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The effect of CNC controller gains on rigid tapping

Chen Shao-Hsien[1,3], Liu Zhi-Xin[2], Lin Jian-Cheng[2], Lin Meng-Ying[2]

Abstract. High-speed cutting is an important technique of modern machining which includes milling, lathing, drilling and tapping. This study focuses on rigid tapping which involves the synchronization adjustment of Z-axis and main axis motions. Machine precision and controller adjustment play an important role in increasing the speed of drilling. Attention is also paid to controller parameters, with the main adjustments in multi-stage servo position gains and multi-stage tapping position loop gains, to observe the effect of different feed rates on error, and the main causes relationship of machine precision and the adjustment of controller parameters. Original factory parameters without any adjustments are downloaded and relationship diagrams showing Z-axis speed and synchronization error are recorded, followed by applying servo guide to conduct the adjustment of synchronization error of rigid tapping. These steps are to observe the impact of parameters on errors, with the goal of achieving minimum error.

Key words. FANUC servo guide, rigid tapping, synchronization error..

1. Introduction

Contemporary electronics industry is moving toward precision molding processing and then fine processing, greatly reducing the steps in lathing, milling and grinding. However, after molding process is completed, finishing, drilling and tapping processes are still needed. This study focuses on the high-speed and high-precision tapping technology, mainly applying the adjustments of controller parameters to reach the optimum synchronization of Z-axis and main axis motions and eventually achieving the goals of high-speed drilling and tapping. This study can improve the work efficiency and precision, as well as the quality of finished products. Mass production is one of the requirements of today's industry, so good efficiency and the quality meeting customer needs are also important. We explore the field of tapping

[1]The Graduate Institute of Precision Manufacturing, National Chin-Yi University of Technology
[2]Department of Mechanical Engineering, National Chin-Yi University of Technology
[3]Corresponding author; e-mail: e6036@ncut.edu.tw

and adjust parameters and compare the relationship between synchronization error, thread precision and work efficiency under different parameters. The process of inner thread has significant importance in metal processing industry. For its relatively high cost, it is needed to look for an effective method [1].

2. The principle of rigid tapping

2.1. The classification of CNC tapping

CNC machine tool on tapping is mainly divided into floating tapping and rigid tapping, in which rigid tapping is a lot faster than floating tapping and can reduce the wear of cutting tools. Therefore, the processing time is shortened, the tool life can be extended and costs can be reduced.

The conventional to floating tapping uses it's mechanism to compensate so the ma-chining speed cannot be too fast. In rigid tapping for the servo motors of main axis and Z-axis need to maintain a certain position ratio. For every turn of the main axis, the servo motor of Z-axis needs to catch up with the next thread pitch [6][7].

2.2. Rigid tapping

There are two types of rigid tapping processes. The first takes the servo motor of Z-axis to follow the main axis. The second has both the servo motors of main axis and Z-axis keep a particular position ratio and uses the adjustment of controller parameters to improve the synchronization of two axes to reduce the error between the two. For rigid tapping, it is essential to synchronize the displacement of Z- and main axes, otherwise the tool may be easily damaged. Good commands for the dynamics of Z- and main axes can help their outputs reach better synchronization [2], [**?**].

When machining rigid tapping, the feeding direction of Z-axis and the rotation direction of main axis need to be consistent and maintain a fixed ratio. The relationship is between the pitch, the speed of main axis and the feed rate of Z-axis. When the feed rate increases, the pitch gets bigger, and when the rotation speed of main axis increases, the pitch gets smaller. The relationship is shown as follows

$$P = \frac{F}{S}\,, \tag{1}$$

where P is the pitch, S denotes the speed, and F stands for the feed rate of Z-axis.

The error ratio of main and Z-axis servo motors can affect the surface roughness and precision of the machining, eventually resulting in the shortened lifespan and breaking of tools. To improve efficiency and maintain the machining precision, it is rather important to use controller parameters to adjust speed and precision, and the purpose of this experiment is to minimize the synchronization error of machine. Figure 2 as shown synchronous control system, synchronous control system for rigid tapping in which the spindle axis is a master and the Z-axis is a slave. The command is input to the spindle axis controller to control the spindle rotation speed, In the

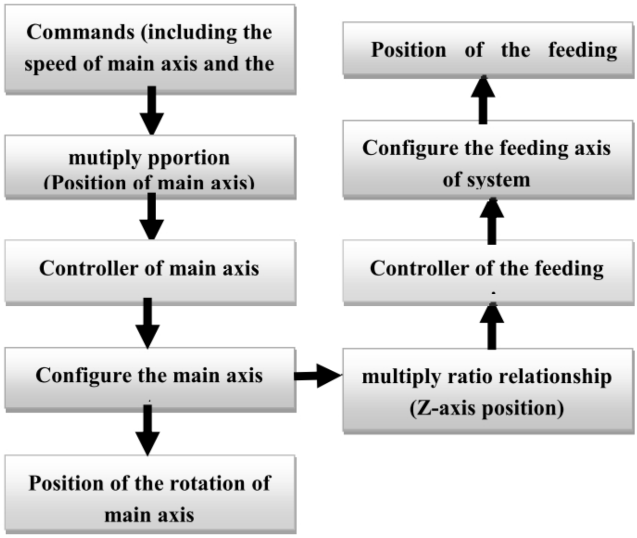

Fig. 1. Control architecture of rigid tapping

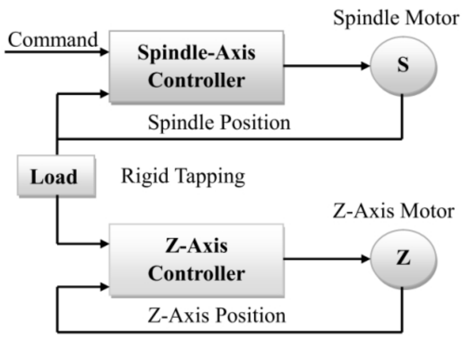

Fig. 2. Synchronous control system

rotation position of the spindle motor feedback to the spindle axis controller is simultaneous input as a command to the Z-axis controller. This system is only feedback loops has the time delay between the command for a master and slave, nowadays, as the tapping speed becomes very high, the command to Z axis controller may be excessively high or out of phase, which results in an abnormal operation. Adapting a feed forward loop is a useful technique to decreased synchronizing errors. In the Fig. 3 as shower, the Z axis controller adapted in a commercialized tapping controller which has a feed-forward loop to modify feedback servo system [2][3] [4]. The display of diagnosis shows the information related to rigid tapping. The information is the results generated by the FANUC controller [4][5], as shown in Table 1.

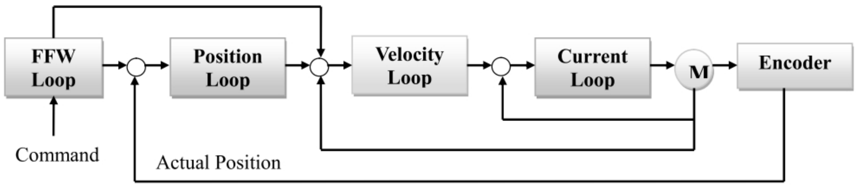

Fig. 3. Feed-forward integrated Z axis servo controller

Table 1. Synchronization error of rigid tapping

Name of diagnosis	**Diagnosis codes**
Difference of motion command of main axis conversion	455
Difference of position deviation of main axis conversion	456
Synchronization error	457
Difference of movement of main axis conversion	460
Difference of machine position of main axis conversion	461
Difference of machine position of main axis conversion	462

Difference of motion command of main axis conversion:

$$S_{\mathrm{m}} = \sum \frac{a}{b} - \sum \frac{c \times d}{e}\,, \tag{2}$$

where a is the command for main axis movement, b is the gear ratio, c denotes the command for drilling movement, d is the number pulses per one rotation of main axis, e stands for the thread pitch and g is the deviation of drilling axis position.

Difference of position deviation of main axis conversion:

$$S_{\mathrm{p}} = \frac{a}{b} - \frac{g \times d}{e}\,. \tag{3}$$

Range of synchronization error:

$$l = SP_{\max} - SP_{\min}\,, \tag{4}$$

where $SP_{\max}$ is the positive maximum value of the difference of position deviation of main axis conversion and $SP_{\min}$ the negative maximum value of the difference of position deviation of main axis conversion.

Machine position of the drilling axis:

$$S_{\mathrm{d}} = \sum(c) - g\,. \tag{5}$$

Machine position of the main axis:

$$S_\mathrm{s} = \sum(a) - g\,. \tag{6}$$

Difference of machine position of main axis conversion:

$$S_\mathrm{c} = \frac{S_\mathrm{d} \times d}{e} - \frac{S_\mathrm{s}}{b} \tag{7}$$

2.3. Display of ratio different of error

When conducting rigid tapping that the error between the instantaneous value and the maximum value of the main axis and drilling are listed in the table, in which the error of Z-axis is related to gains, speed and resolution. Increasing gains and resolution can reduce the error of Z-axis but it can easily cause high-frequency vibration. In the general machining, Z-axis needs to have a safety height which can result in the difference between theoretical and actual errors of Z-axis [5].

Name of diagnosis	**Diagnosis codes**
The instantaneous difference between the errors of main axis and the drilling hole.	452
The maximum difference between the errors of main axis and the drilling hole.	453

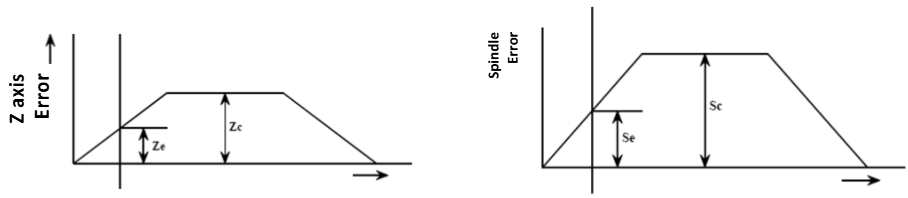

Fig. 4. Example of the drilling and Z-axes

There is a relationship between the error of main axis, gain, rotation speed and resolution. Increasing gains and resolution can reduce the error of main axis. Increasing the rotation speed of main axis can increase the error of main axis. The difference of errors of main and Z-axes can be obtained via $\Delta S - \Delta Z$, and the sampling interval is 8 ms.

3. Experiment steps

4. Plan the experiment

First the experience collects VT18 5-axis machine made by Long Chang Machinery. The synchronization error from the rotation speed of 1000 to 5000 and the rotation speed of Z-axis servo motor for rigid tapping before adjustment parameters, Fig. 3 shows the measuring method.

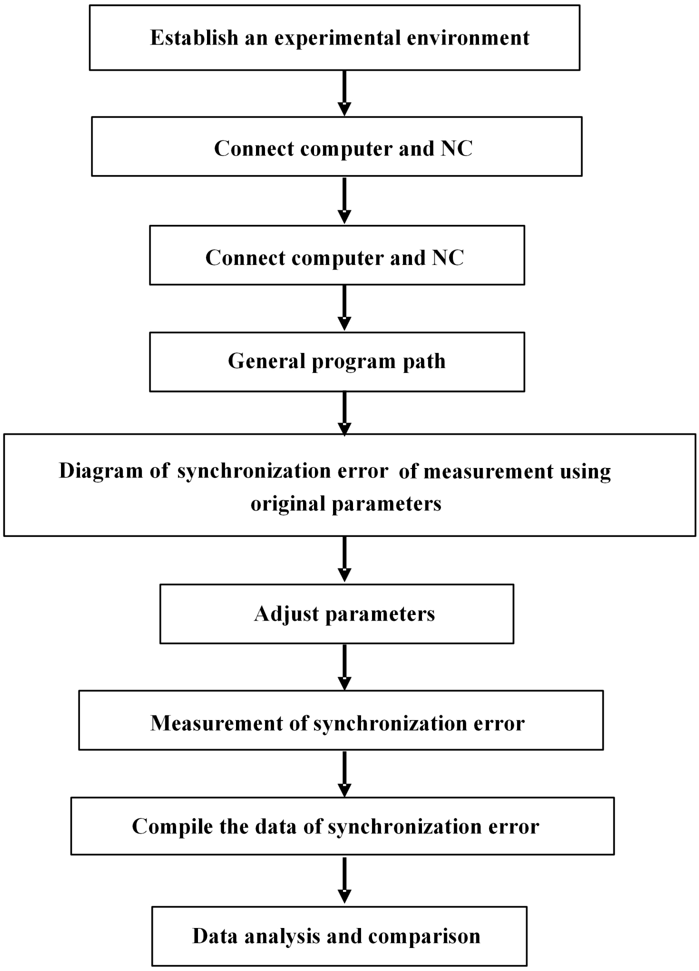

Fig. 5. Flowchart of experiment

Adjust the position gains (parameter codes: 4065∼4068). From 1000 to 3500, at the interval of 500, record the synchronization error and the change of rotation speed of Z-axis servo motor. Adjust the loop gains of position (Parameter codes: 5280∼5283). From 1000 to 3500, at the interval of 500, record the synchronization error and the change of rotation speed of Z-axis servo motor.

Adjust the position gains (Parameter codes: 4065∼4068) and the loop gains of position (Parameter codes: 5280∼5283). From 1000 to 3500, at the interval of 500, record the synchronization error and the change of rotation speed of Z-axis servo motor.

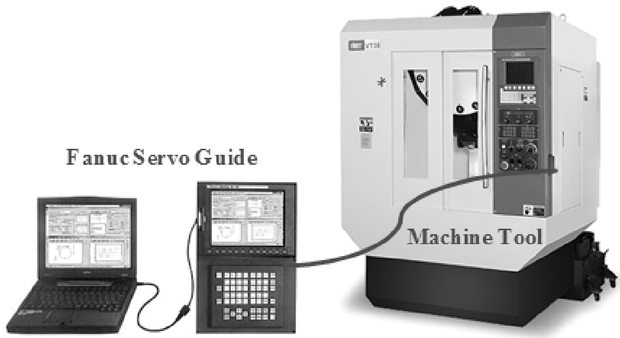

Fig. 6. Experimental Device Shooting

5. Measurement

5.1. Results before adjustments

The main parameters remain unchanged for this experiment are P4065∼P4068 and P5280∼P5283 with the settings at 3000, rotation speed of main axis at 1000 rpm ∼ 5000 rpm and the feed rate at F1000∼F5000 (mm/min). The experiment is the comparison showing different feed rate. It is to observe the relationship between synchronization error and time, as shown in Fig. 7. When the feed rate is faster, the synchronization error gets bigger, as shown in the formula and the errors are in Table 2

Table 2. Average value of synchronization error

Feed rate	**Synchronization error**
1000	7.086
2000	16.286
3000	100.714
3500	114.286
4000	144.286
4500	165.714
5000	201.429

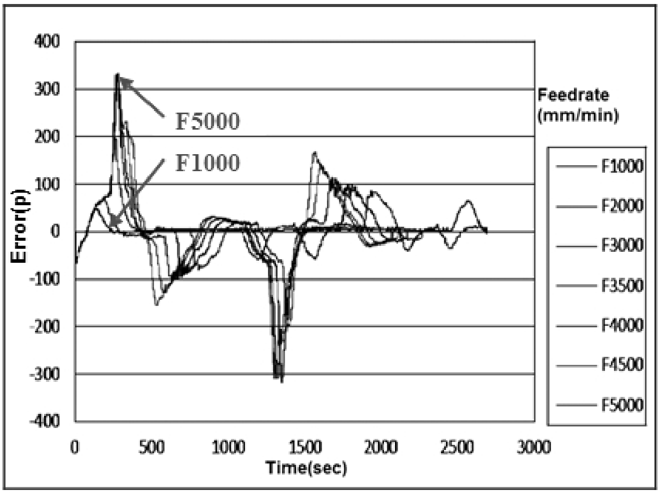

Fig. 7. Waveform showing the synchronization error under original parameters

5.2. Results when changing parameters 4065∼4068

The main parameters remain unchanged for this experiment are P5280∼P5283 with the settings at 3000, and the adjusted parameters are P4065∼P4068 with the settings from 1000∼3500 with an interval of 500, rotation speed of main axis at 1000 rpm, and the feed rate at F1000∼F5000 mm/min. The experiment is the comparison showing different feed rate. It is to observe the relationship between synchronization error and time, as shown in Fig. 8. When the feed rate is faster, the synchronization error gets bigger, as shown in the formula and the errors are in Table 3.

Table 3. Average value of synchronization error with parameters 4065∼4068

Values for parameters 4065 ∼ 4068	**Synchronization error**
1000	9114.29
1500	4571.43
2000	2292.86
2500	914.286
3000	9.029
3500	660

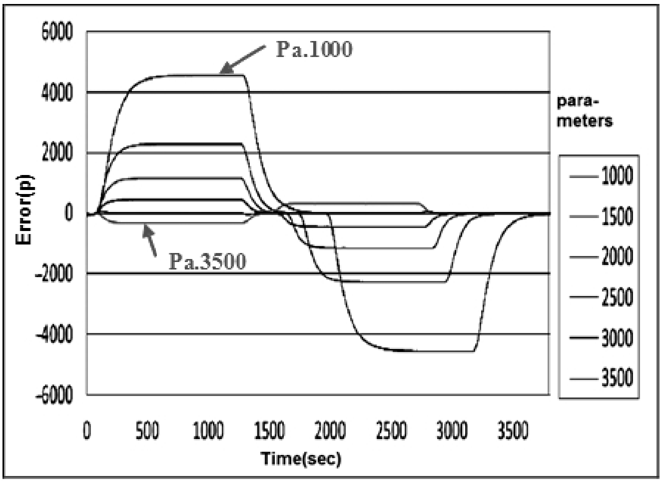

Fig. 8. Waveform showing the synchronization error with parameters 4065∼4068

5.3. Results when changing parameters 5280∼5283

The main parameters remain unchanged for this experiment are P4065∼P4068 with the settings at 3000, and the adjusted parameters are P5280∼P5283 with the settings from 1000∼3500 with an interval of 500, rotation speed of main axis at 1000 rpm, and the feed rate at F1000∼F5000 mm/min. The experiment is the comparison showing different feed rate. It is to observe the relationship between synchronization error and time, as shown in Fig. 9. When the feed rate is faster, the synchronization error gets bigger, as shown in the formula and the errors are in Table 5.

Table 4. Average value of synchronization error with parameters 5280∼5283

Values for parameters 5280∼5283	**Synchronization error**
1000	9114.29
1500	4557.14
2000	2292.81
2500	92
3000	13.143 (Reverse waveform)
3500	660(Reverse waveform)

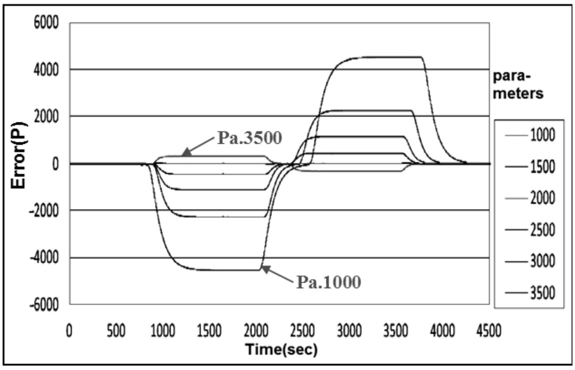

Fig. 9. Waveform showing the synchronization error with parameters 5280∼5283

5.4. Results when changing parameters 4065∼4068 and 5280∼5283

The main parameters changed for this experiment are P4065∼P4068 and P5280∼P5283 with the settings at 3000 and an interval of 500 for the settings between 1000∼3500, rotation speed of main axis at 1000 rpm and the feed rate at F1000∼F5000 mm/min. The experiment is the comparison showing different feed rate. It is to observe the relationship between synchronization error and time, as shown in Fig. 10. When the feed rate is faster, the synchronization error gets bigger, as shown in the formula and the errors are in Table 5.

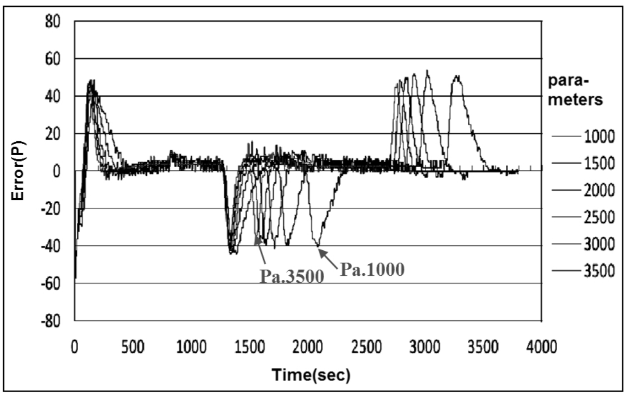

Fig. 10. Waveform showing the synchronization error with parameters 4065∼4068 and 5280∼5283

After adjusting parameters, the position gains (4065∼4068) and position loop gains (5280∼5283), having the same parameters can make the synchronization error minimal, resulting the best work efficiency and

Table 5. Average value of synchronization error with parameters 4065∼4068 and 5280∼5283

Values for parameters 4065∼4068 and 5280∼5283	**Synchronization error**
1000	12.143
1500	15.214
2000	12.143
2500	14.143
3000	13.214
3500	8.057

6. Conclusion

1. When the controller parameters are fixed, the higher the rotation speed of main axis is, the larger the error is. It is mainly due to that rotation speed and feed rate can amplify the error.

2. When the position gains of the servo increase, the errors are significantly reduced. When the compensation of the controller exceeds the mechanical properties, it will result in reverse compensation. Therefore, over-compensation can easily cause the opposite effect.

3. When the controller parameters are kept at minimal, the increase in feed rate does not significantly increase the synchronization error, so the adjustment of controller parameters can significantly improve the feed rate and rotation speed of main axis.

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