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DRILL WEAR MONITORING BASED ON MEASURED INSTANTANEOUS ANGULAR SPEED

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Abstract
Various researchers have investigated the use of vibration and torque measurements to assess drill condition on drilling machines. Although it has been established that such measurements could in principle be used, it however not yet found its way into industry as standard practice, and drill bits are still often replaced non-optimally. Some of the reasons for this relate to factors such as the inconvenience of using drill based strain sensors on production machines. In this paper we compare the use of these conventional monitoring parameters to the use of the instantaneous angular speed of the spindle for drill condition monitoring. It is shown that this approach can generate diagnostic information similar to the torque measurements, without some of the complications.

INTRODUCTION

Tool wear still hampers the reliability and complete automation of machining processes. Since even seemingly insignificant levels of tool wear may cause defects of machined components, optimal machining require constant awareness of the extent of current tool wear. Financial loss due to tool wear may occur because of the scrapping of expensive parts and the non-optimal use of tool inserts. To avoid this a conservative approach is often taken and the insert is recycled long before it should really have been necessary. Consequently, various approaches to Tool Condition Monitoring (TCM) have been proposed in recent years [1],[2].

TCM is commonly approached in two ways: Direct methods are concerned with the measurement of volumetric loss at the tool tip, while indirect methods use a pattern in sensor data to detect a failure mode [3]. Direct methods are affected by dirt and chips. Indirect methods have therefore found more acceptance in industry due to the fact that they are readily interpreted, cost-effective, and often more reliable than the direct methods.

Drill wear is a particularly complicated process because of its strong three-dimensional nature. In addition, non-homogenous material characteristics, temperature effects, varying cooling times, drill bit geometry variations, etc. all contribute to huge variations in drill life. It is therefore not surprising that, despite the fact that various monitoring approaches have been explored, a reliable and practical approach that will survive the pressures of the industrial environment, still need to be developed. Current research focus on the use of monitoring methods that include [4]:

- Torque, drift and feed force
- Vibration and sound
- Acoustic emission and ultrasonic vibration
- Spindle motor and feed drive current

Each of these techniques offer distinct advantages and disadvantages, and although none of these represent the ultimate solution, the simultaneous use of some of these methods promise potential for practical implementation. Bearing in mind the simple relationship between torque and angular speed (power = torque × angular speed) and the more or less linear relationship between torque and speed for small slip, it is however surprising that so little has been done to explore the use of the Instantaneous Angular Speed (IAS) of the spindle as one of the monitoring parameters available in the arsenal of TCM methods. Conceptually the IAS could be measured quite easily, while it can be shown that it provides diagnostic information comparable to information provided by the direct measurement of torque on an instrumented drill shank.

This paper provides a preliminary comparison of the use of IAS for wear monitoring, to more conventional measurands.

EXPERIMENTAL SETUP

Figure 1 schematically illustrates the experimental setup used for this investigation. Drilling experiments were conducted on a three-axis milling machine, equipped with an automatic system that allows keeping the feeding rates constant for all the drilled holes. A 10 mm drill bit was used to machine 16 mm deep holes in a mild steel work-piece.

Accelerometers were used to measure vibration signals in the axial direction (for the feed force) and in the transverse direction (for the drift force) while strain gauges mounted on the drill shank were used for the measure of torque via telemetry. Accelerometers were attached both to the spindle and to the work-piece vice. Details of the hardware and equipment details are provided in Table 1.

A Hengstler 0523 shaft encoder, mounted on the top end of the spindle was used to measure the IAS. The output from the encoder is a chain of 1042 pulses per revolution. The signals from the accelerometers were amplified by means of an ICP sensor signal conditioner and then passed through an analogue filter designed with the FilterLab® filter design software (www.microchip.com) to avoid aliasing. All the signals were sampled using a data acquisition board. Since the sampling rate had to be common for all channels, the signal from shaft encoder determined the choice of sampling rate as follows:

$$f_{\max} = \frac{870\,rev}{\min} \times \frac{1\min}{60\sec} \times \frac{1024\,cycles}{rev} = 14848\frac{cycles}{rev} \approx 15kHz \qquad (1)$$

Hence, the experimental data were sampled at 15 kHz and saved on the hard disk of the computer for further processing and analysis.

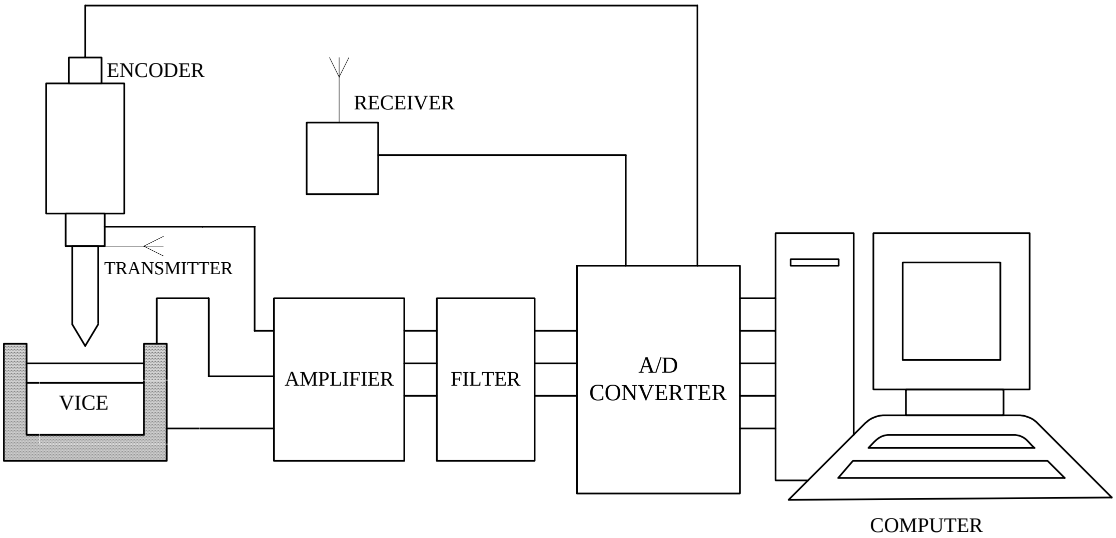

Figure 1 Schematic layout of experimental setup

Table 1 Measurement details

Instrumentation	**Specification**
Drilling machine	Three axis MITCO milling machine
Sensors	Accelerometers: PCB 627A01, PCB E327A01, PCB 352C68 Strain gauges: KFG-2-120-D2-11 Shaft encoder: HENGSTLER 0523
Amplifiers	PCB ICP sensor conditioner
Filter	4^{th} order Chebyshev type with –3 dB roll-off at 4350 Hz
Telemetry system	Torque Track 9000 AII – Digital technology
Data Acquisition	National Instruments A/D card PCI – 6024E with Pentium 4 PC and MATLAB 6.1

TEST PROCEDURE

The experiments comprised drilling holes into a mild steel work-piece under dry cutting conditions. The experiments were conducted on the basis of one size drill bit and the other parameters fixed as recommended in the Machining Data Handbook. However, in order to decrease the duration of the experiments and the size of the data set, the cutting speed was increased by 35%, corresponding to an available speed setting on the machine.

Table 2 Cutting parameters

Cutting parameter	Specification
Tool	HSS
Spindle speed	879 (rpm) = 14.65 Hz nominally
Feed rate	0.13 mm per revolution
Depth of holes	16 (mm)
Cooling	None
Work-piece	Mild steel (~200 HBN) 80×180 mm and 16 mm thick

A manual trigger was used to start the recordings for an overall period of 10 seconds. In order to reduce transient influences on the vibration measurements, the triggering was done a soon as the point of the drill bit completely penetrated the work piece, and the formation of the chips stabilized.

Experiments were conducted on a set of 5 drills, denoted D1 through D5 respectively.

RESULTS

Typical response histories for the thrust and drift accelerations, the IAS and the torque strain measured during experiment D4 for the sharp and worn drill configurations, are shown in figure 2. It is clear how the vibration levels and the torque increase, while the IAS reduces.

By way of example, the evolution of the RMS values and Crest Factors as the number of machined holes increase, are shown in figure 3 for the thrust and drift accelerations, the IAS and the torque signals. The evolution of these features show significant changes in magnitude, specifically after the 15^{th} hole.

These and other time domain features show that the acceleration, torque and angular speed measurements render very similar trends as the number of holes and hence the drill wear increase, and seems to indicate the usefulness of angular speed as a monitoring parameter, even when effectively only the average rotational speed is considered, which will require a simple to measure once per revolution signal.

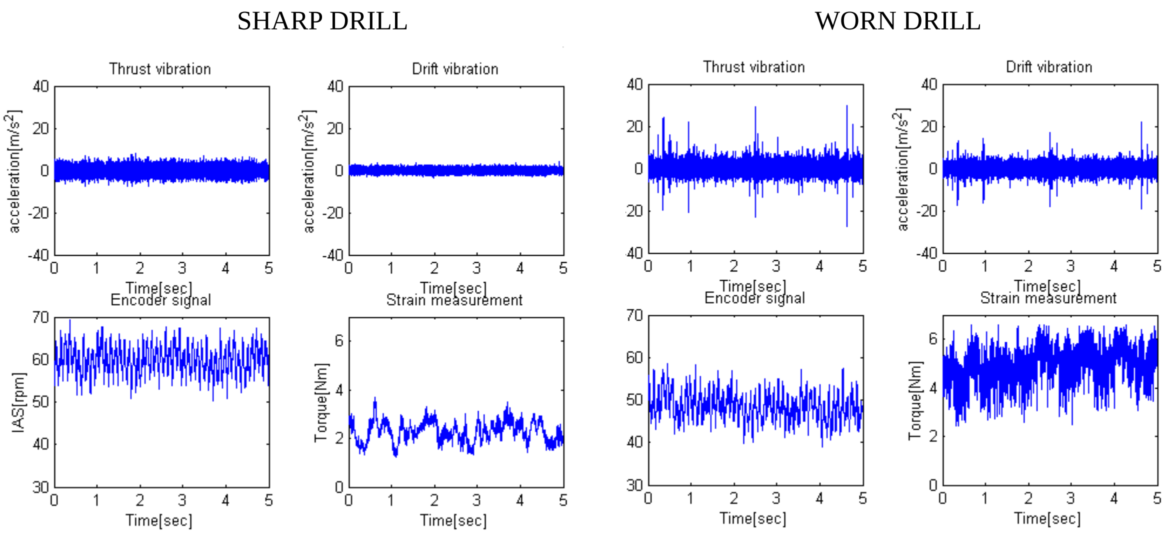

Figure 2 Typical time response histories for a sharp and a worn drill

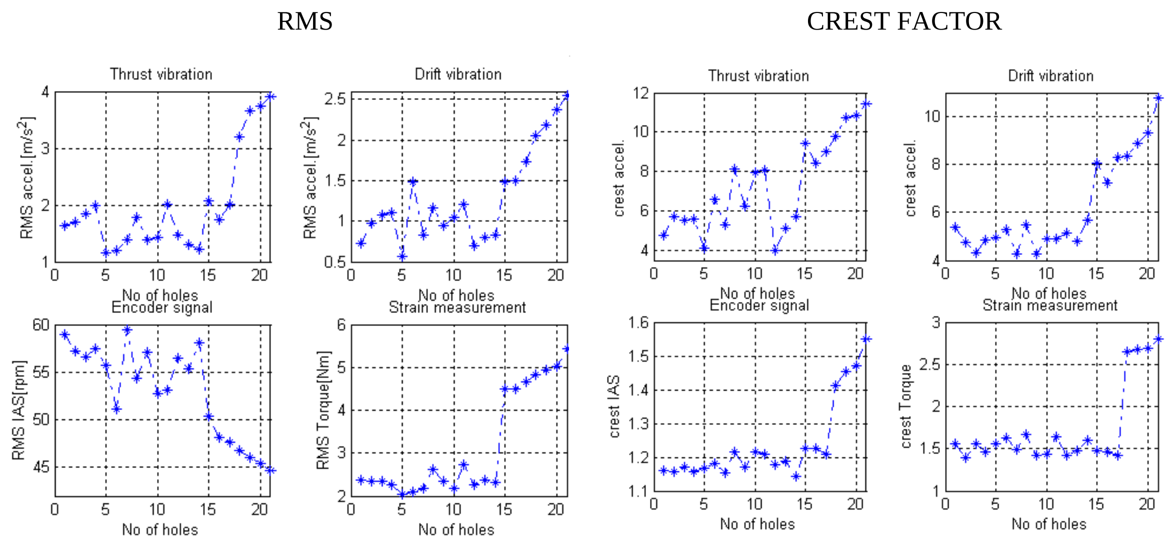

Figure 3 Evolution of RMS values

Figure 4 shows the evolution of RMS for experiments D1 to D5 superimposed on top of each other. Apart from the obvious differences from experiment to experiment (which is part of the justification for this work) the essentially inversely related trends in the torque and angular speeds are clearly seen in the figure.

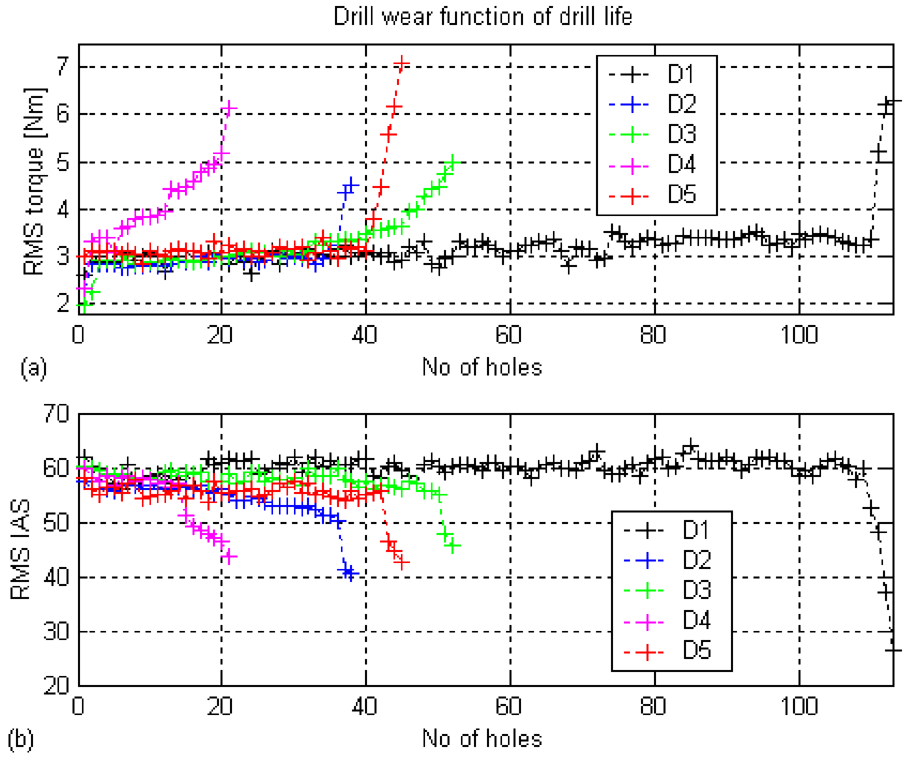

Figure 4 RMS values for experiments D1 through D5

This seems to indicate the usefulness of IAS as a monitoring parameter of sensitivity similar to the more conventional monitoring parameters. Although a digital encoder was used in the investigations presented above, it was also demonstrated during our measurements that simpler measurements that rely essentially on key-phasor information also produce useful monitoring signals.

CONCLUSIONS

The usefulness of the Instantaneous Angular Speed as a drill vibration monitoring parameter was illustrated through a series of systematic tests. Compared to torque measurements on the spindle, the Instantaneous Angular Speed is simple to measure in practice and could represent an important monitoring parameter in an industrial monitoring system.

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