Sensorless monitoring of machining torque on tilting platform driven by hybrid actuator

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Abstract

This paper presents a sensorless monitoring method of machining torque on a tilting platform driven by a hybrid actuator. Sensorless monitoring function can estimate machining torque without additional sensor devices. Performance evaluation results of basic machining tests confirm that the developed system has a capability to monitor machining torque on tilting platform driven by the hybrid actuator.

1 Introduction

Multi-axis controlled precision machine tools have been developed to produce precise parts with complex and freeform geometries. In order to realize freeform nano-machining, it is necessary to develop high performance rotary and tilting platforms. The tilting platform driven by a hybrid actuator that was successfully integrated a pneumatic actuator with an electric actuator has been developed for nano-machining [1]. To realize higher performance machining, the machining force during process should be monitored to control suitable machining condition. However, it is difficult to install monitoring sensors into a rotary axis because it needs hardwiring.

This paper describes a sensorless monitoring method of machining torque on a tilting platform driven by a hybrid actuator. After installing a sensorless monitoring function into a controller, performance evaluation was carried out through actual machining experiments.

2 Sensorless monitoring function for tilting platform

2.1 Tilting platform driven by hybrid actuator

Figure 1 shows a developed tilting platform for precision machining driven by a hybrid rotary actuator [1]. The hybrid actuator consists of a pneumatic actuator at the center of driving shaft and voice coil motors at both ends of the shaft. They are controlled to generate quick and accurate torque by complementing their characteristics each other. Because the platform is supported by aerostatic bearing it can move without friction. The table is installed in parallel with the driving shaft. This structure provides wide working area that is almost equal to the footprint.

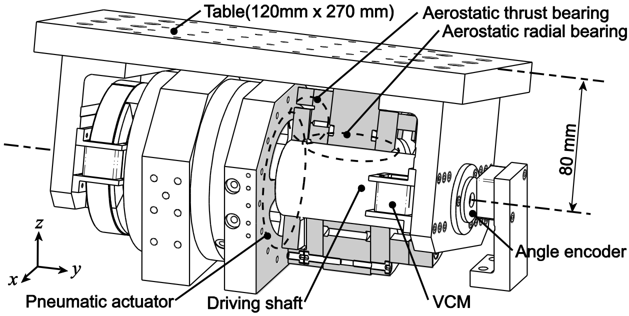


Figure 1: Structural configuration of the developed tilting platform

2.2 Sensorless monitoring function for the platform

Sensorless monitoring function can estimate machining torque using both the output of controller and the measured position based on a disturbance observer [2-3]. Because there is no friction in the developed platform, rotary motion can be expressed by the following equation:

$$J\ddot{\theta} = KT_{ref} + d \tag{1}$$

where θ is angle, J is inertia of the platform, K is torque constant, d is disturbance, and T_{ref} is output of controller, respectively. Therefore, a discretized equation of the system is expressed as the following equation using state variable vector $\boldsymbol{x}$ defined:

$$\boldsymbol{x} = \begin{bmatrix} \theta & \dot{\theta} & d \end{bmatrix}^T \tag{2}$$

$$\begin{aligned} \boldsymbol{x}[i+1] &= \boldsymbol{G}\,\boldsymbol{x}[i] + \boldsymbol{H}\,T_{ref}[i] \\ y[i] &= \boldsymbol{C}\,\boldsymbol{x}[i] \end{aligned} \tag{3}$$

$$\boldsymbol{G} = \begin{bmatrix} 1 & Ts & T_s^{\,2}/2J \\ 0 & 1 & T_s/J \\ 0 & 0 & 1 \end{bmatrix}, \quad \boldsymbol{H} = \begin{bmatrix} KT_s^{\,2}/2J \\ KT_s/J \\ 0 \end{bmatrix}, \quad \boldsymbol{C} = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \tag{4}$$

where T_s is the sampling period of the controller. Thus, an observer for the system is represented by the following equation:

$$\begin{aligned}\hat{\boldsymbol{x}}[i+1] &= \boldsymbol{G}\hat{\boldsymbol{x}}[i] + \boldsymbol{H}T_{ref}[i] + \boldsymbol{K_e}\left(y[i] - \boldsymbol{C}\hat{\boldsymbol{x}}[i]\right) \\ &= \left(\boldsymbol{G} - \boldsymbol{K_e}\boldsymbol{C}\right)\hat{\boldsymbol{x}}[i] + \boldsymbol{H}T_{ref}[i] + \boldsymbol{K_e}y[i]\end{aligned} \qquad (5)$$

where $\hat{\boldsymbol{x}}$ is the estimated state variable and $\boldsymbol{K_e}$ is the feedback gain of observer which is determined to estimate $\hat{\boldsymbol{x}}$ stably. In this study, roots of $\left(\boldsymbol{G} - \boldsymbol{K_e}\boldsymbol{C}\right)$ were set at 100Hz. The designed sensorless monitoring function was installed into the controller.

3 Evaluation of the monitoring performance

3.1 Experimental setup for evaluation

Figure 2 shows the experimental setup for performance evaluation. The tilting platform was controlled at 0 degree by the positioning controller and a workpiece was fixed on the platform. Machining motion was provided by a feed axis with a diamond tool fixed on a dynamometer. Therefore, the estimated machining torque by a sensorless monitoring function in the controller was compared with the output of dynamometer. Machining conditions are shown in Table 1.

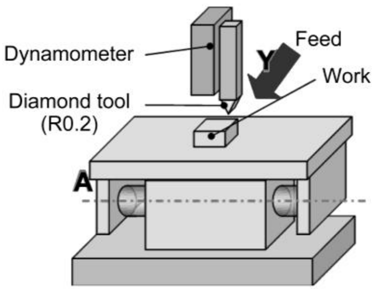


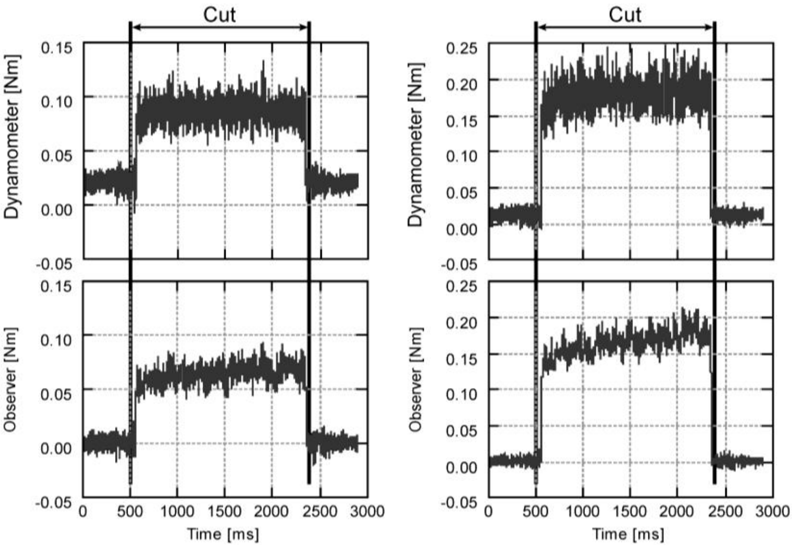
Figure 2: Experimental setup

Table 1: Machining conditions

Tool	Single crystal diamond (R=0.2)
Depth of cut	5μm, 10μm
Cutting speed	20mm/s
Cutting fluid	Dry
Workpiece	Brass

3.2 Monitoring results

Figure 3 shows the measured torque by the dynamometer and the estimated machining torque by the sensorless monitoring function. Because there is no friction in the developed tilting platform, it is easy to make a system model and to identify system parameters accurately. Therefore, the estimated machining torque shows good agreement with the measured torque in both cases.



(a) Depth of cut 5μm (b) Depth of cut 10μm

Figure 3: Monitored machining torque during process

4 Conclusions

This paper presents the sensorless monitoring method of machining torque for tilting platform driven by the hybrid actuator. Evaluation results of actual machining experiments confirmed that the designed monitoring function can monitor the torque during machining without any additional sensor devices.

Acknowledgements

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