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RESEARCH ON TOOL STATE BASED ON SOUND SIGNALS AND COLORS OF CHIPS

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Abstract: In most of cutting processes, a large amount of cutting fluid is utilized for reducing the cutting temperature, providing lubrication and removing chips. However, it produces waste gas and fluid which lead to environmental pollution. Thus, green manufacturing will become the mainstream of future processing gradually due to the promotion of environmental protection in the industry. The experimental method used in this study is dry cutting. To overcome the demand for smart factories and smart manufacturing, sensors are necessities to obtain information from the work. In this experiment, acoustic signals under different cutting conditions are collected through the microphone to research the relationships between colors of chips, time of spark outpouring, and tool breakage. Experimental results show that the standard deviations of the colors of chips are about 20 and 6 for the occurrence of spark and tool breakage, respectively. The proposed scheme in this paper is useful for the tool life prediction.
Keywords: Chip, Tool life, Tool wear

1. INTRODUCTION

In cutting processes, excessive wear of cutting tools causes the increment of defective products and abnormal phenomena. For example, surface roughness or shape error of the workpiece increases, changes in the shape and colors of chips, worse still irregular noise and vibration, sparks occurrences at the cutting point that happen throughout manufacturing processes will result in the deterioration of manufacturing quality. If the cutting tool is not replaced in time, workpieces will be scrapped and may even lead to machine breakdown. Therefore, monitoring the wear condition of cutting tools is vital during the machining processes.

To monitor the performance of cutting tools, the physical state differences of the workpieces and tools before and after the cutting processes can be compared, such as changes in temperature, sound, colors of chips, acceleration, and surface roughness. Chips and heat energy are the products of the relative motion and high friction of the tool and workpiece during cutting processes. The changes of the colors of the chips help for detecting the processing conditions and inferring the quality of the surface of workpieces. Colors of the chips represent the processing temperature [1]. According to the literature in machining, an infrared thermography mounted on the slide of a CNC lathe is adopted to measure the temperature distribution of chips. The experimental results demonstrated that the temperature gradually increases with the wear of cutting tools. Additionally, the tool wear shows a non-linear increment owing to the increment of cutting length or cutting time during the machining processes. The cutting time, cutting speed, feed rate, contact length between tool and chip, and cutting force affect the temperature of chips besides the tool wear [2-3]. Single physical signal feature is not reliable under certain cutting conditions, so through the combination of multiple sensors can improve the resolution, reliability, and stability of the measurement effectively and estimate the condition of actual tool wear accurately [4]. Nowadays, some researchers study tool condition monitoring approaches [5-7]. In this paper, the continuous cutting with high speed is used to carry on the experiment. The sound signals of the relative movement of the cutting tool and the workpiece is intercepted by a microphone during the cutting processes. In the meanwhile, the cutting length for the occurrence of sparks and tool breakage is recorded objectively. The color of chips vary with the increment of the cutting temperature, one can find out the corresponding relationship between the color of chips and the state of the cutting tools.

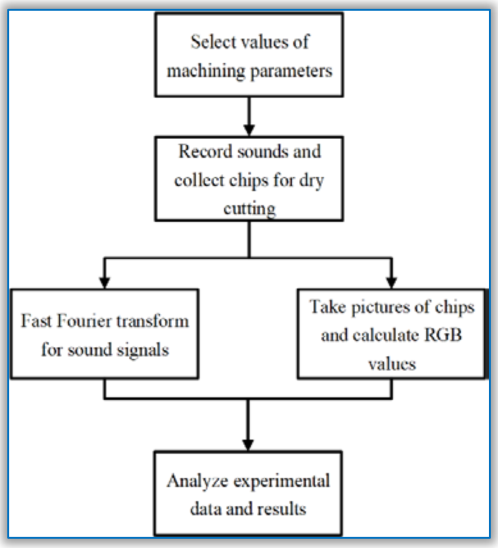

Figure 1 – Flow chart of experiments

2. EXPERIMENTAL METHOD

To begin with we set experimental parameters, and recorded sound signals via an acoustic emission sensor and collected chips to inspect the changes of colors for the dry cutting environment by a three-axis CNC machining center. Then, the fast Fourier transform (FFT) is adopted for processing the sound signals, and the three primary colors (RGB) are calculated for the chips. The experimental flow chart of this research is shown in Figure 1.

— Experimental Parameters

DMU60T high speed milling machining center is used for dry cutting in this experiment. We inspect and record the spark generation and distribution during the machining processes. At the same time, employ a piezotronics microphone to collect and store cutting sound signals via the program of the signal acquisition card. After the experiment, a high precision tool microscope is used to take a picture of chips for measuring the tool wear. Each group of workpiece S45C medium carbon steel, is machined by a tungsten carbide cutting tool which has a diameter of 8 mm with two flutes. By changing the machining parameters, the relationships between the sound signals, colors of the chips, and the tool state are discussed. The parameter configuration of each group experiment is shown in Table 1. The feed rate, spindle frequency, cutting frequency, and volume removal rate of each flute can be calculated according to the experimental parameters in from Table 1 and the results are shown in Table 2.

Table 1 – Parameter configuration table

Parameter	Unit	Exp. A	Exp. B	Exp. C
Diameter	mm	8	8	8
Number of flutes	flute	2	2	2
Rotating speed	rpm	12000	15000	18000
Width of cut	mm	0.2	0.2	0.2
Depth of cut	mm	5.0	4.0	3.0
Feed rate of flute	mm/t	0.015	0.02	0.025

Table 2 – Parameters of F, NF, CF, and Q

Parameter	Unit	Exp. A	Exp. B	Exp. C
Feed rate (F)	mm/min	360	600	900
Spindle frequency (NF)	Hz	200	250	300
Cutting frequency per cutting edge(CF)	Hz	400	500	600
Volume removal rate of each flute (Q)	mm^3/flute	0.015	0.016	0.015

— Data Processing

Firstly, the cutting length for spark is judged according to the first spark generation which is recorded by the operator during the continuous machining processes, and the cutting length of the tool breakage is judged according to ISO specification measurement of tool wear. Furthermore, an acoustic emission sensor is used to capture the sound signals generated during the cutting experiments, and the amplitude corresponding to the spindle frequency and the cutting frequency is obtained through FFT. Secondly, we use MATLAB software to calculate the color distribution of RGB image of the chips, record the most occurrence brightness value shown in the composition of the images. Finally, analyze the processed sound signals and colors of the chips to find out the threshold, thereby establish tool monitoring system that carry out tool condition prediction and tool life estimation.

3. RESULTS AND ANALYSIS

— Sound Signals

Sound is the change in pressure in a medium due to the vibration. The main sources of vibration signals during the machining processes are the running of the machine, the relative motion of the cutting tool and workpiece, the rotation of the spindle, and other external environmental disturbances. When the experimental equipment and cutting conditions are not changed, the short-term external environmental interference is negligible. In the cutting processes, the cutting state can be judged by observing the change of the amplitude of spindle frequency and cutting frequency. In terms of the spindle frequency, there is a little fluctuation in the amplitude under normal conditions, but a rapid change under the abnormal situation. In terms of the cutting frequency, the amplitude changes with the increment of cutting length, which is also an observation index in this paper.

After the experiments are completed, the sound is subjected to FFT processing, and the amplitudes correspond to the spindle frequency and the cutting frequency are extracted and integrated into a trend graph of the audio signal, as shown in Figures 2-4. The observed results show that the amplitude of the spindle frequency has a relatively stable trend and is known from Table 3.

Table 3 – Analysis of frequency response

		Exp. A	Exp. B	Exp. C
Difference	NF	0.658	0.155	0.931
	CF	6.355	7.194	1.693
Standard deviation	NF	0.182	0.046	0.272
	CF	2.138	2.010	0.462
Variance	NF	0.031	0.002	0.069
	CF	4.220	3.728	0.199

Moreover, the amount of tool wear increases as the cutting length increases, the amplitude trend of the cutting frequency shows a significant increase, which can be seen from Table 4. Finally, by comparing the frequency response from experiments A to C, it shows that the cutting length for the sparks generation are all 4.0 m. The cutting length for the tool breakage are 8.0 m, 8.0 m, and 11.0 m, respectively. The change in amplitude of the cutting frequency can be analyzed as the threshold by using Equation (1). The result of the calculation shows that the response of the tool breaks is approximately 1.5 times the response of spark.

$$\text{Threshold} = \frac{\text{The amplitude of each cutting length}}{\text{The amplitude of spark}} \quad (1)$$

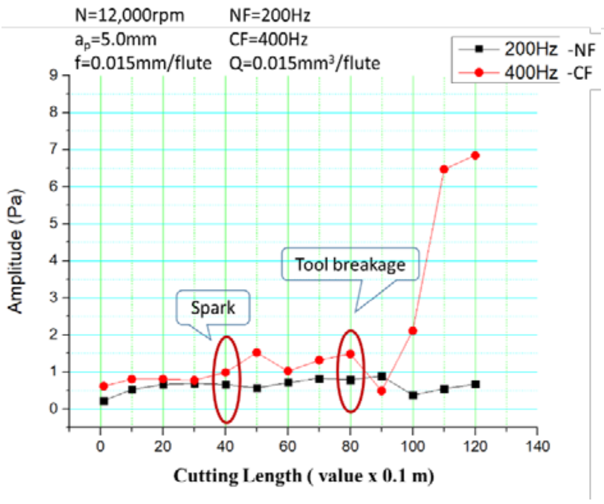

Figure 2 – Variation in sound signals for exp. A

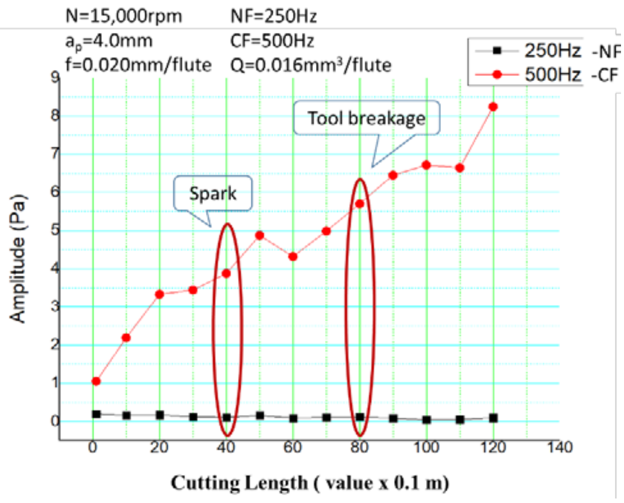

Figure 3 – Variation in sound signals for exp. B

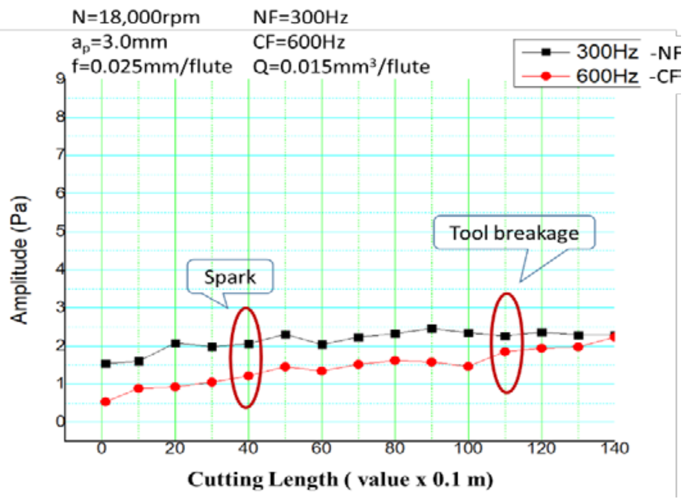

Figure 4 – Variation in sound signals for exp. C

Table 4 – Amplitude of CF and threshold for different cutting length

Length(m)	Exp. A		Exp. B		Exp. C	
	CF (Pa)	Threshold	CF (Pa)	Threshold	CF (Pa)	Threshold
0.1	0.617	0.624	1.051	0.271	0.542	0.446
1.0	0.802	0.812	2.186	0.564	0.889	0.731
2.0	0.805	0.814	3.333	0.860	0.927	0.762
3.0	0.770	0.779	3.447	0.889	1.051	0.864
4.0	0.988	1.000	3.877	1.000	1.216	1.000
5.0	1.523	1.541	4.870	1.256	1.451	1.193
6.0	1.025	1.037	4.320	1.114	1.342	1.103
7.0	1.319	1.335	4.985	1.286	1.514	1.245
8.0	1.489	1.506	5.696	1.469	1.616	1.329
9.0	0.488	0.494	6.452	1.664	1.577	1.297
10.0	2.112	2.137	6.720	1.733	1.461	1.202
11.0	6.465	6.542	6.647	1.715	1.855	1.525
12.0	6.844	6.925	8.245	2.127	1.947	1.601
13.0					1.979	1.627
14.0					2.235	1.838

— Colors of Chips

Cutting chips are by-products of the relative motion and high friction between the tool and workpiece during machining processes. The cutting tool wears or even breaks under high friction. Although in the cutting processes with the same cutting parameters and tool wear, the cutting temperature distribution is not consistent and the colors of collected chips have variety. However, as the wear increases, the frictional coefficient also changes to affect the overall change of the cutting temperature and form different colors of chips. Thus, this change can reflect the state of tool wear and cutting temperature indirectly. The experiments show that the variations of image colors are as shown in Figure 5. When the spark occurs during machining, the color of chips is closer to the color blue. When the tool breakage occurs and loses cutting ability, the color is relatively close to purple.

Figures 6-8 shows the distribution of RGB for different cutting length. The trend of green and red lines is closer, and the variation in green is smaller than red. Therefore, only the relationship between the blue and red is considered. These figures also appear the cutting length for the occurrence of sparks and tool breakage, the phenomenon of divergence can be found for red and blue lines. Table 5 shows the average luminance of RGB and the standard deviation of the chips in a unit cutting length. The analysis results reveal the standard deviations of the colors of chips are about 20 and 6 for the occurrence of spark and tool breakage, respectively.

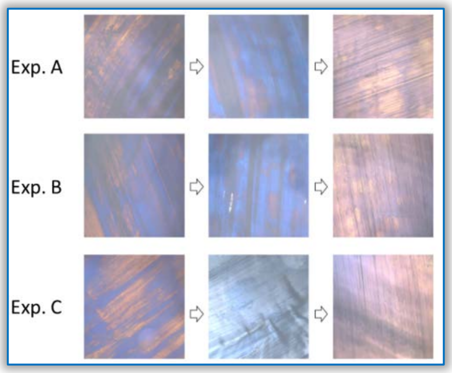

Figure 5 – Variation in colors of chips

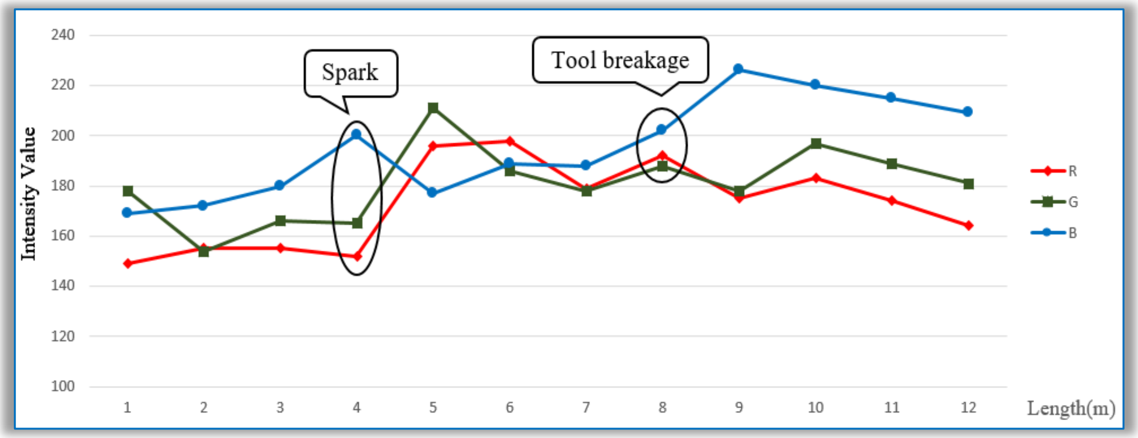

Figure 6 – Color distribution, occurrence of spark, and tool breakage for exp. A

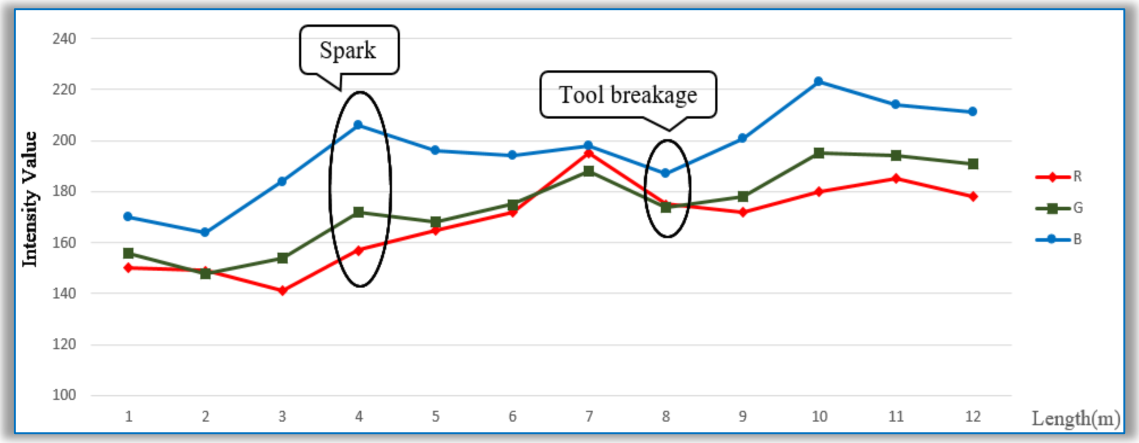

Figure 7 – Color distribution, occurrence of spark, and tool breakage for exp. B

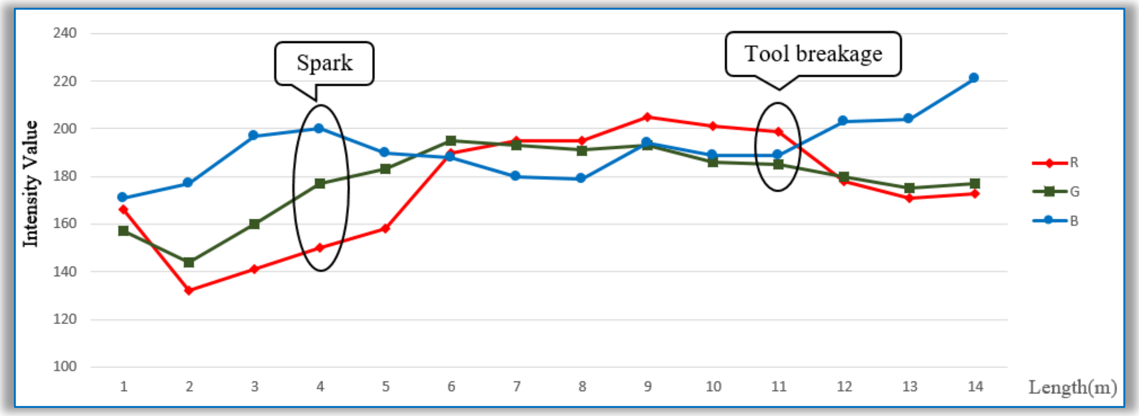

Figure 8 – Color distribution, occurrence of spark, and tool breakage for exp. C

Table 5 – RGB distribution and standard deviation of a unit cutting length

Length(m)	Exp. A				Exp. B				Exp. C			
	R	G	B	Standard deviation	R	G	B	Standard deviation	R	G	B	Standard deviation
1	149	178	169	12.120	150	156	170	8.380	166	157	171	5.793
2	155	154	172	8.260	149	148	164	7.318	132	144	177	19.026
3	155	166	180	10.231	141	154	184	18.006	141	160	197	23.252
4	152	165	200	20.270	157	172	206	20.499	150	177	200	20.434
5	196	211	177	13.912	165	168	196	13.960	158	183	190	13.736
6	198	186	189	5.099	172	175	194	9.741	190	195	188	2.944
7	179	178	188	4.497	195	188	198	4.190	195	193	180	6.650
8	192	188	202	5.888	175	174	187	5.907	195	171	179	9.978
9	175	178	226	23.367	172	178	201	12.499	205	193	194	5.437
10	183	197	220	15.253	180	195	223	17.820	201	186	189	6.481
11	174	189	215	16.938	185	194	214	12.120	199	185	189	5.888
12	164	181	209	18.553	178	191	211	13.573	178	180	203	11.343
13									171	175	204	14.704
14									179	177	221	21.746

4. CONCLUSIONS

This study mainly discusses on the use of sound signals and colors of the chips to determine the tool state in machining processes. The experimental results infer that the amplitude of the tool breakage is approximately 1.5 times of the amplitude of spark in terms of the sounds. In addition, the spark is generated and the cutting tools have a breakdown when the standard deviations of the RGB color value of chips are about 20 and 6, respectively. The changes of the sounds and colors of chips can be used as the characteristics for analyzing the states of cutting tools. The research can be the basis of the tool life prediction and tool monitoring system.

Note

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