Design of Acceleration Command for Feed Drive System in Corner Motion

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Abstract: CNC (Computer Numerical Control) machine tools are required to have high accuracy and production efficiency. CNC machine tools generally generate trajectories such as position and speed within the NC system for commands (usually G code), and then drive each axis. However, in actual contouring motion, the machine often does not move perfectly as commanded, due to tracking errors such as response delays in the control system. NC device manufacturers seem to apply deceleration process to reduce these errors, but their methods have not been disclosed. In this research, we focused on contouring motion with steep acceleration/deceleration, discussed the contouring accuracy when driving the feed drive mechanism with the acceleration/deceleration command generated by the motion controller and our proposed method. Typical NC control controller for machine tools generate trapezoidal or S shaped acceleration/deceleration commands. We propose a command design method based on the Preshaping method which is also known as a vibration suppression method and report the contouring accuracy when applying this method.

1 INTRODUCTION

In recent years, numerical control machine tools have been in high demand for the production of semiconductors and measurement components, requiring both high accuracy and production efficiency. CNC control system with high contouring accuracy is very important in order to achieve products with high accuracy and complex shapes.

Previous studies have revealed that driving the machine tools with high-speed using servo motors leads to excitation of machine vibrations during acceleration/deceleration due to the inertial forces. It makes lower the quality about product surface of the machining (Sato, 2020). In the manufacturing sites, CAM systems are used to generate trajectories for each axis from CAD drawings and convert them into NC data. The machine tool is controlled based on the NC data, and feedforward control is used to reduce the tracking error (Otsuki, 2019). However, high-speed motion in contouring steeply changing trajectory, such as a corner motion, leads to overshooting and tracking errors. NC device manufacturers seem to apply deceleration process to reduce these errors, but their methods have not been disclosed.

In this paper, we first compare trapezoidal and S curve acceleration/deceleration, which are generally used in motion controllers. Additionally, we propose a new acceleration/deceleration command based on the Preshaping method. Generating a velocity command for corner motion using this method, input it to the motion controller, and discuss the contouring accuracy of driving the feed drive mechanism.

2 EXPERIMENTAL DEVICES

2.1 Feed Drive Mechanism

The feed drive used in the experiment is shown in Figure 1. This device consists of a table, a servo motor (made by Panasonic), a ball screw, two sets of guideways (made by IKO) and a base. The servo motor is connected to the ball screw by a coupling. Servo motor has a rated output of 200 W, rated current of 1.5 A, rated torque of 0.64 N·m, and rated rotational speed of 3000 rpm, which are the same for both the X and Y axes.

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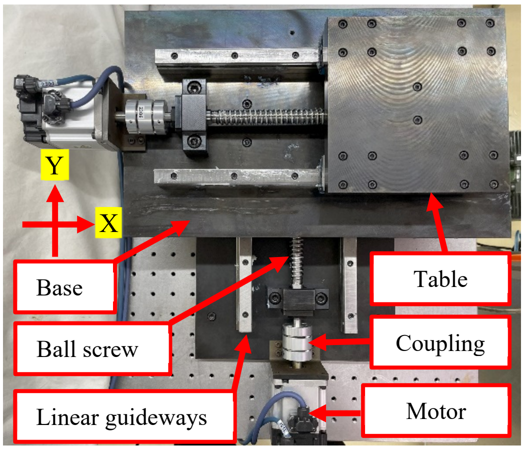


Figure 1: Feed drive system.

The angular position is controlled by such a semi-closed loop and converted to linear motion through a ball screw. The rotary encoder is 17 bits, and the lead of the ball screw is 5 mm, resulting in a minimum position resolution of 38 nm.

2.2 Control System

The control device included a servo amplifier and a motion controller (PMAC made by OMRON) as a host device. The servo amplifier was supplied with 100V AC and 24V DC converted by a switching power supply, simultaneously.

The control method is a semi-closed loop. A velocity command is output from the PMAC (Programmable Multi-Axis Controller) to the servo amplifier, the servo amplifier drives the motor, and the rotary encoder attached to the motor detects the rotational angle and feed it back to the servo amplifier and PMAC. EtherCAT is used for communication between the PC and PMAC, and various control data for the X and Y axes can be gathered at 4 kHz, synchronously. Since this experiment was performed in velocity control, the PMAC handle the position loop and the amplifier handle by the velocity and current loops.

Table 1: Control system setting.

	Symbol	Value
Current Loop	*Cp*	3500
	Ci	350
Velocity Loop	*Vp*	300
	Vi	0
Position Loop	*Kp*	0.012
	Kvfb	0.3
	Ki	0.000001
Ball screw lead	*l*	5 mm

Figure 2 shows a block diagram of the control system. The control system consists of a PMAC and a servo amplifier (one for each axis), with command generation and data gather performed by a PC. The PMAC can select either torque or velocity control mode.

3 FEED EXPERIMENTS

3.1 Control System Setting

We fixed the gains of the control system to compare the contouring accuracy of the corners for various commands. The contouring accuracy evaluated by the distance from the corner vertex to the actual trajectory, with a reference line 45 degrees direction from the corner vertex. This distance is referred to as the inner tracking error. These values were set to give a tracking error of about 200 μm for trapezoidal commands shown in Figure 3. The gains set are summarized in Table 1, and these are the same for the X and Y axes. Figure 4 shows the experimental results when only the proportional gain *Kp* is changed in the range of 0.010 to 0.012, and *Kp*=0.012 was selected as satisfy the tracking error condition.

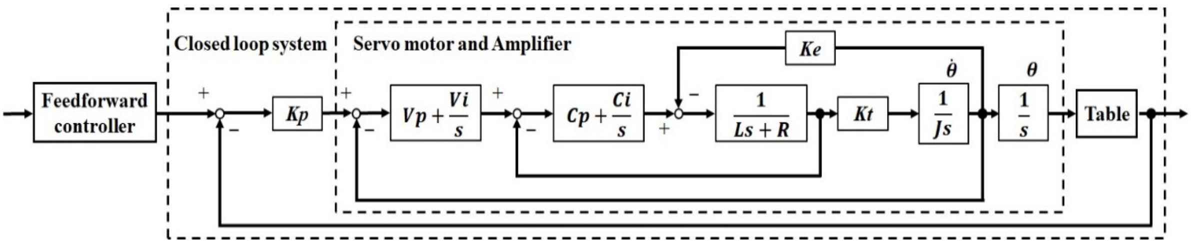


Figure 2: Block diagram of feed drive system.

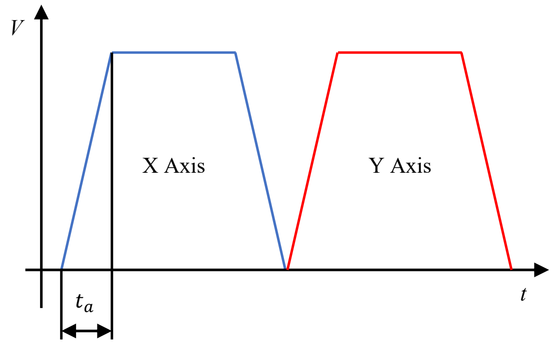


Figure 3: Trapezoidal commands.

3.2 Velocity Commands

In this paper, we performed 100 mm corner motion with three acceleration/deceleration patterns. The feed speed was set to 60 mm/s (3600 mm/min), and the acceleration was set within 0.3 G (3000 mm/s^2) of the acceleration driven by a ball screw, generally.

The first acceleration pattern is trapezoidal command, and if the feed speed reaches 60 mm/s at 0.3 G, the acceleration time is 20 ms. The second acceleration pattern is S curve acceleration, which is shown in Figure 5(a). Where, if the acceleration time is 20 ms as in the trapezoid acceleration, t_s in the figure is 10 ms. For these, commands installed in PMAC are used. The third acceleration pattern is the acceleration designed by the Preshaping method.

It is a suppression method of vibration that cancels out the original vibration by giving an impulse half a period after the natural period of the vibration (Singer, 1988).

Using this method, the acceleration pattern has the shape shown in Figure 5(b). Note that the acceleration time t_p on the Preshaping method is determined by the natural period of the feed drive system, so it is different from the acceleration time used for trapezoidal acceleration. In the experiment, this command is generated in the form of a velocity time series using MATLAB, send to the PMAC and converted to a position command on the PMAC.

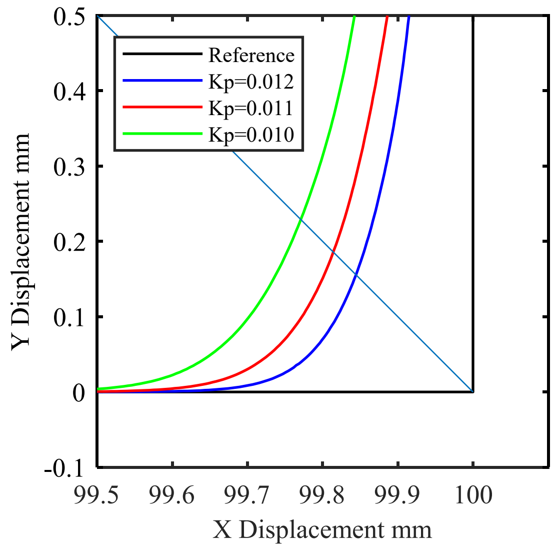


Figure 4: Trapezoidal responses for proportional gain *Kp*.

4 EXPERIMENT RESULTS

At first, we measured the vibration period of the feed drive system. For this purpose, we intentionally excited the vibration by increasing the proportional gain *Kp* at 100 μm step feeds. Figure 6 shows the enlarged view of step feed experiment. From this result, the natural frequency of the feed drive system was approximately 62.5 Hz and the acceleration time on the Preshaping method, t_p=16 ms.

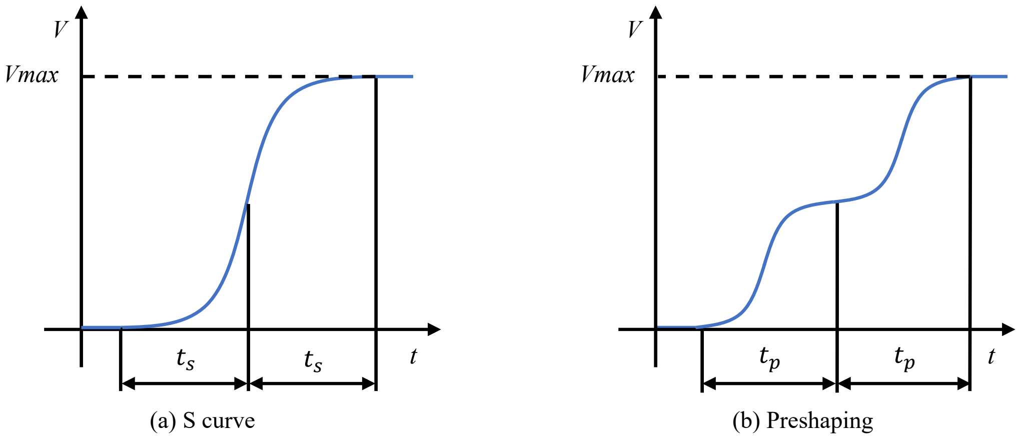


Figure 5: Acceleration time setting.

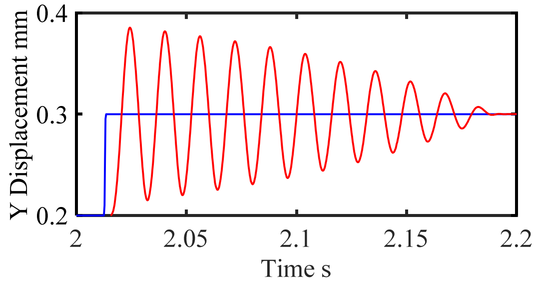
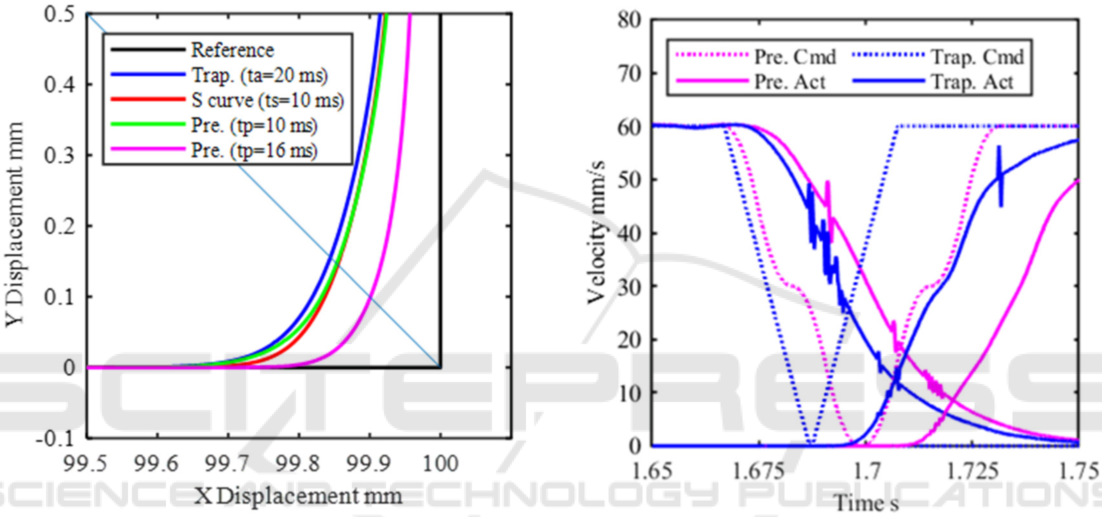


Figure 6: Responses for 100 µm step feed.

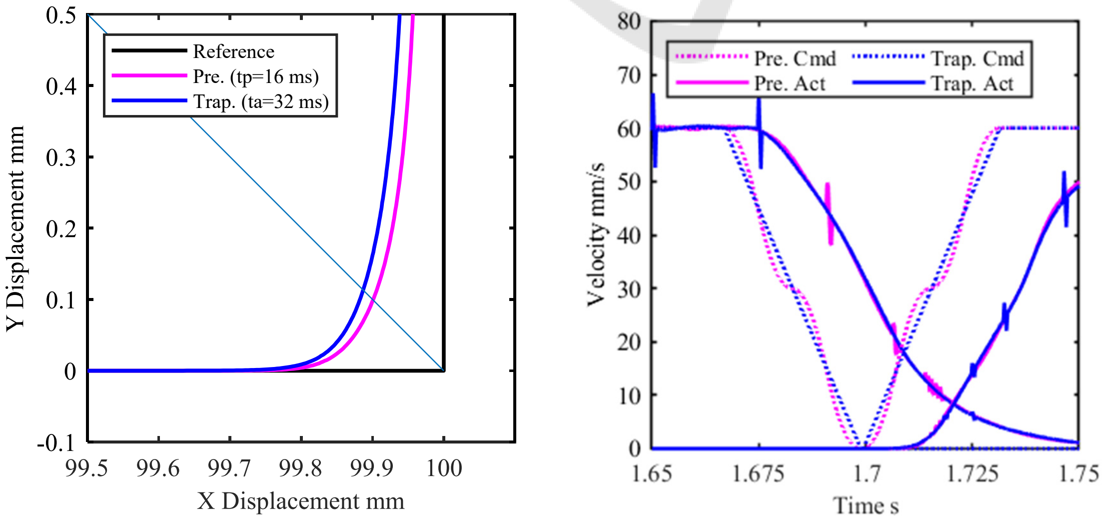
Feed experiment results using four different acceleration/deceleration commands were shown in Figure 7, which is trapezoidal, S curve, Preshaping without consideration of vibration period, and Preshaping with consideration of vibration period. In Figure 7, (a) is contouring error and (b) is velocity in corner motion. about trapezoidal and Preshaping commands with consideration of vibration period. Figure 7(a) shows that the Preshaping without consideration of vibration period does not contribute particularly to contouring accuracy compared to trapezoidal command. S Curve command seems to be a little better than that. The contouring accuracy of the Preshaping with consideration of vibration period was improved about 30 % (60 µm) for trapezoidal commands.



(a) Contouring error in corner motion

(b) Velocity in corner motion

Figure 7: Responses for differential commands.



(a) Contouring error in corner motion

(b) Velocity in corner motion

Figure 8: Responses for differential commands.

According to Figure 7(b), for the trapezoidal commands, the actual velocity of the X-axis is about 12.8 mm/s when Y-axis velocity rises. On the other hand, it is 8.6 mm/s using the Preshaping method. The trapezoidal command has a large inner tracking error because the Y-axis moves before the X-axis decelerates. However, the acceleration time for the trapezoid command is 20 ms, whereas the Preshaping is 32 ms, the total travel time is longer.

For this purpose, we conducted an experiment by setting the acceleration time with trapezoidal command in the same as the Preshaping command. That is t_a=32 ms. The results shown in Figure 8, where (a) is contouring error and (b) is velocity in corner motion. The contouring accuracy was improved about 12 % (20 μm) compared to trapezoidal commands when using the Preshaping command.

5 CONCLUSIONS

In this paper, we performed experiments of corner motion with several types of acceleration/ deceleration commands using two axis feed drive system. As a result, it was found that using a Preshaping command with consideration of vibration period improves the accuracy of the contouring motion compared to the trapezoidal command.

In general, increasing the proportional gain with the trapezoidal command causes oscillations in the actual velocity. The Preshaping method has the effect of suppressing oscillations, the proportional gain will be made higher than usual. It means that improved response of the feed drive system and contributes to reducing machining time.

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