

# Investigation on the Correlation between CNC Spindle Current Value and Tool Wear

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**Abstract.** Metal cutting is the commonly used method in mechanical design, and the tool is the most important key factor in metal cutting. When the tool is severely worn, it will cause the tool to break. This article takes the current value of machining precision turret as an example to study the relationship between current value and tool wear. We used statistical mathematical models to predict tool life and used scatter diagrams to verify the timing of tool change and the actual degree of tool wear, to achieve accurate prediction and reduce tool waste.

In our experiment, the core part of the indexing plate (turret) is machined by the horizontal machining center, The CCD image capture system was utilized to evaluate cutting tool wear. Three methods are analyzed to predict tool wear and current. The probability statistical mathematical model shows good match to predict the tool life. it is possible to find out the holes with poor quality caused by tool wear and calculate the exchange rate.

## Introduction

Machine tools are a key industry in Taiwan's machinery industry. It is an indispensable mechanical equipment for manufacturing processing. An average of 20% machining downtime is caused by cutting tool failure [1]. There are two methods in tool wear measurement: (1) Direct monitoring method: it requires cutting tool off-line observation. This method is not suitable for automated production. (2) Indirect monitoring method: it can be the collection of vibration or current signals. If one needs to collect the vibration signals from the tool, the sensor must be placed closer to the blade, which may affect the part accuracy. Altintas has shown the correlation between cutting force and spindle current [2]. Yang et. al. also used spindle current as control index in their the milling process [3]. Therefore, current signal might be the best index of tool wear [4].

Off-line human measurement is time-consuming and is not reliable due to many human factors. The turret fabrication time is 1 hour, but off-line measurement takes another 0.5 hours. In this study, we demonstrate the correlation between the current value and the precision of the finished product. The tool wear can be predicted through the probability model [5]. The correlation between the turret current value and tool wear can be used in reducing labor costs, increasing machine utilization... etc.

## Experimental Setup

**Machining Parts.** Here we used fabrication a turret as a demonstration case in this study. The turret material is SCM21 nickel-chromium-molybdenum alloy steel. This turret has a total of 24 processing holes. The angle between the two holes is 15° as shown in Fig. 1. The machining parameters are identical among 24 holes, and the ambient temperature has kept between 22~28 °C.

**Cutting Tools.** There are three kinds of tools applied in machining process (in order): face milling cutter, tungsten steel milling cutter, and fine boring cutter. The fine boring tool affect final precision and therefore was used as our wear analysis.

**Tool Tip Image Caption.** The automatic tool image measuring instrument was applied to measure the tool length/diameter. After the cutting tool is processed, the tool wear occurs. The image first converted into a binary image through ImageJ software. By adjusting threshold values, we are able to cancel the noise and find a best tool boundary [6]. Fig. 2 shows the worn region by filling out different color and compute color area.

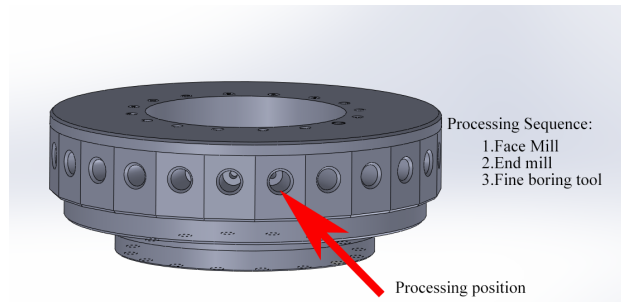


Figure 1. Turret as a core part of the indexing plate (schematic drawing).

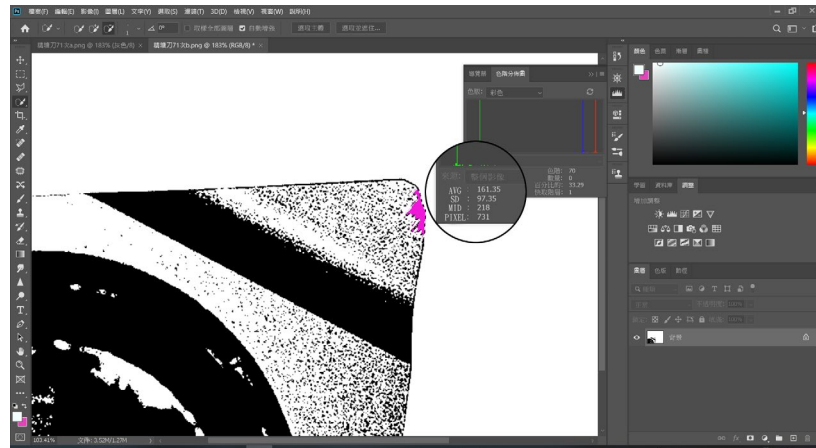


Figure 2. Cutting tool blade binarization with threshold setting.

**Measurement of Turret Inner Diameter.** Use the BLUM TC-52 touch probe to touch the 4 poles of the depth and shallowness of the inner hole of the turret through online measurement, and then measure the inner diameter, roundness, segmentation accuracy and perpendicularity of the hole. According to the probe specification, the repeat accuracy is  $0.3\mu\text{m}$  ( $2\sigma$  range).

**Current Value Collection.** We adopt a current sensor (OP-51675) and converted the spindle current value into a voltage signal. The current capture card collects 1000 data per second and sends them to the PLC through SMB (Smart Machine Box). The sampling frequency of the current value is 1000hz, the total sampling time is 12.6 minutes, and the amount of converted data is about 759,000. Because the noise signal occurred during tool change process, we all collect 1 to 753399 data for entire 24 holes process.

**Current as an Index.** Using averaged current to predict tool wear is a well-known method. When the tool starts to wear, the overall current will shift upward due to the increase in cutting resistance. Using current peak value to predict tool wear is also commonly used in the industry. This peak current can be correlated to average inner diameters. Here we proposed a method based on selection the current peak threshold value over 500 (user-defined value) (Fig. 3)

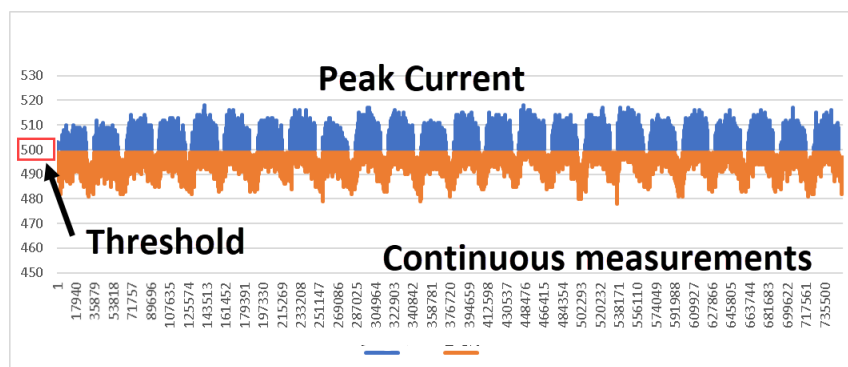


Figure 3. Current acquisition over machining process. Only peak current used to check with threshold.

## Experimental Results

**Lifetime of Cutting Tools.** The new fine boring cutter will have blade replacement after processing 3 to 4 turrets. The diameter of the fine boring cutter reaches 7.96mm (initial diameter is 8.0mm). If we use fine boring cutter continuously, the diameter can reach 7.94mm and decrease slowly afterward. There is no significant decrease in the length of the tool. The Fig.4 shows entire boring tool features recording over 95 turrets. Regarding the jittering region, it is considered that there is a slight height error between the tool holder platform and the tool holder in the tool detector. Therefore, we could use tool diameter as index of tool wear.

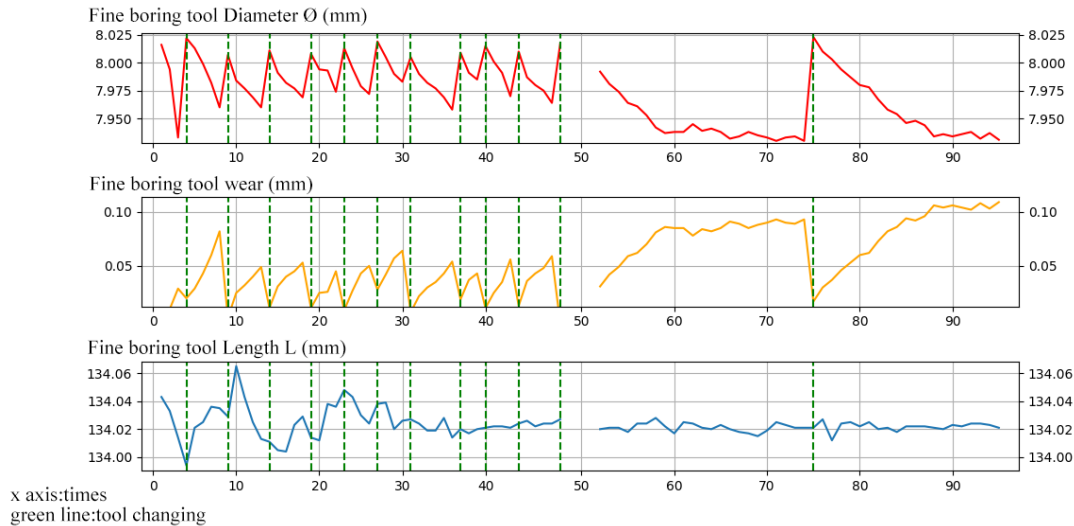


Figure 4. Measurement of fine boring tool over 95 turrets: diameter, wear region and length.

### Comparison of Wear Area and Tool Diameter

There were 95 turrets processed in this study. The cutting tool was empirical replaced for the first 48 turrets (i.e., 1~48 turrets). In other words, the cutting blades were replaced after 3 to 5 turrets completed. We continuously use the same cutting blades from the 49<sup>th</sup> to the 74<sup>th</sup> (phase 1) and 75<sup>th</sup> to the 95<sup>th</sup> (phase 2). Figures 5 and 6 show tool diameter reduced as number of turret increases in both phases 1 and 2, respectively.

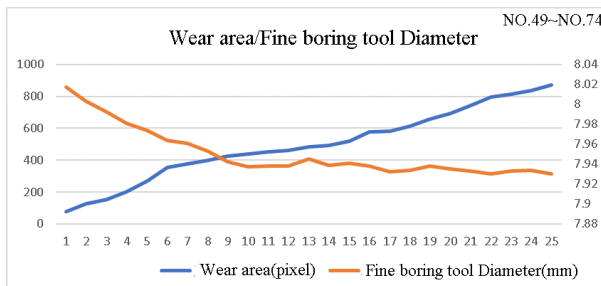


Figure 5. The relationship between tool diameter and wear area in Phase 1.

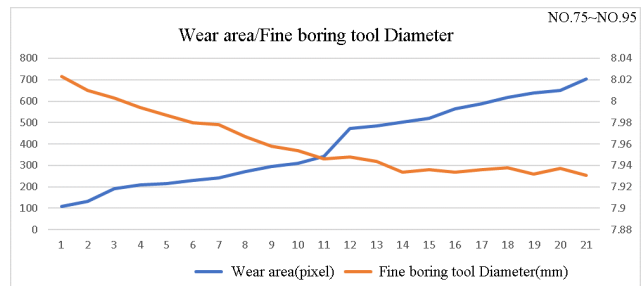


Figure 6. The relationship between tool diameter and wear area in Phase 2.

### Comparison of Tool Outer Diameter AND Turret Inner Diameter

After processing the 64<sup>th</sup> turret, a measurement of the turret maximum inner diameter of 24 holes is shown in Fig.7. This measurement can more accurately observe the effect of tool wear on the finished product (without changing the cutting tool). The two show a proportional relationship.

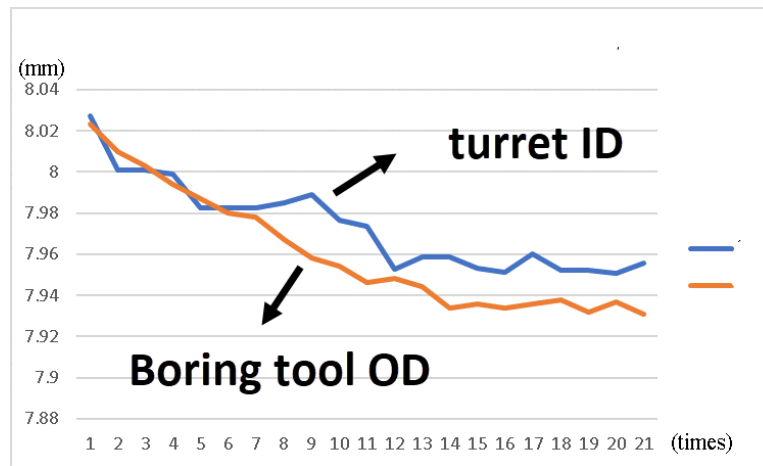


Figure 7. Line chart of turret max inner hole diameter and boring tool outer diameter (OD).

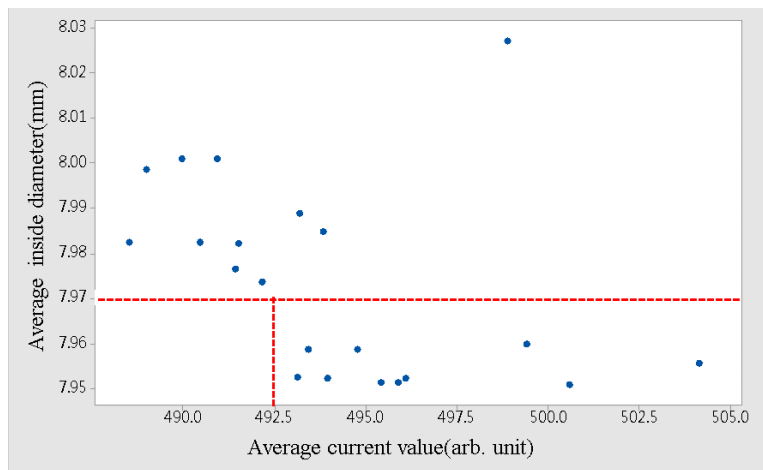


Figure 8. Scatter diagram of average inner diameter and average current value.

### Comparison Of Spindle Current Value And Inner Diameter Of Turret

We took measurement data in phase 2 as demonstration. The averaged current exceeds threshold 492.5 which reflect the tool diameter lower than 7.97mm, can provide 77% prediction quality accuracy (Fig.8). If we use peak current as an index with threshold 513 and same tool diameter 7.97mm as criteria, it reaches 80% prediction quality accuracy (Fig.9).

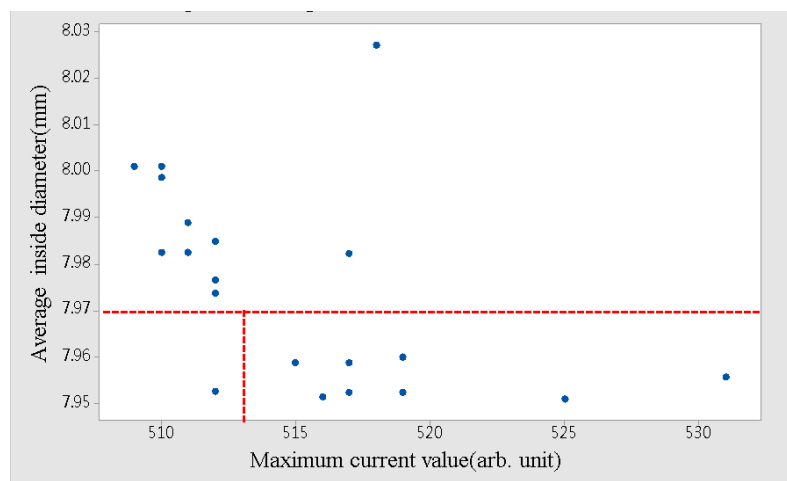


Figure 9. Scatter diagram of average inner diameter and peak current value.

### Probability Statistical Model In GO/NG Judgement

In phase 2, a total of 21 turrets were processed with a total of 504 holes. Two pieces were removed from analysis due to abnormal data acquisition issue, we included 456 holes in the analysis. There are 222 holes (out of 456) have an inner diameter of less than 7.97mm. By setting up threshold current to 6650, we are able to achieve a 73% data collection success ratio using peak current as an index (Fig.10). Applying the same threshold to samples in phase 2 sample, we can achieve 90% correct GO/NG judgement rate. Similar threshold values can be applied in phases 1 and 2 and they are all listed in Table 1. It looks very promising in using probability model to achieve success GO/NG judgement rate as long as a proper threshold value is set in the model.

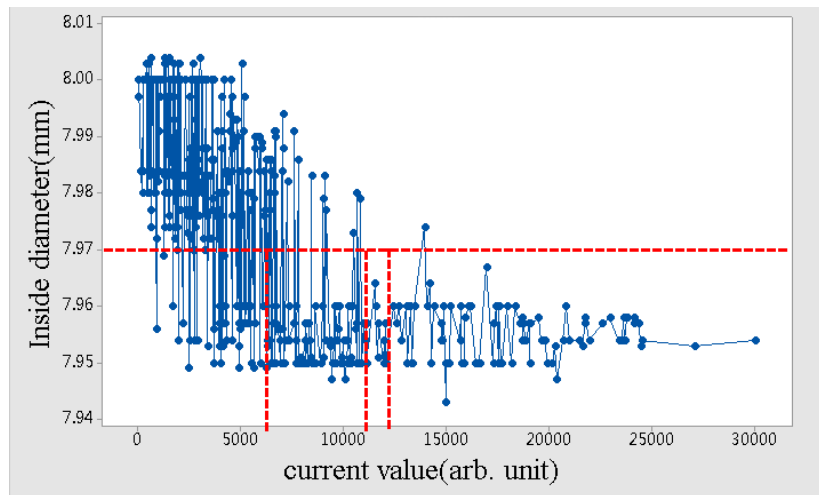


Figure 10. Using probability statistical model provides better GO/NG judgement rate.

Table 1. Results for setting various threshold current in phases 1 and 2 samples.

Phase 2 sample size=222	Correct Counts (A)	Missing Count (B)	A+B	Success OK/NG judgement rate (A/A+B)	Data Collection Success Rate (A+B)/222
Threshold current=1200 and ID<7.97mm	85	1	86	98.8%	38%
Threshold current=1100 and ID<7.97mm	95	1	96	98.9%	43%
Threshold current=6650 and ID<7.97mm	162	17	179	90%	73%
Phase 1 sample size=256	Correct Counts (A)	Missing Count (B)	A+B	Success OK/NG judgement rate (A/A+B)	Data Collection Success Rate (A+B)/256
Threshold current=1200 and ID<7.97mm	145	1	146	99.3%	57%
Threshold current=1100 and ID<7.97mm	152	2	154	98.7%	59%
Threshold current=6650 and ID<7.97mm	210	4	214	98.1%	82%

### Conclusions

This study correlated the current value, tool wear, and finished product accuracy of precision turret machining. By continuing using cutting tool in machining process, we are able to collect all current information and compare against with tool outer diameter.

1. It has been verified that tool wear is highly related to spindle current and can be used for prediction.
2. With a proper selection of threshold current, we are able to get success OK/NG judgement rate up to 99% which is under assumption that all data can be successful collected.
3. The current value can be used as an index to correlate product geometric accuracy (e.g., inner diameter), tool wear status, as well as estimating the tool life time.

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