Sensor Applications for Monitoring High Speed Cutting
Part I: Turning

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Introduction

The turning process is easier to monitor than other manufacturing processes because the sensors can be mounted on the tool without problems. In fact, due to a large variety of sensors, turning is the most monitored process in machining. An outline of the most important sensor methodologies for monitoring turning processes at high cutting speed is presented. The sensor applications, taken into consideration, can be divided into two groups: sensor applied for HSC, and sensors which can be used for HSC monitoring. For each group more important sensor applications are presented.

Sensors for High Speed Cutting in Turning

Based on an ultrasonic sensor, a setup for on-line tool wear measurement is presented in Fig. 1a [1]. A transmitter and receiver single ultrasonic transducer is placed in contact with the tool. The ultrasonic wave returning from the tool nose and flanks can be broken down into two waves (Fig. 1b) [1]. The first is the direct reflection of the tool nose and of surrounding areas of the flanks; the second reflection is an internally reflected wave, which corresponds to the energy that strikes the flanks at the starting point of nose curvature. The change in the amount of reflected energy is linked to the wear level and mechanical integrity of the tool.

A setup for tool rake face temperature measurement using a thermocouple is presented in Fig. 2a [2]. The thermocouple, set in a groove ground in the chip breaker (Fig. 2b), provides the output signal which is then utilised in a FEM analyse to obtain the required temperature [2].

A dual-mode-sensor (Kistler) which combines an acoustic emission (AE) sensor with a three component force sensor is presented in Fig. 3a [3]. The sensor monitors cutting force, feed force, passive force and associated AE. Some records are presented in Fig. 3b [3].

An automatic technique for chip breaking detection, based on dynamic feed force frequency analysis, is presented in Fig. 4 [4]. The results show a correspondence between chip breaking frequency and the feed force spectrum (Fig. 5) [4]. There are two variables in the detecting algorithm: X threshold - a lower limit for the width of the peak which can be considered as a chip breaking peak; Y threshold - derived from the mean force.

Widatronics piezoelectric quartz strain transducer (Fig. 6) can be used for measuring cutting forces [5]. Mounting the transducer in the 45 deg. direction, the gauges provide optimum sensitivity for measuring the feed cutting force; mounting it at 90 deg. the optimum sensitivity to measure the main cutting force is achieved.

The workpiece roughness consists of: kinematic roughness (dependent on radius tool tip and cutting feed) and vibrational roughness (dependent on distance variation between tool and workpiece). The combination of the two effects gives the real roughness. Based on cutting vibration monitoring (Fig. 7a) there is the possibility to predict the surface roughness [6]. Experiments show a good correlation between roughness and cutting vibrations (Fig. 7b) [6].

Sensors which can be used for High Speed Cutting in Turning

During turning, a special device (Fig. 8a) could be used for measuring the tool rear part displacement which is proportional to the cutting force [7]. The flexural deformation is detected with an optic fiber sensor which has two roles: as a light emitter; as a light sensitive tube. The light, emitted by the light emitter, is reflected by a deflecting face mounted on the rear part of the cutting tool and then it is received by the light sensitive tube. In Fig. 8b one of the recordings is presented [7].

The Fringe Field Capacitance (FFC) method, based on the capacitance of the system given by the measured surface and the head electrode (Fig. 9), can be used for in-process roughness control [8]. The maximum error is 18 % when the edge of the measuring head is positioned along the generatrix of the finished shaft. Experiments show that thin (molecular) liquid layers do not affect the measurements while the layers with thickness comparable with the roughness could affect them. A pneumatic head for cleaning the surface represents a solution in this case.

Side Effect in High Speed Cutting in Turning
The clamping force decreases with the increase of the rotational speed of the spindle. To evaluate this side effect of HSC a device (Fig. 10a) with two active gauges and two dummy gauges mounted on its body can be used [9]. The measured signal is broadcast through a wireless transmitter and visualised with a x-y recorder (Fig. 10b). Fig. 10c shows the evolution of the dynamic gripping force against rotational spindle speed [9].

**Future work**

The review presented in this report shows that the electrical or piezoelectric sensors are useful for monitoring HSC in turning; other sensors could be adapted to this relatively narrow field of machining.

Future work will be aimed at designing an integrated sensor for HSC monitoring in turning. This new integrated sensor will have to combine the advantages offered by electrical sensors (force and temperature measurements) with those offered by the AE sensors (tool wear monitoring).

**References**


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Fig. 1 - Setup for tool wear measurement based on ultrasonic method (a) and waveform of the tool echoes (b).
Fig. 2 - Experimental setup (a) and positioning way for thermocouple (b).

Fig. 3 - Dual-Mode-Sensor (a) and output signals (b) where: A - break out; B - tool break.
Fig. 4 - Chip breaking detection diagram.

Fig. 5 - Spectrum for experiments with/without broken chip.

Fig. 6 - Widatronics gauges system.

Fig. 7 - Setup for monitoring $R_s$ parameter using cutting vibration (a) and test results (b).
Fig. 8 - Scheme for evaluating cutting force based on the tool rear part displacement (a) and the output signal (b).

Fig. 9 - FFC method for $R_a$ evaluation: a) setup; b) capacitance model of roughness profile.

Fig. 10 - Side effect evaluation in HSC in turning
(a) - measuring device; (b) - experimental setup; (c) - spindle speed vs. chucking force.