Proceedings of Mechanical Engineering Research Day 2016, pp. 198-199, March 2016

Practical controller for positioning control of X-Y ballscrew mechanism

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Keywords: *X-Y* ball screw mechanism; CM NCTF; practical controller

ABSTRACT – This paper describes the evaluation of a practical controller performance for point-to-point positioning motion using a *X-Y* ballscrew mechanism. The proposed controller is Continuous Motion Nominal Characteristic Trajectory Following (CM NCTF) controller which is easy to design and having a simple control structure. The performance of the CM NCTF controller is compared with the PI-D controller, which have similar control structure. The experimental result proved that the CM NCTF controller has better positioning performance in point-to-point motion.

1. INTRODUCTION

Motion control systems play an important role in industrial equipment such as machine tools and robotics. They are required to have not only fast response with little or no overshoot, but also robustness.One type of the motion control systems is point-to-point (PTP) positioning system, which is used to move a plant from one point to another point. The positioning systems generally require a controller to satisfy requirements such as high accuracy, fast response and robust.

In industrial, PID controllers are the most popular and often used for positioning systems. Huang and Chen stated that, the PID gains used performed well in point-to-point (PTP) precision positioning [1]. However, it is difficult to simultaneously satisfy the requirements of fast response and robust. Researchers have changed the structure of PID controller to more advance controller, which is able to overcome the weakness of the classical PID controller.

The advance PID controller have solve the problems stated above, but the control structure of PID controller has become complicated [2]. Besides that, many kinds of controllers such as sliding mode controller (SMC) and disturbance observer (DOB) have been proposed for ballscrew mechanism. However, those controllers require the exact plant model and its parameters which are difficult to be identified [3-4]. The function of the controller increased and the complexity of the control structure will be increased. When the control structure of a controller is complex, the design procedure will become complex because more parameters change needed to be concerned. In these cases, the Continuous Motion Nominal Characteristic Trajectory Following (CM NCTF) controller was proposed. The CM NCTF controller does not require exact model parameters of plant, straightforward design procedure, simple control structure and does not require deep control knowledge.

2. NCTF CONTROL SYSTEM DESIGN

Figure 1 shows the structure of the CM NCTF control system. The NCTF controller consists of two important elements which are nominal characteristic trajectory (NCT) and a Proportional Integrator (PI) compensator. The NCT is functioned as a motion path for the object to follow. On the other hand, the PI compensator functions as velocity control and make the mechanism to follow the NCT and finish at origin. The NCT is constructed using the object responses during the open loop experiment while the PI compensator is designed based on a practical stability limit that obtained experimentally [5].

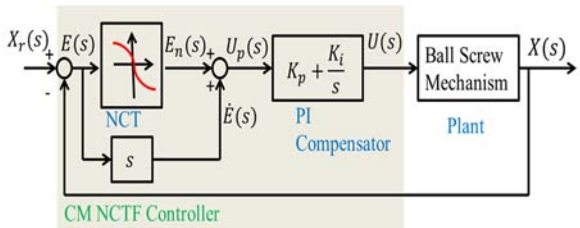


Figure 1 Control structure of CM NCTF controller.

Generally, the design procedure of the CM NCTF controller consists of 3 major steps and it is proved free of friction characteristic [6]. The steps are:

Open loop response:
The mechanism is driven in open-loop and the displacement and velocity are measured
Construction of NCT:
The NCT is constructed on the phase plane using the displacement and velocity of the mechanism during deceleration.
Design of PI compensator:
The PI compensator is designed based on the practical stability limit that determined experimentally.

Figure 2 shows the constructed NCT in the phase plane. The gradient near the origin, $\beta = 87s^{-1}$. Table 1 shows the controller parameter of the CM NCTF controller.

The practical stability limit is obtained by driving the mechanism with the CM NCTF controller using only the proportional element. The K_p value is increased until continuous oscillations are generated, which denoted as the ultimate proportional gain (K_{pu}). ζ and $\omega_n T$ are selected from the stable region in the practical stability limit graph. K_p and K_i values are calculated using Equation (1) and Equation (2):

$$K_p = \frac{2\xi\omega_n}{K} \tag{1}$$

$$K_i = \frac{{\omega_n}^2}{K} \tag{2}$$

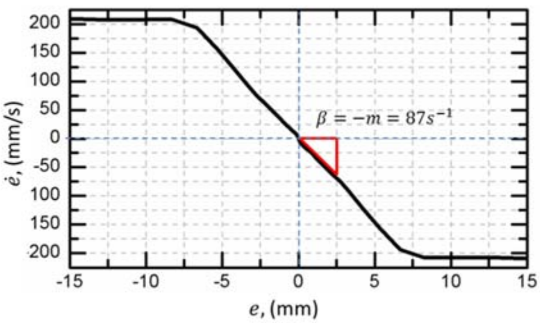


Figure 2 Constructed NCT from open-loop response.

Table 1 Controller parameter.

Parameter	Value
Proportional gain, K_p	0.08
Integrator gain, K_i	1.34
Inclination near origin, β	87s^{-1}

3. PERFORMANCE EVALUATION

A *X-Y* ballscrew mechanism that used to clarify the usefulness of the CM NCTF controller is shown in Figure 3. In this paper, only 1-DOF (*Y*-Axis) which has lighter weight is considered. The positioning performance of the CM NCTF controller is compared with the PI-D controller.

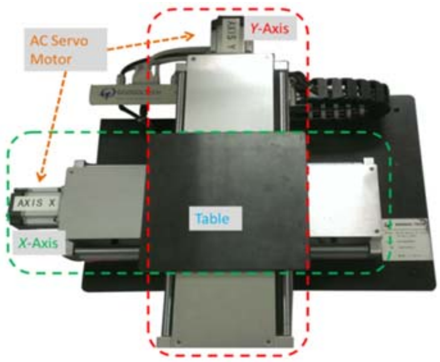


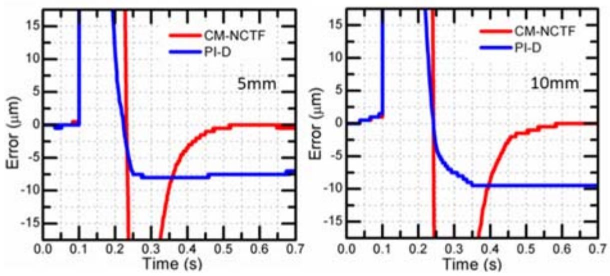
Figure 3 *X-Y* ballscrew mechanism.

Figure 4 shows the comparative experimental positioning performance to step input 5mm and 10mm. The transient responses of the CM NCTF controller and the PI-D controller are shown in error of 0.1%.

Table 2. The CM NCTF controller has showed overshoot 0.76% and 0.94% for step input 5mm and 10mm respectively. Besides that, the CM NCTF controller has succeeded to compensate the steady state error to zero, while the PI-D controller has steady state error of 0.1%.

Table 2 Experiment transient response of CM NCTF and PI-D controller.

Controller	Amplitude (mm)	Overshoot (%)	Steady state error (%)
CM NCTF	5.00	0.76	0.00
	10.00	0.94	0.00
PI-D	5.00	0.16	0.10
	10.00	0.10	0.10



(a) (b)

Figure 4 Experimental PTP performances with step height (a) 5mm and (b) 10mm.

4. CONCLUSION

The CM NCTF controller has demonstrated slightly higher overshoot, but it has succeeded to compensate the steady state error to zero as compared with the PI-D controller. Overall, it can be concluded that the positioning performance of the CM NCTF controller is better than the PI-D controller in point-to-point motion.

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