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Opera suspicionată (OS)	**Opera autentică (OA)**
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OS	ZICHIL, V. A Tool worn-out and breakage detection system using the vibration monitoring. *Modelling and Optimization in the Machines Building* Field (MOCM). no.6. 2000. 241-246.
OA	CHEN. J.C. and CHEN, W.L. A tool breakage detection system using an acceleromenter sensor. *Journal of Intelligent Manifacturing*. No.10. 1999. 187-197.

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A tool breakage detection system using an accelerometer sensor

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An on-line and in-process based monitoring system to detect tool breakage via an accelerometer was developed and successfully evaluated in an end milling operation. Prior to testing and evaluation of the tool breakage condition, a simulation model was developed. Transfer of the on-line vibration signal to the frequency domain employed the fast fourier transfer function, and set thresholds were used to determine the tool condition after various experimental tests. In comparison to other in-process methods, such as those that employ dynamometers and acoustic emission sensors, the proposed system is easy to set up and does not require changing of the mechanism. Additional benefits of the system are its high reliability and low cost. Thus, the new monitoring system is potentially useful for untended milling operations in on-line and real-time tool breakage detection in linked-cell manufacturing systems (L-CMS).

Keywords: End milling operations, accelerometer, tool breakage detection

1. Introduction

Through a review of the literature (Tlusty and MacNeil, 1975; Iwata and Moriwaki, 1977; Tlusty and Ismail, 1983; Altintas, 1988; Barkman, 1989; Tansel and McLaughlin, 1993a,b; Tarng *et al.*, 1994) on compliant machining operations and personal communication with leading private industrial research and development laboratories, several issues surface. Some issues of interest for automated tool breakage detection are: limit learning capability, flexibility problems in Computer Numerical Control (CNC) or Numerical Control (NC) controller, including relatively large dynamic errors; instability effects in the controller; the noise problem of the sensor technique; variability effects of different machining processes; and vibration effects of different environments (laboratory and factory). In spite of all these problems, the advantages of automated tool breakage detection systems still outweigh those of a manual approach. With the use of tool breakage detection in machine tools, one is able to increase machine tool life, reach a zero-defect rate, and utilize the unmanned manufacturing environment fully. Without the use of compliance in tool monitoring systems, automation of many machining processes would be simply impossible. Due to these interests and concerns, significant progress has been made in developing algorithms and sensors for tool monitoring systems in machining processes. The progress is summarized as follows.

1.1. *Algorithms for tool monitoring systems*

In the past two decades, numerous research studies have been conducted using force signals for tool breakage detection. Altintas *et al.* (1985) demonstrated that a low-order series tool breakage detection model can be developed using the periodic characteristics of the cutting forces, and synchronizing measurement sampling and tool frequencies in milling. Lan and Naerheim (1986) demonstrated an interesting approach to monitor cutting forces of a milling machine using a very high-order autoregressive, AR(15), time series filter to detect tool failures. These methods rely on tool breakage templates, which are recorded in trial machining of the first workpiece in a batch. Such trial cuts may not be suited to a flexible manufacturing environment where the lot size is small. Additionally, there is great possibility of faulty tool breakage detection due to variation in size of the raw material, which causes the cutting force to exceed prerecorded threshold limits (Altintas and Yellowley, 1989).

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It is assumed that Figs 3 and 4 represent an ideal situation. In real end milling operations, noise in addition to other factors is present, and the assumption of constancy of mass and displacement is not always valid. However, based on the difference between Fig. 4a and b, a tool breakage detection model was developed in this research. The magnitude of these $|F(\omega)|$ values provides some indication of detecting the tool condition using a vibrational signal. To have a full picture of the model, an experimental set-up is necessary; this is represented in the next section.

4. Experimental set-up

The experimental set-up for this research can be divided into two parts: (1) hardware, and (2) software.

4.1. *Hardware set-up*

The hardware set-up requires the following equipment:

(1) A Fadal vertical machining centre (VMC40, Mode 1904) that has 21 tools, operates at a high spindle speed ranging to 10 000 r.p.m.

(2) A 3/4-inch Morse high-speed steel centre hole type cutting tool (EDP 43282).

(3) An ICP accelerometer (Model Number 353B33) used to measure the response of the acceleration.

(4) An ICP battery power unit (Model 480E09), not only to supply power for the accelerometer, but also to amplify the voltage of the signal coming from the accelerometer. In order to initiate a stronger signal, the battery power supply was set to the X100 sensor kit.

(5) A Tektronix power supply (Model CPS250) was used to avoid a shortage due to insufficient battery power during long-term testing; in addition, a 21 V 10 mA power supply was used to maintain a stable current supply.

(6) An APEX 386 PC was used for recording data, analysis and feedback.

(7) An analogue–digital (A/D) board (Omega DAS-1400) was used to convert an analogue signal to digital.

(8) A low-pass filter (1 kHz, 3 dB) was constructed to filter unwanted high-frequency signals and allow only low-frequency information to pass through unattenuated (without a reduction in amplitude).

(9) A torque wrench was used to apply a consistent force in setting up the accelerometer pound per inch.

(10) Aluminum T6160 workpieces.

Figure 5 provides a diagram of the experimental set-up used in this research study. The milling test was performed using a Fadal CNC machining centre. The tool used was a 19.05 mm diameter high speed steel cutting tool. The geometry of the workpiece was composed of 66.04× 19.05 × 38.10 mm aluminum blocks. In order to study the end milling process related to the sensitivity and robustness of the proposed monitoring methodology, a series of milling processes was carried out for cutting at a spindle speed in the range 600–3000 r.p.m., feed rates in the range 127–635 mm min^{-1}, and depths of cut in the range 0.13–0.64 mm. All experiments were conducted under dry cutting conditions. The workpiece material was aluminum and was of average hardness. Each workpiece used in the experiment was mounted on a vise and fixed at the same tightness.

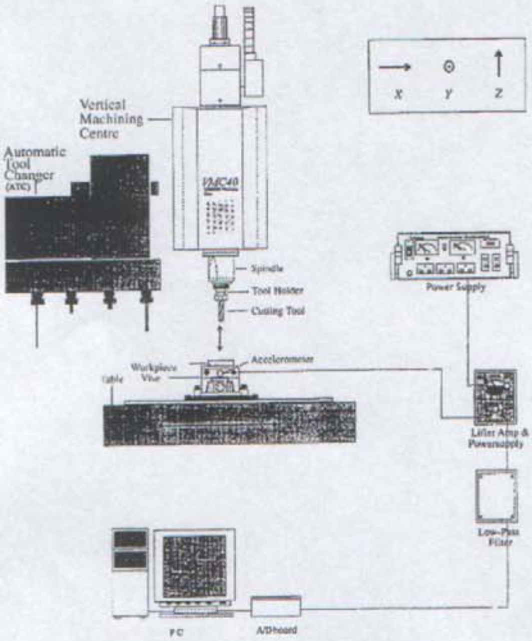

Fig. 5. A diagram of the experiment set-up.

4.2. *Software set-up*

The software set-up requires the following programs:

(1) In this experiment the NC program was written to operate the Fadal vertical machining centre to perform the end milling cutting process. The cutting parameters (spindle speed, feed rate and depth of cut) were reset in the CNC manually for each run according to different cutting conditions.

(2) A data collection program, programmed in C+ +, received the digital vibration data through an IPC accelerometer, IPC power super with amplifier, and low-pass filter, which has an anti-aliasing function allowing only low-frequency information to pass through unattenuated. Figure 6a, b indicates the experimental data for the vibration signal of good and broken cutting tools, respectively. The cutting conditions were: spindle speed,

Table 2. The testing result using different combinations of cutting conditions (the underlined tests indicate a fail trail)

Tool condition[a]	*Spindle speed* (r.p.m. min^{-1})	*Feed rate* (inch min^{-1})	*Depth of cut* (inch)	$(P1/P2)$		*Mean*
B	500	4	0.01	0.44	0.58	0.51
B	600	10	0.01	0.47	0.63	0.55
B	800	10	0.01	0.59	**0.29**	0.44
B	1200	10	0.01	1.00	0.69	0.85
B	1600	10	0.01	0.52	0.68	0.60
B	1800	5	0.01	0.63	0.68	0.66
B	1800	10	0.01	0.90	0.72	0.81
B	1800	15	0.01	1.02	1.42	1.22
B	1800	5	0.02	0.66	0.35	0.51
B	1800	10	0.02	0.7	0.9	0.80
B	1800	15	0.02	1.12	1.25	1.19
B	2000	10	0.01	0.77	0.50	0.64
B	2400	5	0.01	0.28	0.34	0.31
B	2400	10	0.01	0.64	0.64	0.64
B	2400	15	0.01	0.75	0.82	0.79
B	2400	5	0.02	0.37	0.28	0.33
B	2400	10	0.02	0.60	0.46	0.53
B	2400	15	0.02	0.70	0.70	0.70
G	500	4	0.01	0.17	0.23	0.20
G	600	10	0.01	0.27	**0.31**	0.29
G	800	10	0.01	0.21	0.21	0.21
G	1200	10	0.01	0.15	0.22	0.19
G	1600	10	0.01	0.21	0.17	0.19
G	1800	5	0.01	0.35	0.28	0.32
G	1800	10	0.01	0.24	0.27	0.26
G	1800	15	0.01	0.16	0.23	0.20
G	1800	5	0.02	0.30	0.29	0.30
G	1800	10	0.02	0.26	0.20	0.23
G	1800	15	0.02	0.22	0.15	0.19
G	2000	10	0.01	0.08	0.08	0.08
G	2400	5	0.01	0.27	0.26	0.27
G	2400	10	0.01	0.20	0.28	0.24
G	2400	15	0.01	0.10	0.17	0.14
G	2400	5	0.02	0.30	0.30	0.30
G	2400	10	0.02	0.28	**0.33**	0.31
G	2400	15	0.02	0.19	0.23	0.21

[a] B, broken; G, good.

6. Conclusions

An on-line based monitoring system was developed in this research to detect tool breakage in the milling process. The ability of the monitoring feature to detect tool breakage was also verified experimentally. The detection system can measure tool condition on-line and in-process. The method to mount the accelerometer used to detect tool breakage provides a less mechanical vibration collection technique that can record strong vibration signals produced by the cutting process. The experimental results show that the proposed threshold method has a high success rate in monitoring tool breakage under varying cutting conditions. Compared to other in-process methods, such as those that employ dynamometers and acoustic emission sensors, this system is easy to set up and does not require a change in the mechanism. An additional benefit of the system is its high reliability and low cost. Therefore, the new monitoring system can potentially be useful for untended milling operations in linked-cell manufacturing systems (L-CMS).

6.1. *Limitations*

Even though the proposed tool breakage detection system has been experimentally proven to have great usefulness at different cutting parameters, it still has some limitations, which are described as follows:

(1) The constant of the proposed threshold value is suitable only for a particular range of end milling machining parameters (spindle speed, 900–3000 r.p.m.; feed rate, 76.2–635 mm min^{-1}; depth of cut, 0.13–0.64 mm).

(2) The cutting tool is suitable only for a 3/4-inch Morse high-speed steel centre hole type cutting tool (EDP 43282).

(3) The workpiece material set-up is only suitable for aluminum (Al 6160).

(4) The technique cannot measure tool breakage where chatter vibrations are present. The alarm system cannot be used to measure tool breakage due to chatter vibrations originating from unsuitable machining processes; when this happens, the cutting tool removes different size chips for each cut. When the chatter vibration is large enough, the tool will jump out and not cut sequentially. The chatter vibration will be similar to the vibration of a broken cutting tool and, in this case, the alarm system will cause an unexpected error of interpretation of the tool's actual condition during the measurement process.

6.2. *Recommendations for future research*

The following recommendations were made based on an analysis of the results of this research experiment:

(1) Further research should employ a model analysis to detect the rigidity of the machine. The cutting condition can be effectively controlled to avoid chatter vibration by using appropriate cutting parameters.

(2) In this research, an accelerometer was used for collecting vibration data from the y-direction for analysis. In order to increase the success rate, an additional sensor might be added to detect vibration signals coming from the x-direction. Vibration data from both directions can then be compared or combined to approach a zero false alarm.

(3) Additional work is needed to investigate the accuracy of the proposed threshold value when using different shapes, forms and diameters of cutting tools to cut different material and geometric workpieces.

(4) An attempt should be made to use fuzzy nets or neural networks to build a widely useful tool breakage detection system that can adjust and choose an adaptive threshold value for different combinations of cutting tools and workpieces.

Because feedback control is necessary for an automated production system, the tool breakage detection system should be connected to a CNC machine. When the tool condition detection system detects tool breakage, the CNC machine can stop the machining process immediately, decreasing the possibility of damage to the machine tool and workpiece.

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