International Journal of Machine Tools & Manufacture 52 (2012) 69–76

Contents lists available at SciVerse ScienceDirect

International Journal of Machine Tools & Manufacture

journal homepage: www.elsevier.com/locate/ijmactool

A new strategy for tool condition monitoring of small diameter twist drills in deep-hole drilling

Robert Heinemann*, Sri Hinduja

School of Mechanical, Aerospace and Civil Engineering, The University of Manchester, Sackville Street, Manchester M13 9PL, UK

ARTICLE INFO

Article history:
Received 21 June 2011
Accepted 6 September 2011
Available online 22 September 2011

Keywords:
Small deep holes
Twist drills
Tool life
Tool condition monitoring

ABSTRACT

Tool condition monitoring (TCM) systems employed in industry are mostly used to detect tool fracture, although the prevention of it should be the principal aim. This would not only allow for the avoidance of any fracture-related damage to both the workpiece and machine tool, but also for recondition the tool for further use.

This paper presents a strategy, which utilises several features extracted from the spindle power and acoustic emission (AE-RMS) signals recorded when drilling small deep holes using twist drills in order to predict an imminent tool failure. A key to achieving this is the subdivision of the drilling cycle into sections and only monitoring those sections in which the most significant change occurs over the tool life. By doing this it is possible to identify the final (i.e. tertiary) tool life stage and replace the worn out tool shortly before fracture occurs, thus improving the overall tool utilisation to. Of 24 drills tested, the TCM system was able to utilise an average of 84% of the tool life; in only one case it failed to detect tool breakage.

1. Introduction

The growing use of automatically operating machine tools has necessitated the development of strategies to avoid a machine tool continuing to run after a tool has broken or been severely damaged during the operation, in order to prevent further damage to the workpiece and machine tool. Two different approaches have been used so far: The first one relies on fixed tool change intervals, based on tool life assumptions usually provided by the tool manufacturers or shop-floor tool life tests. In drilling, the success of this strategy appears to be questionable due to strong fluctuations in tool life [1–3], which can be attributed to workpiece material in-homogeneities, irregularities in the cutting fluid supply, chip motion and tool geometry [4–6]. To avoid tool fractures within the selected tool change interval, rather short tool change intervals are chosen, which has a negative impact on productivity. In the second approach the cutting process is continuously monitored by analysing process signals that provide information about the cutting tool's condition, albeit indirectly.

In the case of drilling, the most commonly-used signals for monitoring are torque and thrust force [7,8] due to the direct linkage between the operation of a drill and the level of forces it generates [9–13], as well as acoustic emission (AE). König et al. [2] observed a steep increase in the AE signal at the end of tool life of small diameter drills, which made them believe that this signal is very suitable for TCM. Heinemann et al. [14] pointed out that both spindle power and AE, unlike the thrust force, showed a significant change with progressing tool life of small diameter drills, in particular the slope of the signal curves.

In deep-hole drilling, Kavaratzis [9] and Heinemann et al. [14] observed fluctuations in the process signals, implying this process's stochastic nature, where aspects such as chip evacuation have a significant effect. This made Ravindra et al. [15] come to the conclusion that monitoring the AE signal for tool wear detection is less practical, because it is polluted with noise, which affects the quality of the signal and makes it difficult to set up proper correlations between the signal and tool wear. Moreover, when drilling deep holes using twist drills, Dong et al. [16] noticed that the magnitude of the AE signal increased strongly with the borehole depth. This might have been caused by the chips inside the flutes, rubbing against tool and workpiece [17].

The research conducted so far implies that monitoring the tool condition when drilling deep holes is not at all straightforward. In this paper a new strategy is introduced, which aims to identify the final stage in the life of small twist drills when drilling deep holes. Although this new strategy uses process signals and features utilised before, the novelty is that the features are only extracted from certain parts of the drilling cycle. It must be emphasised that this strategy does not aim to capture the

---

* Corresponding author. Tel.: +44 161 306 3809; fax: +44 161 306 3755.
E-mail address: robert.heinemann@manchester.ac.uk (R. Heinemann).

0890-6955/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijmachtools.2011.09.002

incident of drill fracture but to avoid the breakage by identifying the onset of the drill's final tool life stage.

2. Experimental setup

The experiments were carried out on a 3-axis machining centre (Takisawa MAC-V3). The power of the machine's main spindle was measured by the two Hall sensors: fixed around the voltage cables. This indirect method of measuring the torque has proved to be sufficiently accurate [14], and is much more appropriate for a subsequent implementation in industry compared to the use of piezo-electric dynamometers. The acoustic emission was detected by an AE-sensor (Kistler, 8152A1), screwed to the machine tool table next to the workpiece vice, connected to an AE-piezotron coupler (Kistler, 5125A2), which automatically calculated the root mean square (RMS) value. Both signals were recorded to a PC using LabVIEW. Fig. 1 depicts a schematic diagram of the setup.

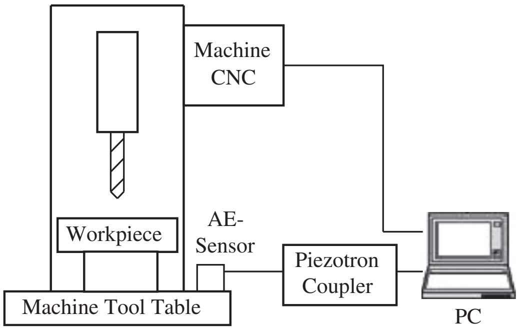

Fig. 1. Schematic diagram of the experimental setup.

Table 1
Twist drill specifications and process parameters.

Drill diameter (mm)	Borehole depth (mm)	Twist drill specifications	Cutting speed (m/min)	Feed rate (mm/rev)
1.5	15	Titex A1249TFL, standard flute length, enlarged chip flutes, split point with notches, thinned web, TiAlN-multilayer coating	26	0.026
2.0	20		30	0.03
3.5	35		30	0.04

The tools employed were TiAlN-coated Co-HSS twist drills with diameters of 1.5, 2.0 and 3.5 mm, which had shown a good deep-hole drilling capability in previous research [3]. Tool specifications and cutting parameters are provided in Table 1.

A bar of plain carbon steel (C45; AISI 1045) was cut and pre-milled into plates with a thickness equivalent to ten times the hole diameter. Each borehole was pre-centred to a depth of twice the diameter using Mikron Pilot Drills. For the 1.5 mm twist drills, the drilling tests were carried out with external minimal quantity lubrication (18 ml/h) using a synthetic ester with 20% alcohol; the tests with 2.0 and 3.5 mm drills were run dry.

3. Behaviour of spindle power and AE-RMS in relation to tool life progression

Initial cutting tests were carried out to acquire spindle power and AE signals and study them to obtain information about the change in each process signal as well as to identify suitable features.

According to Fig. 2(a), progressing tool wear seems to have three effects on the spindle power: Firstly, it shows a moderate increase in magnitude at low borehole depths, which can be attributed to the growing rounding of the cutting edges. Secondly, the fluctuations become more pronounced, which is brought about by severe chip jamming. Thirdly, the slope of the spindle power signal in a drilling cycle changes, so much so that the point at which the spindle power begins to rise occurs progressively earlier, in combination with a significantly higher maximum peak. During the initial period of tool life, a rise in spindle power was mostly observed at borehole depths beyond 11 to 12 mm, caused by chip jamming. But with progressing tool life the protective and adhesion-reducing TiAlN-coating is worn away, promoting material adhesion to the cutting edges, which aggravates their bluntness. This then increases the amount of friction being generated between the tool, chips and workpiece [3], which, in the case of the 1.5 mm drills, promotes the evaporation of the minimal quantity lubricant and, as a result, causes the chip disposal to deteriorate even further.

For all the drills tested, the AE-RMS signal showed a very significant increase in magnitude during the final 20–40% of drill's tool life, see Fig. 2(b). During the first half of the tool life, the AE-RMS signal is very small, indicating a smooth cutting process without serious chip jamming. However, once the drill reaches approximately 65% of its life, both the magnitude and fluctuation

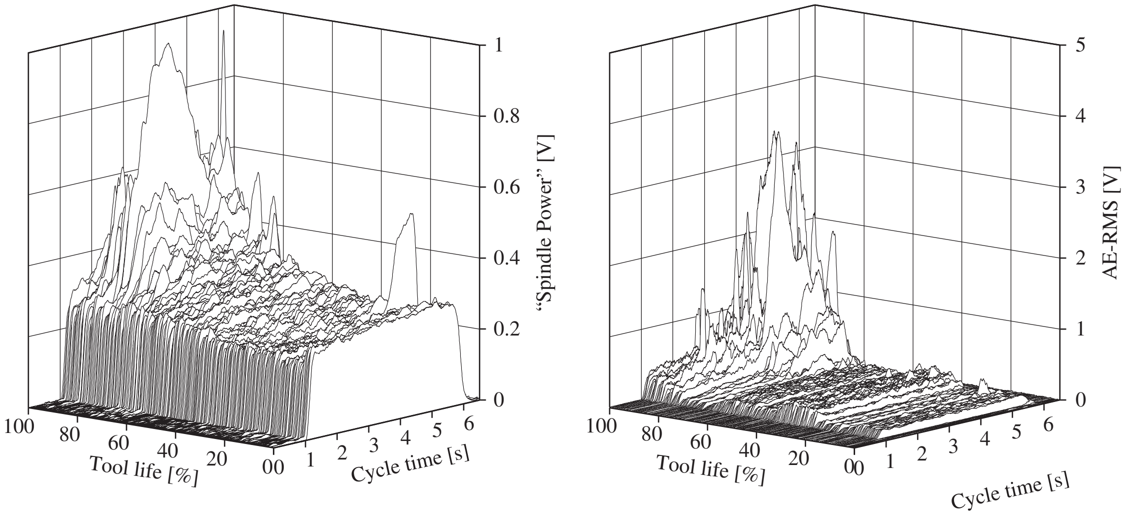

Fig. 2. Spindle power and AE-RMS over the life of a 1.5 mm diameter twist drill.