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Recognition of Chip Forms During the Metal Cutting Process

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The continuous chips cause problems in the automation for cutting process due to the difficulty of chip disposal. In order to solve these problems, the proper chip forms are required as a precondition for control of the chip forms. In this study, the relationships between the peak frequency and chip breaking frequency are investigated with the tool/workpiece thermocouple, the accelerometer and tool-dynamometer. Based upon the experiments, the following results are obtained. (1) The dynamic components of electromotive force exactly reflect the characteristics of the chip breaking, and the chip breaking frequencies exist below 200 Hz. (2) If chip breaking is not regular, the power of peak frequency gets lower in magnitude and wider in width. (3) The brittle material is hard to observe the frequency of the chip breaking.

Key Words: Recognition, Chip Forms, Cutting Process, Tool/Workpiece Thermocouple, Accelerometer, Tool-Dynamometer, Dynamic Components

1. Introduction

Chip disposal is one of the most serious problems in modern machine operation. Machine tools can not be automated without controlling the chip form. The size and form of chips are also important to design the cutting tools. The recent tendency to control the chip can be broadly classified into two main categories.

The first is to use chipbreakers with various shapes of obstacles on the tool surface for the desired chip form. Many types of chipbreakers have been developed, which is applicable to wide range of feedrate and depth of cut. The trend of chipbreaker is to change the geometric shape of chipbreaker from 2-dimension to 3-dimension. But the new technique of chip disposal is required to overcome the limitations of chip breaking range for the purpose of the flexible automation in cutting process. The second is to use active control technique. This is based upon feedback control theory with the sensed information during the cutting process. This method needs the accurate monitoring of the cutting process, which is one of the most important factors to control the chip forms actively.

In this paper, the experiments are carried out to find the relationships between the frequency characteristics and the chip forms by using accelerometer, tool-dynamometer, and tool/workpiece thermocouple method. The experimental results of tool/workpiece thermocouple method are compared with those of accelerometer and tool-dynamometer, and are presented according to the feedrate and cutting speed.

2. The Recognition of Chip Forms

The researches have been studied to recognize the chip forms by using the various instruments.

Chung et al.(1989) investigated the relationship between chip breaking and the dynamic component of cutting force using tool-dynamometer. They showed that the chip forms could be recognized by detecting the fluctuating forces when the chips collided with the tool. The peak frequency occurs in accordance with the period of chip breaking when the constant length of broken

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chips are formed. But the output signals from these instruments include the frequencies of both chip breaking and tool vibration.

Tool/workpiece themocouple method using Seebeck effect was introduced by Hirota et al. (1979). It means that the thermo-EMF (electromotive force) generates when the different two metals have a junction with temperature difference. This method can be considered as a thermocouple of parallel junction which has a lot of hot junctions at the cutting point. Therefore the mean temperature at the cutting point can be measured. The thermo-EMF can be expressed as follows,

$$E=\int \alpha\, dT_a+\int \beta\, dT_b, \tag{1}$$

where

E : Output voltage of thermocouple,

α, β : Seebeck coefficient,

T_a, T_b : The temperature at point "a" and "b."

In Eq. (1), the first term is the thermo-EMF generated at point "a" and the second is the thermo-EMF generated at point "b" as shown in Fig. 1. The second term varies when the chips are broken regularly. Therefore this influences the peak frequency of the thermo-EMF.

Also the chip forms can be recognized by using the photodiode (König et al., 1979) and infrared sensor (Arai et al., 1985). The direction of chip flow can be detected by photodiode which senses the emitted energy from the chip. And the infrared sensor can recognize the chip flow out by sensing the magnitude of the radiation energy from the chips.

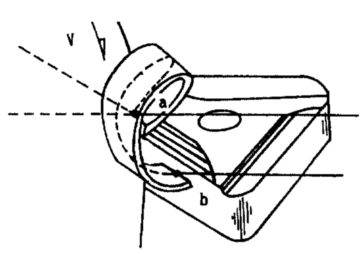


Fig. 1 A circuit of tool/workpiece thermocouple for regular chip breaking

3. Experimental Method

The schematic diagram of experimental set up is shown in Fig. 2 in case of tool/workpiece thermocouple method. Besides this, tool-dynamometer and accelerometer are used in experiments. As the thermo-EMF signal from the junction of tool and workpiece during cutting process has very low voltage and current, it is very difficult to protect the output signal from being contaminated by noises. So, many noise sources must be excluded from power supply, electrical amplifier, signal cables, noise from lathe, surrounding effects, and etc. In order to remove one of the critical noise problems, the slip ring of mercury type is designed. This minimizes the friction effects from contacting point which happens in general slip rings. The insulation materials are inserted between chuck and workpiece. And the flexible spring is used in order to guide the rotating signal cable.

The steady-state output signals, obtained from the experimental instruments, are used for signal analysis. Because the signals of initial stage repre-

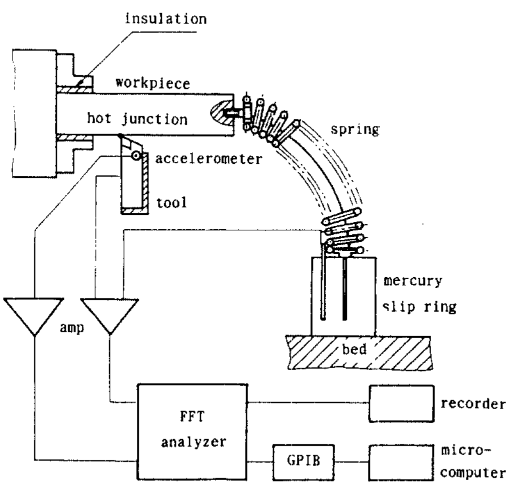


Fig. 2 Block diagram of appartus for tool/workpiece thermocouple method

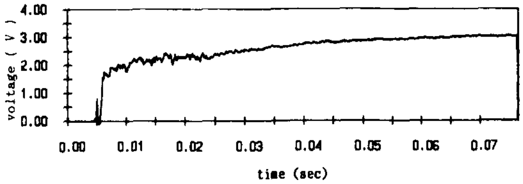


Fig. 3 Transient condition of thermo-EMF

Table 1 Specification of tool

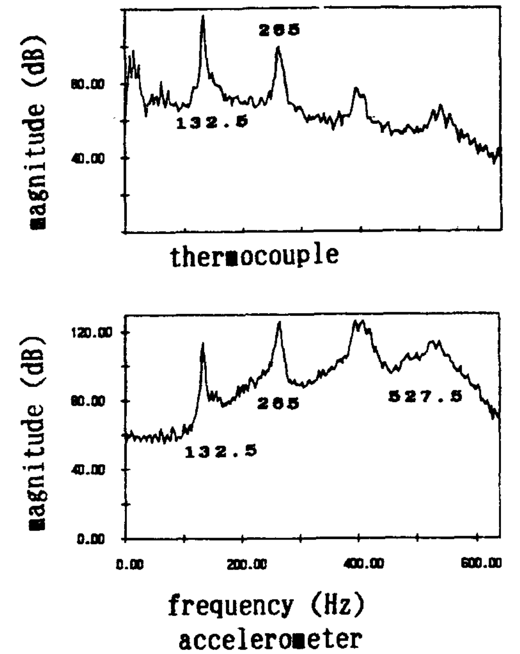
Item	Specification
Insert tip	The width of chipbreaker : 2.0 mm The angle of chipbreaker : 14 deg Thickness : 4.76 mm Nose radius : 0.8 mm
Tool holder	The angle of setting : 15 deg The overhang length : 53 mm The direction of setting for accelerometer : main cutting force

sent the transient condition as shown in Fig. 3, the signals are taken after a few milliseconds to get reliable data. The signal analysis is executed by signal processing softwares with averaging number of 16. The workpiece materials used in experiments are steel (C 0.45%, Mn 0.74%, balance Fe) and brass (Cu 57%, Pb 1.5%, balance Zinc). And the tools used in machining are shown in Table 1.

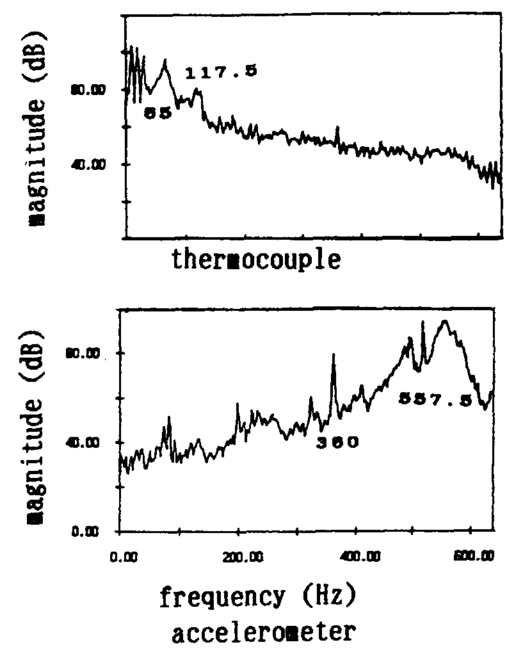
4. Results and Discussion

4.1 The recognition of chip forms by the dynamic component of thermo-EMF

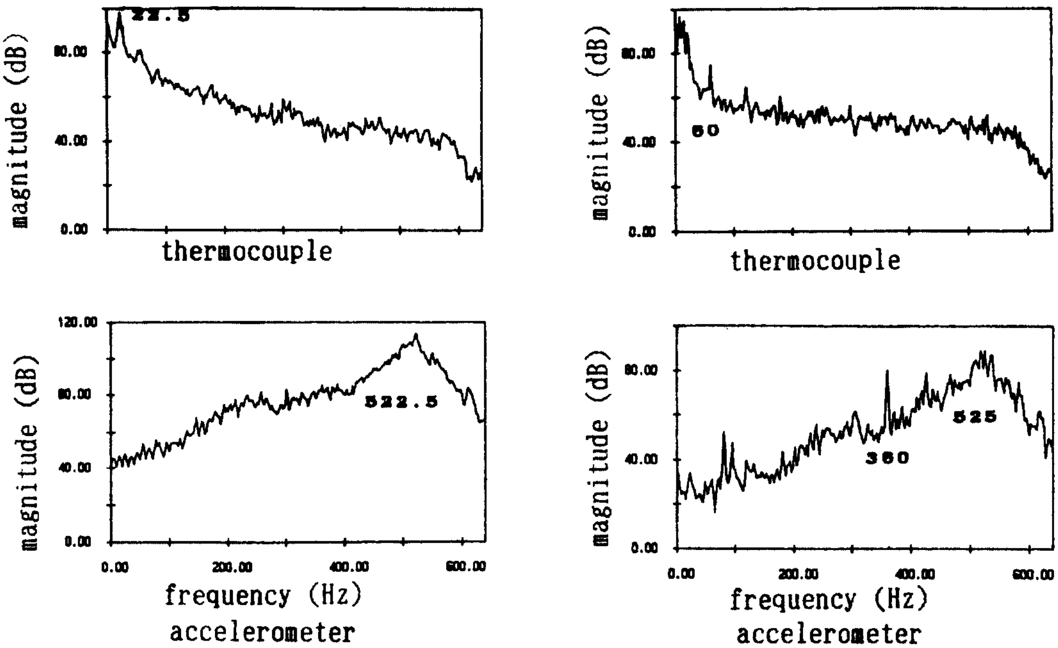
The relationships between the power spectrum (thermo-EMF, acceleration) and chip forms are shown in Fig. 4. The peak frequencies can be shown in Fig. 4(a), (b), (c) because the chips are broken regularly. However, the outstanding frequencies are not shown in any other figures because of irregular chip broken. This comes from the fact that the new circuit of thermo-EMF by regularly broken chip at point "b" are not formed as shown in Fig. 1. In Fig. 4(c), the regularly broken chips are mixed with irregularly broken chips, but the frequency component of 22.



(a) Long comma chip
V = 106 m / min, d = 2 mm, s = 0.6 mm / rev

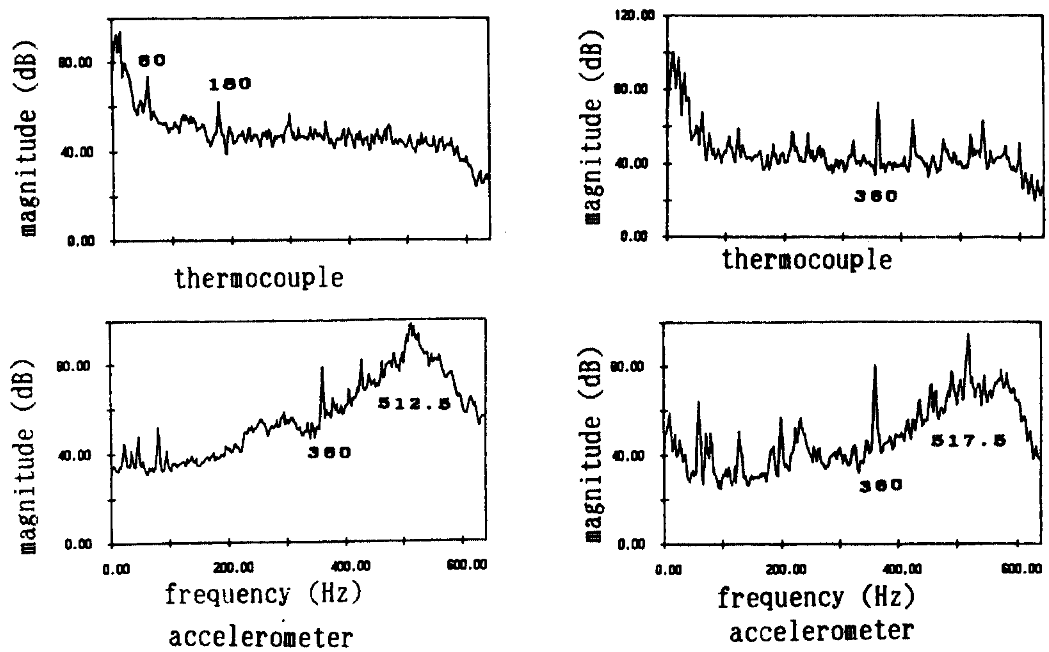


(b) Spiral chip
V = 109 m / min, d = 1.5 mm, s = 0.2 mm / rev



(c) Short tubular chip + Long comma chip
V = 30 m/min, d = 1 mm, s = 0.3 mm/rev

(e) Tangled chip
V = 83 m/min, d = 1 mm, s = 0.05 mm/rev



(d) Corkscrew chip
V = 83 m/min, d = 1 mm, s = 0.1 mm/rev

(f) Ribbon chip
V = 115 m/min, d = 1.5 mm, s = 0.05 mm/rev

Fig. 4 Power spectrum of thermo-EMF for chip form

5 Hz is only related with the broken chips. If the length of broken chips varies a little, the power of peak frequency gets lower, and the width of the frequency gets wider. In the most cases of Fig. 4, the peak frequency below 10 Hz exists on account of the vibration of machine structure and the eccentricity of workpiece. The accelerometer's signals have almost similar peak frequency around 500 Hz. These represent the vibration of tool. Provided that chips are broken regularly as shown in Fig. 4(a), accelerometer's signals have a peak frequency. But there is no peak frequency if chips vary a little in the length of broken chips. The reason is that the fluctuation of chip breaking force increases according to the increase of the feedrate, and then the vibration of tool occurs according to chip breaking. But if the feedrate decreases such as Fig. 4(b), (c), and etc., the magnitude of peak frequency is smaller than that of tool vibration, though chips are broken regularly. Therefore peak frequency does not appear.

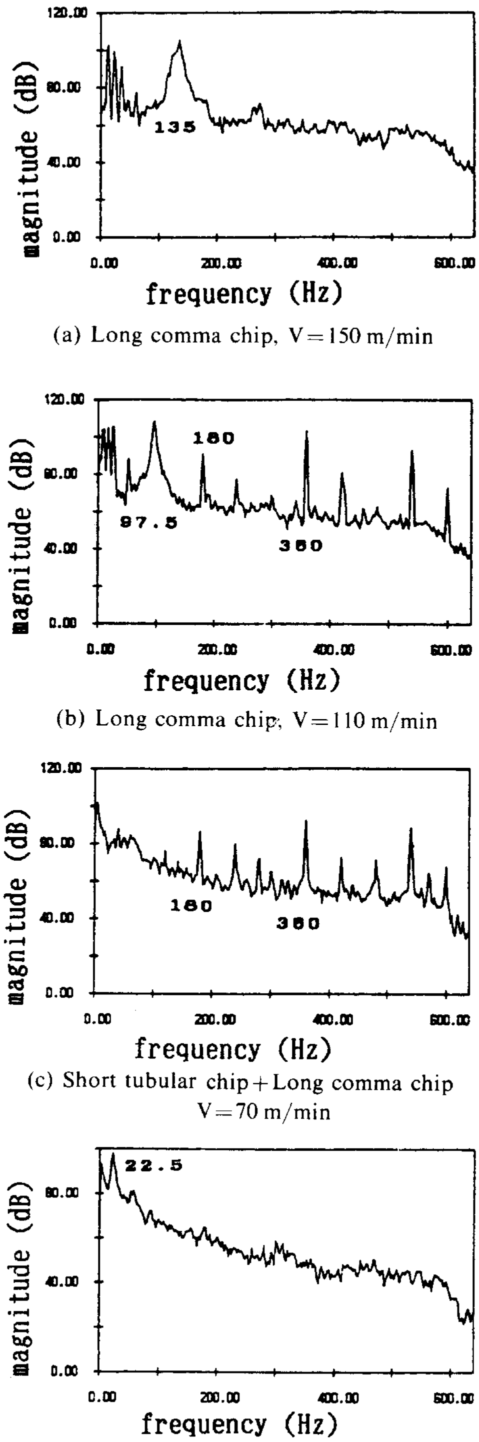
As a result, the tool/workpiece thermocouple is more effective than the accelerometer in the recognition of chip form.

4.2 The dynamic characteristics of thermo-EMF according to the cutting speed

Figure 5 represents the power spectrum of thermo-EMF according to the cutting speed. The peak frequency of 135 Hz exists when cutting speed is 150 m/min. And the peak frequency of 97.5 Hz can be observed at 110 m/min. But the peak frequency can not be observed in other cutting speed. The reason is that the long comma chips are generated at 150 m/min, and 110 m/min. If the cutting speed increases from 110 m/min to 150 m/min, peak frequency increases from 97.5 Hz to 135 Hz, because chip is generated quickly and then chip breaking takes place quickly.

4.3 The dynamic characteristics of thermo-EMF according to the feedrate

The power spectrum of thermo-EMF according to the feedrate is shown in Fig. 6. If the feedrate increases, chip breaking takes place easily because the chip thickness increases. Futhermore, if the chip thickness increases, the radius of chip curling decreases, and the chip breaking takes place



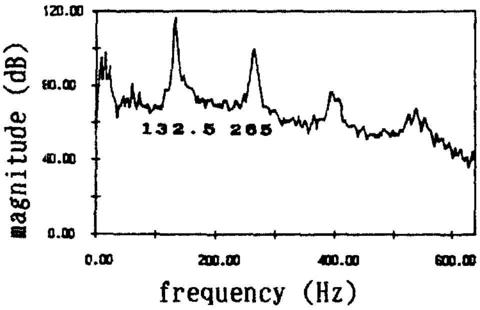
(a) Long comma chip, V=150 m/min

(b) Long comma chip, V=110 m/min

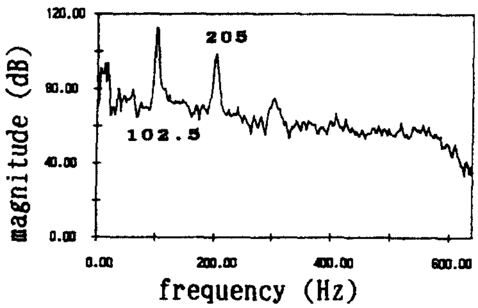
(c) Short tubular chip+Long comma chip V=70 m/min

(d) Short tubular chip+Long comma chip V=30 m/min

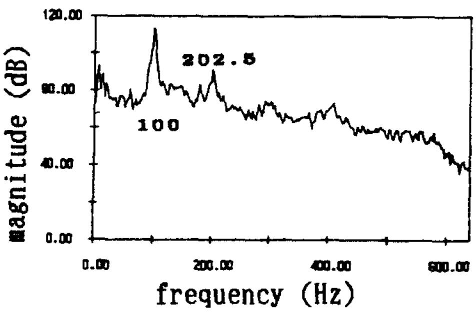
Fig. 5 Power spectrum of thermo-EMF for cutting speed (s=0.3 mm/rev, d=1 mm)



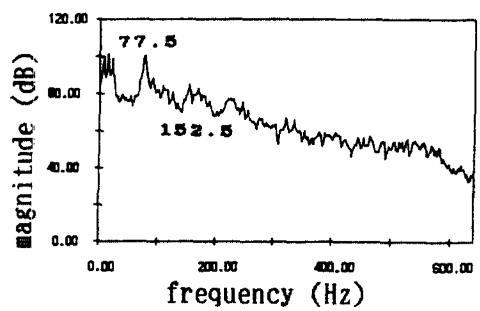
(a) Long comma chip, s=0.6 mm/rev



(b) Long comma chip, s=0.5 mm/rev

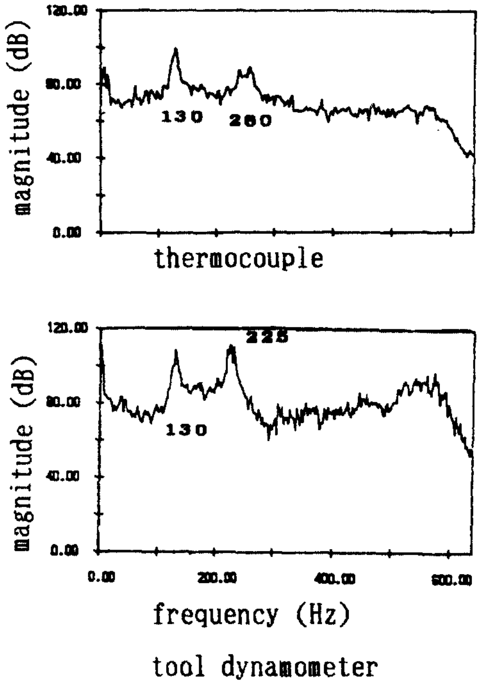


(c) Long comma chip, s=0.4 mm/rev

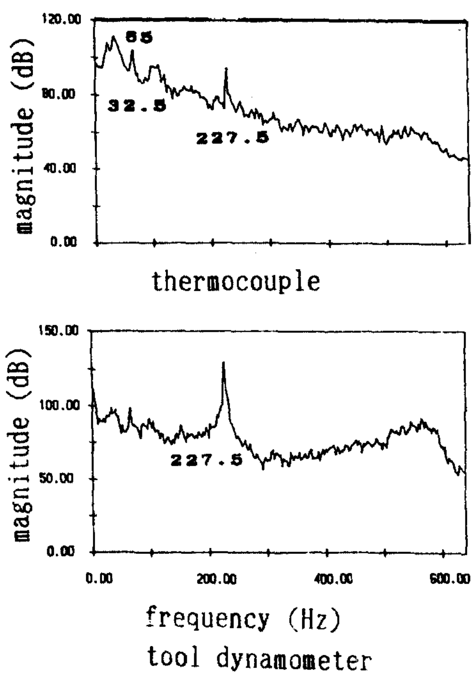


(d) Short tubular chip + Long comma chip
s=0.3 mm/rev

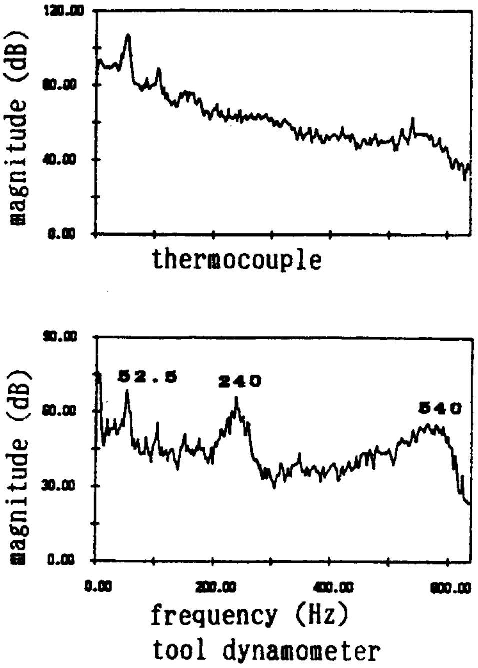
Fig. 6 Power spectrum of thermo-EMF for feedrate
V=106 m/min, d=2 mm



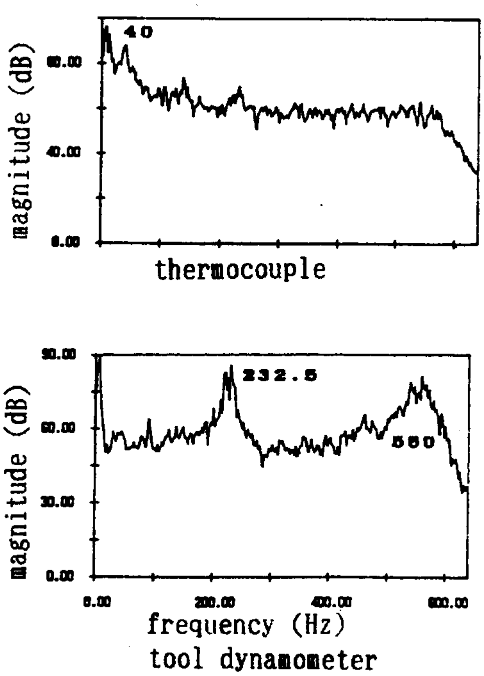
(a) Long comma chip
V=87 m/min, d=1 mm, s=0.32 mm/rev



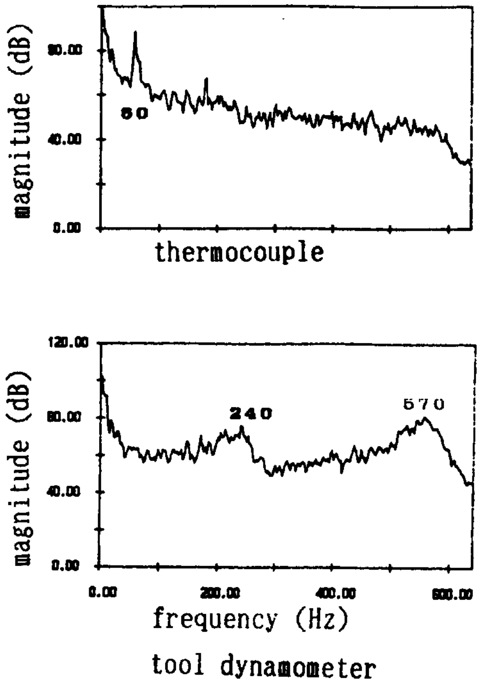
(b) Long comma chip + Spiral chip
V=78 m/min, d=1.5 mm, s=0.32 mm/rev



(c) Short tubular chip
V = 103 m / min, d = 1 mm, s = 0.25 mm / rev



(d) Corkscrew chip
V = 92 m / min, d = 1 mm, s = 0.14 mm / rev



(e) Very short comma chip
V = 106 m/min, d = 2 mm, s = 0.3 mm/rev

Fig. 7 Power spectrum of thermo-EMF and cutting force

quickly, therefore, the peak frequency increases. But the peak frequencies of 102.5 Hz and 100 Hz at the feedrate of 0.5 mm/rev and 0.4 mm/rev each, are almost same. This shows that peak frequency is not linear according to the feedrate.

4.4 The recognition of chip forms by the dynamic component of thermo-EMF and main cutting force

Figure 7 shows the dynamic component of main cutting force and thermo-EMF. The frequency of 130 Hz shows up clearly in the long comma chip as shown in Fig. 7(a). In the case of long comma and spiral chip, the peak frequencies of 65 Hz and 32.5 Hz exist in the thermo-EMF signal as shown in Fig. 7(b). Cutting force does not have peak frequency related with chip breaking.

But this has the peak frequency related with tool vibration. In addition, it can be observed that the peak frequency of 52.5 Hz exists because chips are broken at constant length with the shape of the short tubular chip as shown in Fig. 7(c). Also, the peak frequency does not exist as shown in Fig. 7(e) in case of the brass. The peak frequencies of 240 Hz and 570 Hz can be observed in the dynamic component of the main cutting force. Because in case of brass, chips are broken into very small pieces, and the broken chips do not excite the tool. Therefore the peak frequency has nothing to do with the chip breaking frequency in case of brass.

5. Conclusion

The relationships between the peak frequency and chip breaking frequency are investigated by the tool/workpiece thermocouple, the accelerometer and tool-dynamometer. Based upon the experiments, the following results are obtained.

(1) The dynamic components of electromotive force exactly reflect the characteristics of the chip breaking, and the chip breaking frequencies exist below 200 Hz.

(2) If chip breaking is not regular, the power of peak frequency gets lower in magnitude and wider in width.

(3) The brittle material is hard to observe the frequency of the chip breaking.

References

Arai, M., Nakayama, K., Tsukada, Y. and Kagami, N., 1985, "The Monitoring of Chip Flow in Metal Cutting using Radiation Thermometer," JSPE, Vol.51, No.4, pp. 122~127.

Chung, E.S., Namgung, S. and Ito, Y., 1989, "In-Process Recognition of Chip Forms using Dynamic Component of Cutting Force," JSME, Vol.55, No.518, pp. 2632~2636.

Hirota, H., Suzuki, S. and Shinozaki, N., 1979, "Fluctuation Characteristics of Tool/Work Thermo-Electromotive Force," JSPE, Vol.45, No. 45, pp. 592~598.

König, W., 1979, "Present Knowledge of Chip Control," Annals of the CIRP, Vol.28, No.5, pp. 441~455.

Lee, J.H. and Lee, S.J., 1990, "Recognition of Chip Forms During the Metal Cutting Process," SME, Pacific Conference, Vol.2, pp. 842~849.