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Tool wear detection in milling—An original approach with a non-dedicated sensor

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ABSTRACT

The aim of increasing productivity often makes optimising processes a priority and a means of anticipating defects. Metal cutting conditions are monitored to detect tool wear or breaks, so as to protect both machines and workpieces. Such monitoring relies on many different signals though two main approaches can be considered. The first consists in adding numerous sensors to the machine to obtain specific information, such as vibrations and cutting forces. The second consists in using information, often current or shaft power consumption, that can already be obtained from the machine and detected by standard sensors.

This work focuses on the second approach that relies on using the sensors already installed, but optimising their capacities to the maximum for use under industrial conditions. The spindle rotary encoder signal is acquired through two systems: the first uses classical time-sampling while the second uses specific angular-sampling methodology. The differences between the two rotational frequency calculation technologies are described and discussed before focusing on the second methodology. Comparisons of cutting forces and variations in spindle rotational frequency reveal considerable similarities. Thus the occurrence of tool wear can be observed by monitoring variations in rotational frequency, and the genesis of tool tooth breaks can be established. Finally, we establish criteria for critical wear detection in both time and frequency domains.

1. Introduction

Optimising processes are often a priority for increasing productivity and anticipating defects. In metal cutting, the purpose of tool condition monitoring (TCM) is to detect tool wear and breaks, so as to protect both the machine and the workpiece. By detecting the limit wear of a tool, the latter can be changed only if needed, resulting in substantial savings. Instead of directly measuring tool properties many times during cutting operations, requiring interruptions in the process and time-wasting, it is possible to perform indirect, in-process measurement of cutting tool conditions. This can be achieved by using a wide range of different signals, as shown in Fig. 1.

Dimla [2] described the main signals indicating tool wear as being acoustic emission, tool temperature, cutting forces and vibrations. All these signals significantly increase with wear, thus these are the parameters that must be processed. In most cases, TCM systems based on these signals must firstly be compared with a reference signal [3], generally cutting force, to validate their accuracy. Indeed, wear phenomena are well known and they lead to changes in cutting force, with a

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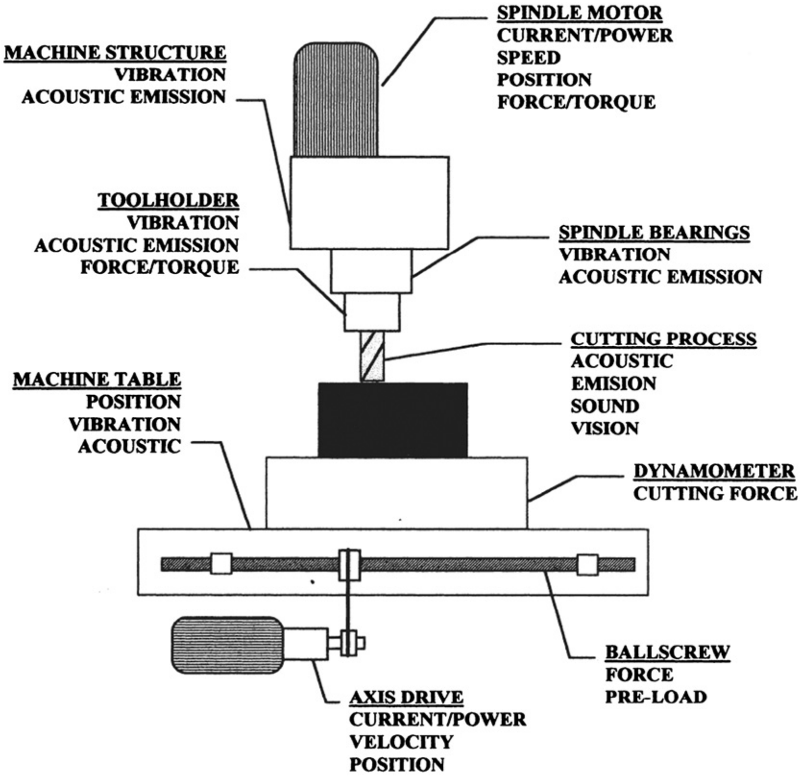

Fig. 1. Multi-sensor cutting tool monitoring options [1].

decrease of the latter due to the wear of one tooth that cuts less material, followed by an increase in cutting force for the next tooth [1]. Altintas developed many indicators based on this observation for detecting tool breakage, such as differences of mean forces between successive teeth [4] and relative variations of mean tooth forces between two consecutive revolutions [5], thereby introducing the concept of monitoring each tool tooth individually. Nevertheless, cutting force analysis based on parameters such as vibration, acoustics and temperature require the addition of equipment to the cutting system, often leading to constraints. Moreover, regarding cutting force, the use of a dynamometer is difficult in industrial production, when considering the size of certain workpieces and the cost of adapting force transducers.

Other methods focusing on the indirect estimation of cutting force have been developed with relative success, such as the measurement of feed motor and spindle current [6–8] and power [9]. Nevertheless, these methods are limited by the available bandwidth of sensors, which have problems in providing a bandwidth between 100 and 200 Hz [10], whereas the usual bandwidth of a dynamometer is about 1 kHz [11]. This leads to real problems in milling due to successive shocks of teeth on the material. For example, a 100 Hz bandwidth limits the rotational frequency of a four teeth tool to 1500 rpm, whereas under real operating conditions, spindle speeds reach from 15 000 to 40 000 rpm [12,13] especially in aeronautical construction.

This paper deals with the use of the rotational frequency of a spindle to observe the cutting process in milling. This technique has been utilised successfully for observing a large number of rotating machine characteristics. For example, Yang [14] used instantaneous angular speed in a case of diesel engine characterisation. Variations in instantaneous angular speed enable the detection of faults relating to gas pressure in the cylinder, i.e. combustion-related faults and fuel leakage in the fuel system. Stander [15] used the fluctuations in instantaneous angular speed for monitoring a gear shaft and detecting deteriorating gear fault conditions while introducing a distinction between cyclic stationary load modulation and non-cyclic stationary load modulation. Rémond and Mahfoudh [16] started from multiple instantaneous angular speed measurements to compute gear transmission errors and finally used specific and single angular sampling for detecting faults in a gear box transmission by using different cyclic means in an angular representation. Instantaneous angular speed seems to be a very efficient indicator for observing faults in rotating machines such as diesel engine and gear transmissions via discrete events during rotation. Milling systems are also discrete angular systems whose tools are equipped with large numbers of teeth that work successively, so instantaneous angular speed—rotational frequency—may be a good indicator of cutting behaviour in milling.

According to Dimla [2], signals used for TCM systems must be easy to measure, consistent regarding sensitivity to wear, and require a minimal number of peripheral instruments for utilisation. Spindle rotational frequency is quite easy to