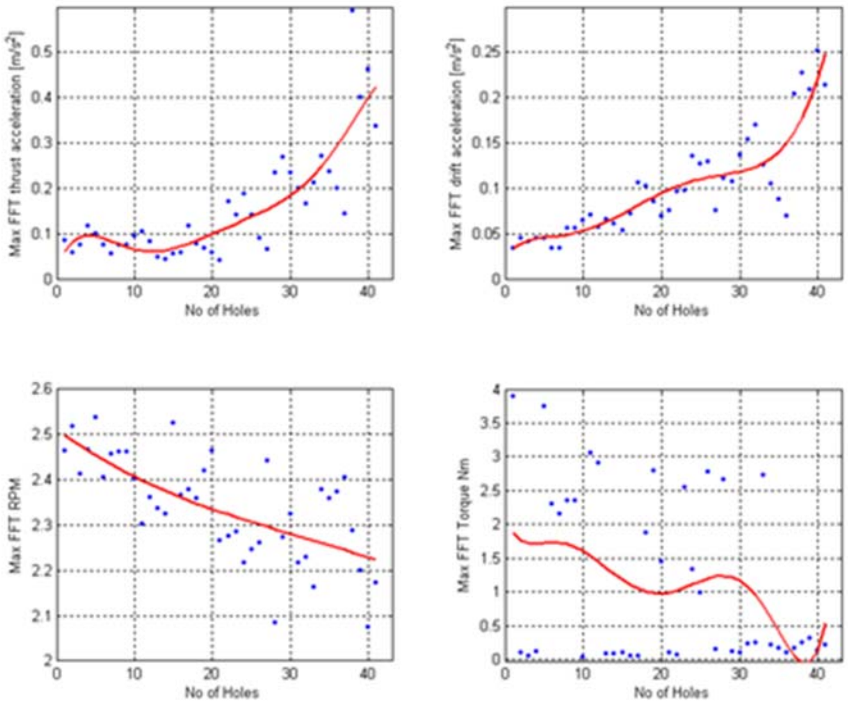
Diagnosis – Regression analysis



Regression analysis for drill D3: vibrations in thrust and drift direction; angular speed and torque

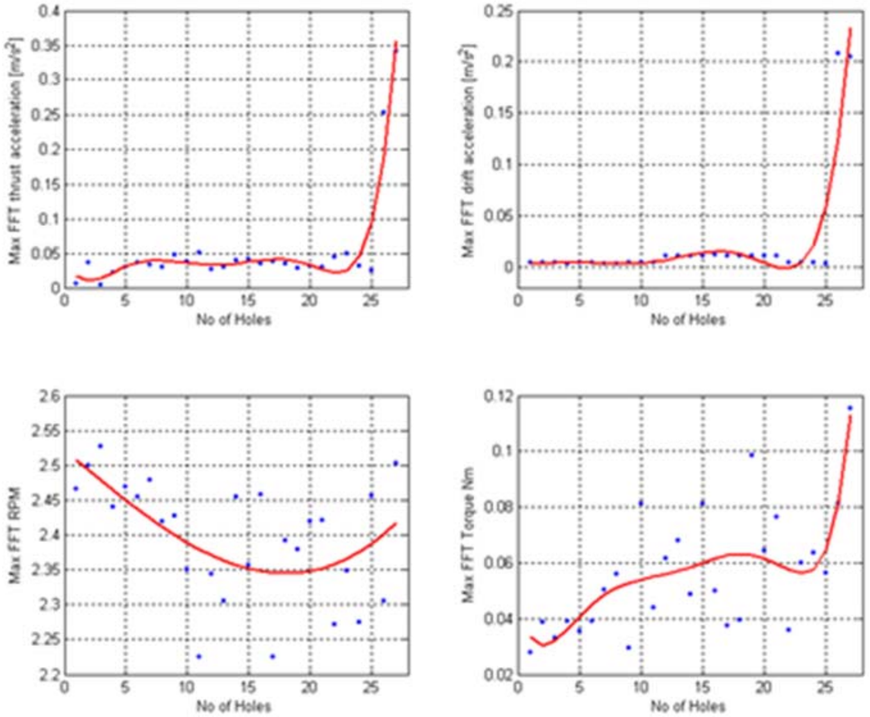
Diagnosis – Regression analysis

- Regression analysis – Frequency domain



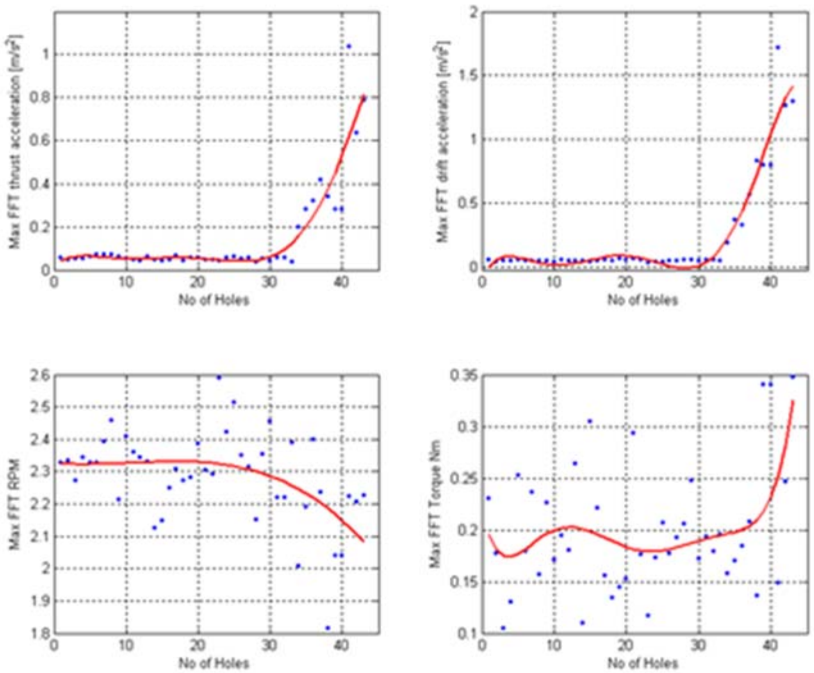
Regression analysis for drill D1: vibrations in thrust and drift direction; angular speed and torque

Diagnosis – Regression analysis



Regression analysis for drill D2: vibrations in thrust and drift direction; angular speed and torque

Diagnosis – Regression analysis

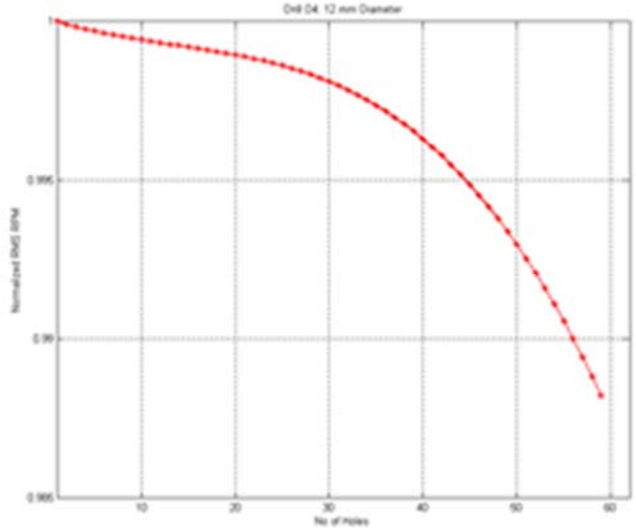


Regression analysis for drill D3: vibrations in thrust and drift direction; angular speed and torque

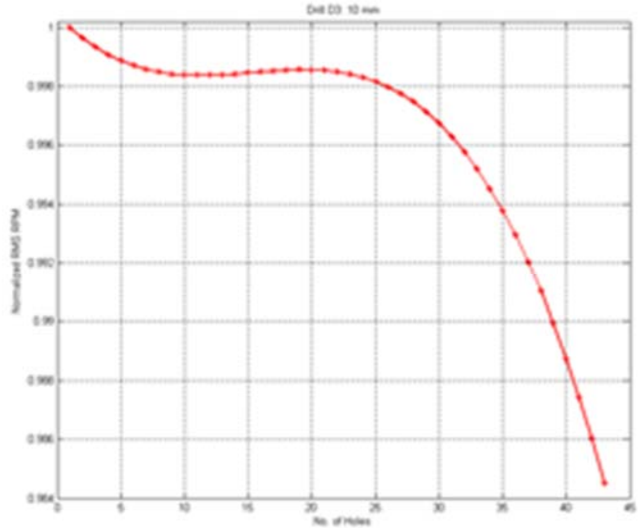
Encoder reliability

To test the encoder reliability, additional drill bits of different diameters were tested to determine to which extend the results were valid:

Drill D4: 12mm

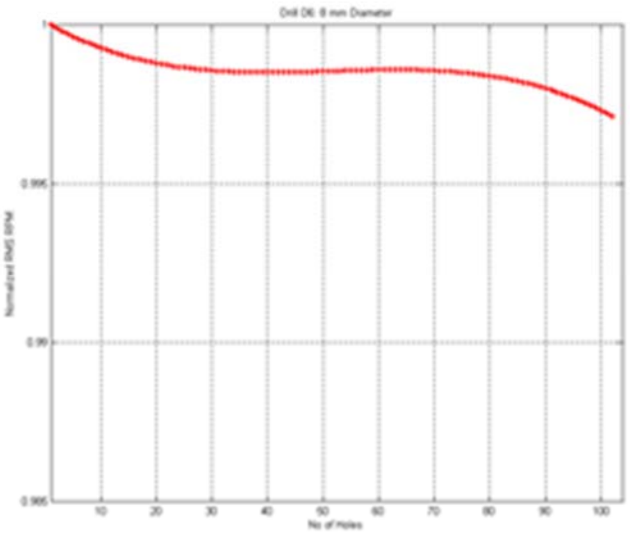


Drill D3: 10mm

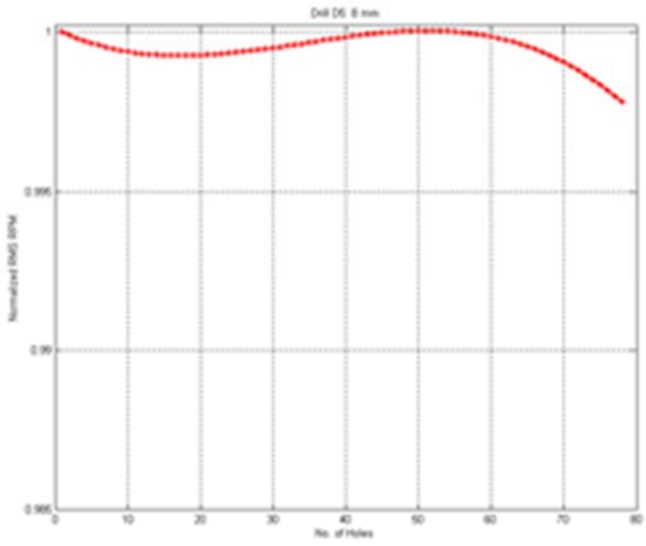


Encoder reliability

Drill D6: 8mm

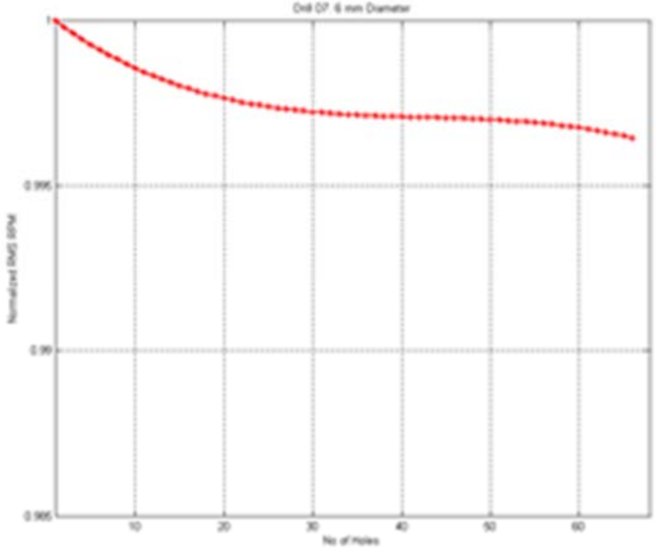


Drill D5: 8mm

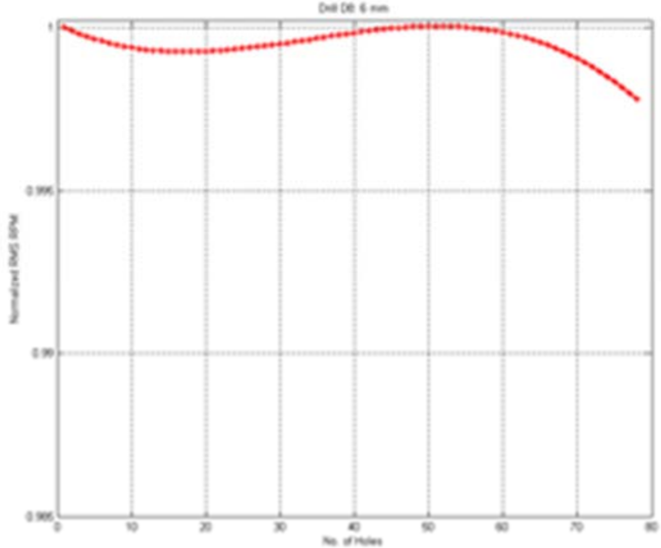


Encoder reliability

Drill D7: 6mm

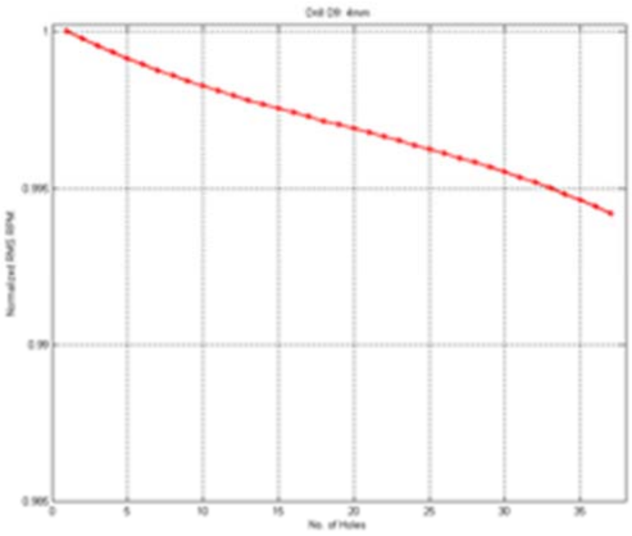


Drill D8: 6mm

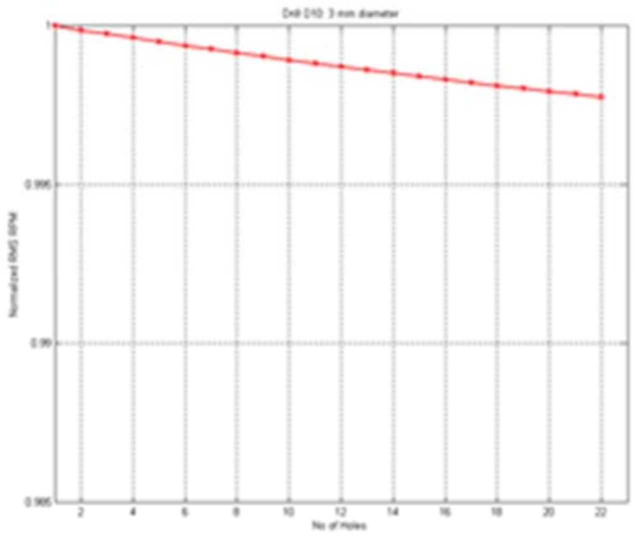


Encoder reliability

Drill D9: 4mm



Drill D10: 3mm



Conclusion

- Development of an encoder based sensor is presented to challenge the limited interest in conventional technology sensors in industry's TCM despite successful results in laboratories
- Results show that the encoder based sensor could provide similar diagnosis information related to drill wear
- Successful comparison between an encoder-based sensor and sensor based conventional technologies was achieved in:
  - Time domain
  - Frequency domain
  - Time frequency domain
  - Diagnosis using the regression analysis
- The reliability of the encoder sensor was successfully tested using different drill sizes

Acknowledgements

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