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Type-2 fuzzy tool condition monitoring system based on acoustic emission in micromilling

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A B S T R A C T

In this paper, a micromilling type-2 fuzzy tool condition monitoring system based on multiple AE acoustic emission signal features is proposed. The type-2 fuzzy logic system is used as not only a powerful tool to model acoustic emission signal, but also a great estimator for the ambiguities and uncertainties associated with the signal itself. Using the results of root-mean-square error estimation and the variations in the results of type-2 fuzzy modeling of all signal features, the most reliable ones are selected and integrated into cutting tool life estimation models. The obtained results show that the type-2 fuzzy tool life estimation is in accordance with the cutting tool wear state during the micromilling process. The information about uncertainty prediction of tool life is of great importance for tool condition investigation and crucial when making decisions about maintaining the machining quality.

1. Introduction

Currently, both experimental and commercially available tool condition monitoring (TCM) systems are based on the measurements of physical phenomena that are correlated with tool wear and can be exploited as tool wear symptoms. Cutting force and acoustic emissions (AE) are most often used for TCM in the micromilling process. Compared to conventional machining, the noise component in the signal for monitoring micro-machining is usually very high and difficult to separate [47]. AE are particularly well-suited because they are not only a capable detector of microscale deformation mechanisms but also have a relatively uncontaminated signal within the noisy machining environment [47].

AE are a class of phenomena whereby transient elastic waves are generated by the rapid release of energy for a localized source or sources within a material, or transient elastic wave(s) so generated (ANSI/ASTM E 610-89). Emissions from process changes, like tool wear, chip formation, can be directly related to the mechanics of the process. As illustrated in Fig. 1 [34], along with the scale of precision machining that becomes finer and closer to the dimensional scale of material properties, microscopic sources become very significant and must be introduced as important AE sources in precision manufacturing.

Despite the small material removal rate in micromilling, the AE signal is strong, easy to record, and shows a very short reaction time to the tool – workpiece contact, which makes it a very good means of detecting this contact and monitoring the

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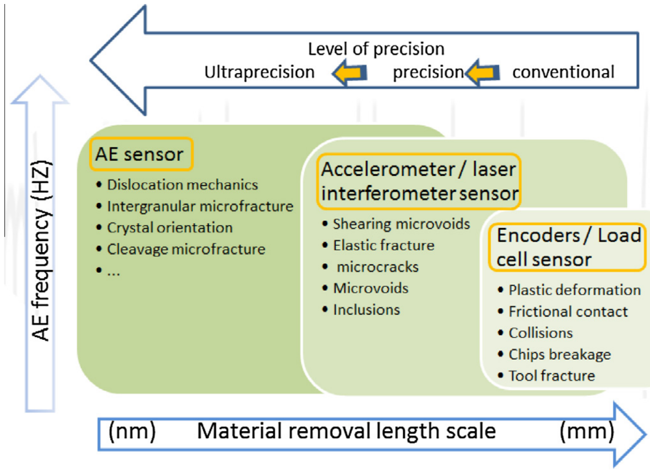

Fig. 1. Application of sensors and sources of acoustic emission.

integrity of the cutting process [50]. However, very limited work has been conducted on the micro-scale TCM system [5,12,13,21,35,38,39,48,49].

The possibility of obtaining a reliable tool wear evaluation using conventional statistical methods based on one signal feature (SF) has been questioned; this is because the measured feature depends not only on tool wear but also on a variety of other process parameters and random disturbances. Attempts at rectifying these shortcomings have focused on pursuing a multi-sensor fusion strategy. Because of the dependence of the magnitude and frequency characteristics of the AE signal on the nature of the transmission path of the signal and the sensor itself [31], the impossibility to detect damage of millimeter-sized end mill directly, and the difficulty in understanding the exact physics in micromilling processes, means the establishment of intelligent models for modeling and propagating uncertainties of multiple AE SFs to characterize the tool condition have been key elements in making small parts accurately.

Recently, type-2 fuzzy sets and systems has become a very strategic and active research area around the world. When comparing it with traditional mathematical modeling methods and the traditional fuzzy approach (type-1FLS) type-2 FLSs not only can obtain a modeling result directly from vague input–output information, but also can capture the uncertainties in the estimation results. This information is very helpful to a decision maker as he can better handle the decision.

While type-1 fuzzy logic proved its effectiveness in several applications whether in fault diagnosis applications and condition monitoring [45,46,51] as well as fuzzy control [11,43]. However, the new type-2 FLSs are very useful in circumstances in which it is difficult to determine an exact membership function for a fuzzy set. They can be used to handle rule uncertainties and even measurement uncertainties. These uncertainties can be modeled in different ways namely centroid, cardinality, fuzziness, variance and skewness [50], this allows one to use uncertainty as an attribute of information for decision support or prediction purposes. Type-2 FLSs move the world of FLSs into a fundamentally new and important direction. To date, type-2 FL moves in progressive ways where type-1 FL is eventually replaced or supplemented by type-2 FL [16,27,44].

Dereli et al. reviewed industrial applications of type-2 fuzzy sets and systems [8]. Here, recent research on type-2 TSK fuzzy systems are categorized as follows: fuzzy system modeling [2,28,33,36]; decision feedback equalizer for nonlinear time-varying channels [23]; system identification [1]; uncertainty estimation on cutting force [40]; fuzzy controllers [3,4,9,20,24,44]; acoustic emission signal feature analysis [38]; short-term power load forecasting [52]; simulation of the bird age-structured population growth [32]; edge detection [25]; image recognition [10,29,53], *etc.*

Based on the literature review and our previous studies, type-2 fuzzy logic should be very suitable to identify the uncertainty in machining, which has a direct effect on products. And research on this subject is limited. In this paper, a reliable type-2 Takagi–Sugeno–Kang (TSK) fuzzy logic system-based (FLS) TCM system based on acoustic emission in micromilling is proposed. In the TCM system, numerous AE SFs obtained from micromilling are calculated because it cannot be determined in advance which ones will be useful in a particular application. To make the comparison and evaluation of the SFs easier and more transparent, type-2 TSK fuzzy analysis is used to model SFs and to estimate the ambiguities and uncertainties associated with them. Depending on the estimation of variations in modeling results of AE SFs, reliable SFs are selected and integrated into tool life evaluation.

The rest of the paper is organized as follows: type-2 fuzzy logic and type-2 TSK FLS are introduced in Section 2. In Section 3, the proposed type-2 fuzzy TCM is presented. Section 4 is an experimental study to show the effectiveness of type-2 fuzzy logic based TCM in micromilling. A discussion is made in Section 5 and the conclusions are given in Section 6.