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An automatic system based on vibratory analysis for cutting tool wear monitoring

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ABSTRACT

The aim of this work is to develop a new, simple to use and reliable automatic method for detection and monitoring wear on the cutting tool. To achieve this purpose, the vibratory signatures produced during a turning process were measured by using a three-axis accelerometer. Then, the mean power analysis was proposed to extract an indicator parameter from the vibratory responses, to be able to describe the state of the cutting tool over its lifespan. Finally, an automatic detector was proposed to evaluate and monitor tool wear in real time. This detector is efficient, simple to operate in an industrial environment and does not require any protracted computing time.

1. Introduction

In the machining process, the quality of the workpiece, for example dimensional accuracy and surface roughness, depends mainly on the state of the cutting tool. Monitoring of the cutting tool condition therefore plays a significant role in achieving consistent quality and controlling the overall cost of manufacturing. High performance machining consequently requires an automatic detection system to evaluate cutting tool wear. A wide variety of sensors, modeling and data analysis techniques have been developed for this purpose. Dan et al. [1], Prickett et al. [2] and Jantunen [3] have presented reviews of the various methods which are widely used in turning, milling and drilling, respectively. However, to provide a fast response to an unexpected tool failure in order to prevent possible damage to the workpiece, the sensing signals from the cutting process provide one of the most promising methods. The majority of these techniques involve the use of cutting force [4–6], motor power [7,8], acoustic emission [9,10] and vibratory signals [11–16].

Monitoring of tool condition has received considerable attention in the research literature. However, there are few reliable industrial applications [17] due to the complexity of the cutting process, which requires a great number of dependent parameters, resulting in the difficulty of creating an industrial process monitoring system. Although several studies have proposed various monitoring systems based on empirical concepts, this research field is still widely opened for new investigations, and, according to the machining process (milling, turning, drilling...), the machining operation (fine, rough...) and the tool/material combination, there are a lot of significant physical data to be taken into account.

Therefore, we propose a new strategy for evaluation of cutting tool wear based on analysis of the vibratory signals acquired in the turning process.

In general, the wear phenomenon on the cutting tool insert appears in several forms (e.g. flank wear, crater wear, chipping...). These forms depend essentially on cutting tool characteristics, workpiece material, cutting

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conditions and types of machining process. Under normal machining conditions, flank wear is observed as the most preponderant. Measurement of the width of flank wear (VB) is the most important parameter used to evaluate cutting tool lifespan [18]. The development of this wear form on the cutting tool is not a random phenomenon, and three phases can be observed during its lifetime, i.e. tool breaking-in, wear stabilization and wear acceleration [19].

It is well known in the turning process that the allowed limit of tool flank wear (i.e., VB) is approximately 0.15 mm for fine machining. For rough machining, the limit is 0.3 mm if the flank wear fringe is uniform; in contrast, the acceptable limit is fixed at 0.6 mm [11].

Our contribution in this field is to design an efficient automatic detector which is able to locate transitions between the three conventional phases of cutting tool life, breaking-in/stabilization and stabilization/acceleration of flank wear. Detection of the second transition (stabilization /acceleration) is fundamental for machining since it leads to optimal utilization of tool life, which is highly desirable.

The classical signal analysis methods are complex, difficult to implement, it requires qualified personnel and are not useable in industrial applications. Our approach is therefore to propose an industrial monitoring system based on simple and automatic methods which do not need qualified personnel or expensive investment in equipment. A general evaluation of tool wear in the turning process was first undertaken with thirty cutting tool inserts under the same cutting conditions, followed by a second series with fifteen cutting tool inserts under various cutting conditions. This evaluation was the first step in which we extracted the wear feature from vibratory responses based on mean power analysis. This last parameter was defined as an efficient wear indicator and it was validated for automatic detection.

2. Experimental set-up and instrumentation

2.1. Machining procedure

Machining experiments were conducted in the setting of a turning process and the cutting tests were performed using a computer numerically controlled lathe (CNC) as shown in Fig. 1. The workpiece material was gray cast iron (FGL 250) and the cutting tool insert was produced by Sandvik Coromant Company (reference CNMG 1204 08 5B OR2500). First, thirty cutting tool inserts selected from the same production batch were used for a statistical study with identical experimental conditions. Then, fifteen cutting tool inserts were studied under different cutting conditions to generalize this work.

Cutting operations were performed without applying cutting fluid. For the statistical study, all cutting experiments took place under the following cutting conditions: cutting speed $V_c = 340$ m/min, feed $V_f = 0.18$ mm/rev and depth of cut $a_p = 1.5$ mm. For the validation study, machining parameters were selected to be close to industrial practice.

2.2. Vibratory measurements

The monitoring strategy adopted involved using a three-axis piezo-electric accelerometer type Brüel & Kjaer 4507. This accelerometer was fixed on the tool holder to carry out measurements in three directions (x, y and z, Fig. 1). This generated a large number of features to acquire maximum information about tool state. Signals, issued from the sensor, were acquired for a 70 s observation time and sampled at 16.384 kHz. Each signal contained 1,146,600 samples. The data collected was stored directly on the PC hard drive using Pulse Lab Shop® software developed by Brüel & Kjaer. Signal processing was performed with Matlab® software using our proposed interactive interface.

2.3. Flank wear width measurements

For the statistical study, the state of the cutting tool was monitored, from the first use up to end of its lifespan, after each cutting experiment using a modern CCD camera linked to a binocular optical microscope for the picture acquisition in an integrated desktop PC with a commercial digital image processing software (AnalySIS®). High resolution picture (768 pixels × 576 pixels) of the flank face at 4X zoom was taken and imported into AnalySIS software, therein to further measure VB. Wear measurements were

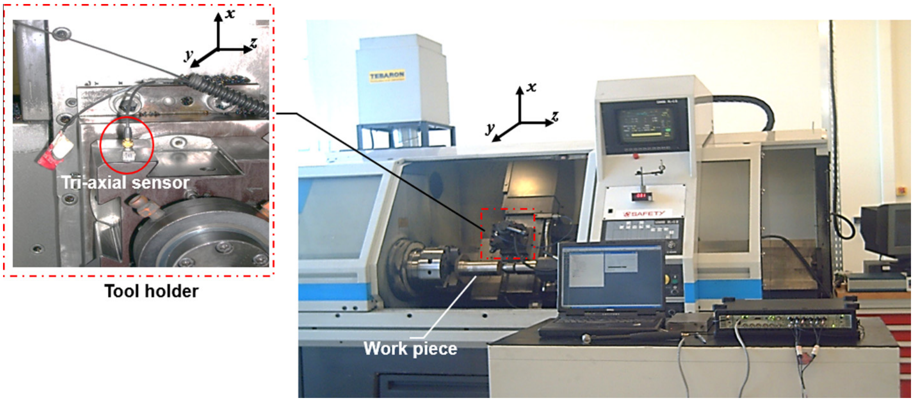

Fig. 1. CNC lathe with data acquisition system and a tri-axial accelerometer located on the tool holder.