Proceedings of Mechanical Engineering Research Day 2016, pp. 204-205, March 2016

Positioning control of ball screw mechanism with disturbance observer

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Keywords: Ball screw; PDDO controller; tracking motion

ABSTRACT – In this paper, a disturbance observer with PD controller (PDDO) is proposed to improve the positioning performance of the ball screw mechanism that is subjected to nonlinearities. The tracking performance of the PDDO controller is examined and compared with a PID controller experimentally. The PDDO controller displays better tracking performance than the PID controller.

1. INTRODUCTION

A ball screw mechanism is a mechanical actuator that is widely applied in different industries due to its high stiffness and efficiency. However, the mechanism often experiences problems such as non-linear frictions and hysteresis that affects the positioning performance of the ball screw mechanism [1]. In order to overcome these problems, various controllers such as H-infinity controllers [2] and Fuzzy Logic Controller [3] were proposed to perform positioning control for ball screw mechanism. Among these controllers, a Disturbance Observer with PD controller (PDDO) has a simpler structure. The PDDO controller does not compensate the system directly [4]; the disturbance observer estimates the disturbances and parameter variations in the system while the PD controller compensates the error.

In this paper, a PDDO controller is proposed for positioning control of ball screw mechanism. This paper is categorized as follow: Section 2 discusses the experimental setup while Section 3 covers the controller design procedures. Section 4 examines and compares the positioning performance of the PDDO controller with PID controller while Section 5 concludes this paper.

2. EXPERIMENTAL SETUP

In this paper, the ball screw mechanism is driven by a rated 24V DC servomotor. The ball screw lead comes in 8mm/rev and a linear encoder of 5µm/pulse is used to measure the displacement of the table. The ball screw mechanism is shown in Figure 1 while its corresponding free body diagram is presented in Figure 2.

A ball screw mechanism consists of two parts: a rotating DC motor that give rise to a driving force drives the table on the lead screw linearly. The transmission ratio of the ball screw is given as $R = r/2\pi$, where r is the radius of the lead screw. The value of parameters of free body diagram is presented in Table 1.

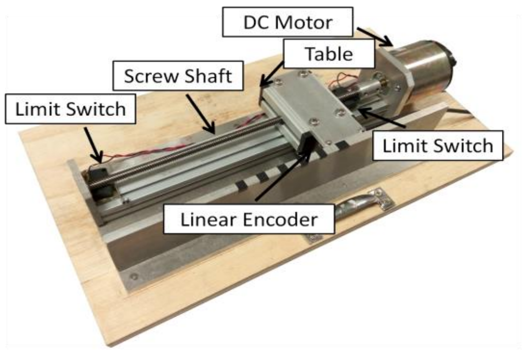

Figure 1 Ball screw mechanism.

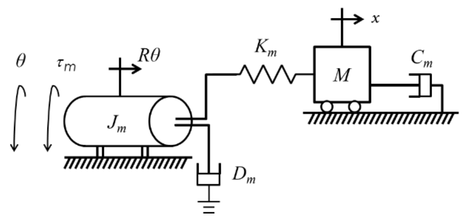

Figure 2 Free body diagram of ball screw mechanism.

The motion of the ball screw mechanism is represented in the equations as follow:

$$J_m\ddot{\theta} + D_m\dot{\theta} + RK_m(R\theta - x) = \tau_m \quad (1)$$

$$M\ddot{x} + C_m\dot{x} = K_m(R\theta - x) \quad (2)$$

Table 1 Parameters of the ball screw mechanism.

Parameter	Description	Value	Unit
J_m	Motor inertia	$6\text{x}10^{-5}$	kgm^2
D_m	Motor Viscous Friction	$0.385\text{x}10^{-3}$	Nm/rad/sec
K_m	Stiffness of screw shaft	$1.82\text{x}10^3$	N/m
M	Mass of Table	0.5	kg
R	Ball screw transmission ratio	$1..273\text{x}10^{-3}$	m/rad
C_m	Viscous Friction of mass	50	N/m/sec

3. CONTROLLER DESIGN

To design the PDDO controller, the control structure in Figure 3 is considered. The disturbance observer is made up of an inverse nominal plant, $P_n(s)^{-1}$ and a low pass filter, $Q(s)$. To design the nominal plant,

$P_n(s)$, a general second order transfer function is first considered:

$$P_n(s) = \frac{\omega_n^2}{s^2 + 2\varsigma\omega_n s + \omega_n^2} \quad (3)$$

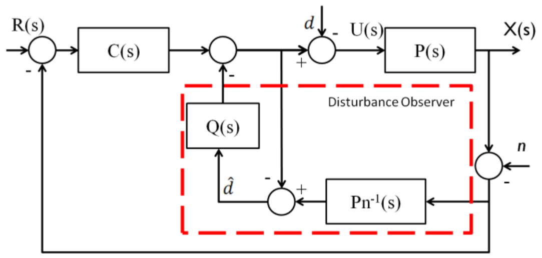

Figure 3 Control structure of PDDO controller.

To design $Q(s)$, the cut-off frequency, ω_d is determined from the operating frequency of the mechanism, $P(s)$. $Q(s)$ is given as:

$$Q(s) = \frac{\omega_d}{s + \omega_d} \quad (4)$$

In the PD controller design, root locus approach is adopted. By specifying the desired transient response, the equation of PD controller is obtained as:

$$C(s) = K_p + \frac{K_d s}{T_d s + 1} \quad (5)$$

The value of T_d was chosen such that the noise picked up by the derivative action is attenuated. The obtained gains are then fine-tuned experimentally.

4. POSITIONING PERFORMANCE

In this paper, the positioning performance of the PDDO controller is examined in tracking motion with sinusoidal input. In order to validate the effectiveness of PDDO controller in positioning control, a PID controller is designed and its performance was compared with PDDO controller. To design a PID controller, three terms are considered: Proportional (P), Integral (I) and derivative (D) of error. By combining these terms, a PID controller equation as shown in Equation (6) is presented.

$$C(s) = K_p + \frac{K_I}{s} + K_D s \quad (6)$$

In the PID controller design, root locus method is adopted to obtain the gains K_p, K_I and K_d. By setting the desired transient response, the desired poles were obtained. The controller gains are then fine-tuned experimentally.

In the tracking performance validation, a sinusoidal input with frequency of 3Hz and amplitude of 5mm was considered. The tracking motion of the controllers is shown in Figure 4.

When the ball screw mechanism moves in fast motion, the relative viscous frictions increase. Since a PID controller is sensitive towards changes of dynamic, its exhibits large tracking error as it is unable to compensate such changes. A PDDO controller, on the other hand, is capable of estimating such parameter changes, and therefore able to act in reducing the tracking error of the mechanism. It can be observed that PDDO controller experienced large overshoot at the beginning of the response, but eventually settled down. One conclusion that can be made from this observation is that the PDDO controller has a large observer gain, thus generating the large overshoot.

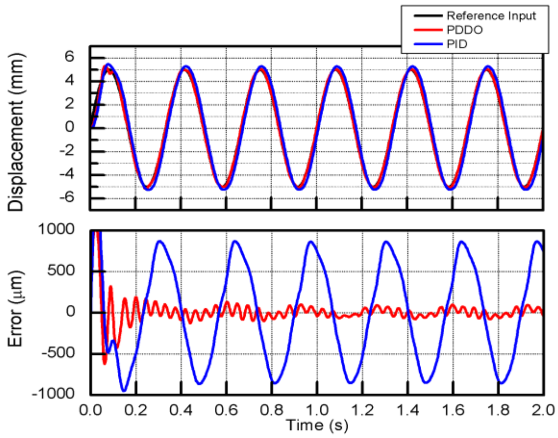

Figure 4 Tracking motion of PDDO and PID controller with sinusoidal input of 3Hz and amplitude 5mm.

5. CONCLUSION

In this paper, the experimental setup of the ball screw mechanism with its corresponding free body diagram was presented. It is concluded that a PDDO controller has better tracking performance than a PID controller. The PDDO controller estimates parameter variations or disturbances in the system, and compensates them such that the mechanism follows the reference input.

ACKNOWLEDGEMENT

The authors would like to be obliged to Motion Control Research Laboratory, Universiti Teknikal Malaysia Melaka for the provision of facilities and equipments. The Research Grant RAGS/2014//TK03/FKE/B00047 is gratefully acknowledged.

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