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Estimation of tool wear during CNC milling using neural network-based sensor fusion

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Abstract

Cutting tool wear degrades the product quality in manufacturing processes. Monitoring tool wear value online is therefore needed to prevent degradation in machining quality. Unfortunately there is no direct way of measuring the tool wear online. Therefore one has to adopt an indirect method wherein the tool wear is estimated from several sensors measuring related process variables. In this work, a neural network-based sensor fusion model has been developed for tool condition monitoring (TCM). Features extracted from a number of machining zone signals, namely cutting forces, spindle vibration, spindle current, and sound pressure level have been fused to estimate the *average flank wear of the main cutting edge*. Novel strategies such as, signal level segmentation for temporal registration, feature space filtering, outlier removal, and estimation space filtering have been proposed. The proposed approach has been validated by both laboratory and industrial implementations.

Keywords: Data fusion; Back propagation neural network; Tool condition monitoring; Signal segmentation; Feature space filtering; Outliers

1. Introduction

In a Machining Center, due to thermal fracturing, attrition, abrasion, plastic deformation, diffusion, chemical wear, and grain-pullout, the cutting tool gradually wears out, loses its sharpness and becomes blunt (Fig. 1). This affects the machining process and the health of the machine tool as well. Blunt tools lead to unwanted vibration, which spoils the surface finish and causes dimensional inaccuracy. In the worst case, the cutting tool may break while it is engaged with the work-piece. Sudden release of the load and consequential

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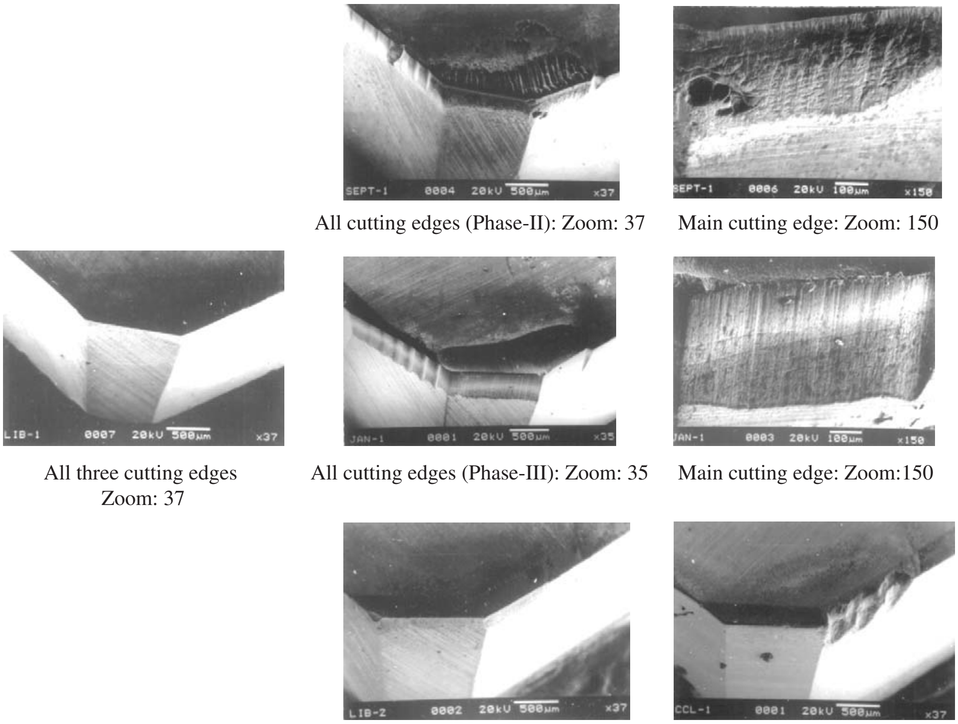

All cutting edges (Phase-II): Zoom: 37

Main cutting edge: Zoom: 150

All three cutting edges
Zoom: 37

All cutting edges (Phase-III): Zoom: 35

Main cutting edge: Zoom:150

Tool-library SEM: Zoom: 37

Cracked tool SEM: Zoom: 37

Fig. 1. Representative scanning electron microscopy (SEM) figures of tool wear.

inertial effects can leave incurable stress effects on the costly work-piece as well as the machining center. Estimation of the tool wear can help decide about possible optimization of the machining parameters (cutting speed, feed, and depth of cut) or replacing the worn out tool with a fresh tool. Estimation of tool wear can be done by several offline methods, like volumetric measurements, and microscopic measurements. Although these offline processes are quite accurate, they are not cost effective for the industries as they consume valuable machining time and hence reduce productivity. Hence manufacturing industries need an online system that continuously monitors the tool wear condition while the machining continues.

In the recent years, a few researchers have worked on the application of laser- and video-based online artificial vision systems for direct online tool condition monitoring (TCM) [20,21,29]. But high cost and inconsistency due to variation in illumination have prevented this method from being implemented in the industry. A more economic proposition is to use an indirect method of monitoring tool wear from measured signals (which are affected by tool condition) like cutting force [4,5,8,10,11,12], machine vibration [8], motor load current [26], acoustic emission (AE) from the machining zone [16,17,25] or various combinations of these signals [8]. In application specific domains, this indirect method of monitoring works reasonably well. But unfortunately, most of the indirect online TCM systems developed so far are tested on the turning process [1,14,15,26,28]. Turning is a fixed-tool machining process that generates continuous signals. Therefore these systems are not guaranteed to work satisfactorily for a semi-intermittent process like grinding or a fully intermittent process like milling. Recent attempts in developing TCM for drilling [13], end milling [9,24], and face milling [11,12] lack the data fusion strategies in the true sense proposed in some innovative works [3,6,23], because a particular signal may not work well for a particular machining process. As for example, use of AE has been reported as not being that helpful for processes like milling or grinding [17,18]. Machining centers usually have automatic tool changers (ATC) and utilise most of the different machining processes to carve out complex products. So a practical online TCM system requires to function well for different machining processes for industrial acceptability. Most of the present-day TCM systems lack this capability and hence a commercial scale TCM is yet to appear in the market.