Comparison of Tracking Performance between Nonlinear Proportional-Integral-Derivative (NPID) Double Hyperbolic Controller and NPID Controller

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ABSTRACT – This paper presents the comparison of performance evaluation of controllers under cutting force disturbance with spindle speed of 2500 rpm. Nonlinear Proportional-Integral-Derivative (NPID) Double Hyperbolic controller design is more effective in improving the tracking performance of the system compared to conventional NPID controller. The performance evaluation with two different speeds of motor; 0.2 Hz and 0.4 Hz is conducted based on maximum tracking error and root mean square error (RMSE). The experimental results of NPID Double Hyperbolic controller show the improvement based on tracking performance by more than 80% compared to NPID controller.

1. INTRODUCTION

CNC milling machine is a machine tool technology that able to manufacture a desired shape of products. Recently, the performance of CNC machine is still investigated by many researchers [1]. CNC machine with a good condition has potential to improve the product quality with a better surface roughness [2]. Basically, a control system is designed to improve the machine performance. For example, Giorgio Bort et al. [3] developed an optimal process controller which is the Evaluation Perception Controller (EPC) for 3-axis CNC milling process. The EPC is able to lessen the production time and costs and raise the quality of product. This paper is aimed to improve the tracking performance of XY Table Ball-screw drive system. This system imitates to the CNC milling machine as the mechanical structure of the machine is same.

Nonlinear Proportional-Integral-Derivative (NPID) controller is an extension from a PID controller. The last two decades, Seraji [4] introduced nonlinear function of sigmoidal, hyperbolic and piecewise-linear of NPID controller for robotic arm application. Consequently, the NPID controller is still widely investigated by many researchers afterward. For example, Agnoletti et al. [5] designed an adaptive nonlinear PI controller for single-phase phase-locked loop algorithm. This controller able to produce a faster response compared to conventional PI controller. Hence, the literature indicated that the NPID controller was widely used for various applications. However, the PID controller which is designed with only one nonlinear component is not sufficient to produce more accuracy of the system. In order to improve the single NPID controller, more than one nonlinear are designed and added before proportional, integral or derivative gains. For example, Isayed and Hawwa [6] designed nonlinear proportional and nonlinear derivative with a hyperbolic function and nonlinear integral with an exponential function. This improvement NPID controller produced a better transient response of hard disk drive servo system. Thus, in this paper, the performance of NPID Double Hyperbolic controller is compared to existing controller, namely NPID controller. In previous work [7], the proposed controller is compared to PID controller.

2. METHODOLOGY

The experimental setup consists of computer, digital/analog converter, amplifier and XY Table Ball-screw drive system further explained in [7].

The NPID Double Hyperbolic controller as shown in Figure 1 is used to compare in term of tracking performance with NPID controller. The nonlinear proportional is designed by decreasing the nonlinear gain when the error is small and vice versa. In contrast, the nonlinear integral is designed by increasing the nonlinear gain when the error is small and vice versa. Meanwhile, the derivative acts as a linear control. The detail explanation is discussed in previous work [7]

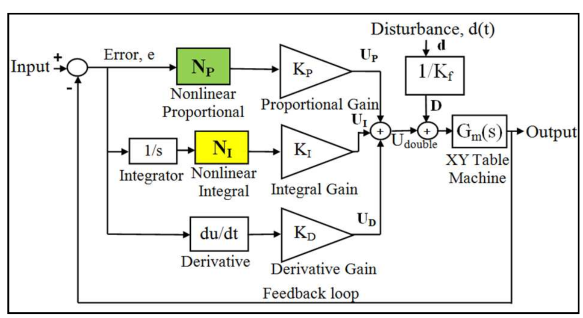

Figure 1: NPID Double Hyperbolic Controller Scheme

3. RESULT AND DISCUSSION

In this section, the NPID Double Hyperbolic and NPID controller were tested experimentally under cutting force at spindle speed of 2500 rpm. The amplitude used was 15 mm. Figure 1 and Figure 2 showed the results at low speed of motor (0.2 Hz) and high speed of motor (0.4 Hz), respectively.

From the results, the NPID Double Hyperbolic controller produced smaller maximum tracking error of 0.0061 mm and 0.0096 mm for 0.2 Hz and 0.4 Hz, respectively. Meanwhile, the NPID controller produced maximum tracking error of 0.0458 mm and 0.0760 mm for 0.2 Hz and 0.4 Hz, respectively. Table 1 and Table 2 lists the maximum tracking error and RMSE respectively. The tracking error is highly reduced due to the adaptability of the nonlinear gains. The nonlinear, N_P and N_I play an important role in reducing the error. The nonlinear gains are changed according to the tracking error. Subsequently, the PID gains are changed automatically, so that a suitable signal control is injected onto the system. The new value of signal control is producing a better tracking performance.

By using the Equation (1), the overall result shows that the NPID Double Hyperbolic controller produces more than 80% of percentage of improvement compared to NPID controller.

$$\begin{matrix} Percentage\ of \\ improvement \end{matrix} = \frac{Controller\ A - Controller\ B}{Controller\ A} \times 100 \quad (1)$$

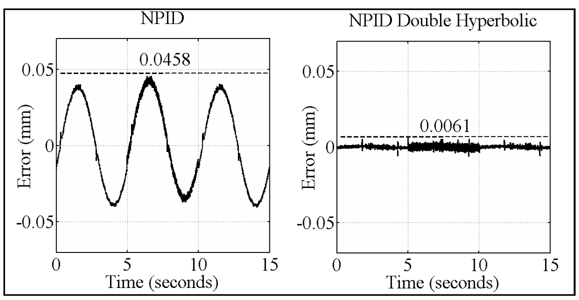

Figure 2: Experimental Result for Speed of 0.2 Hz

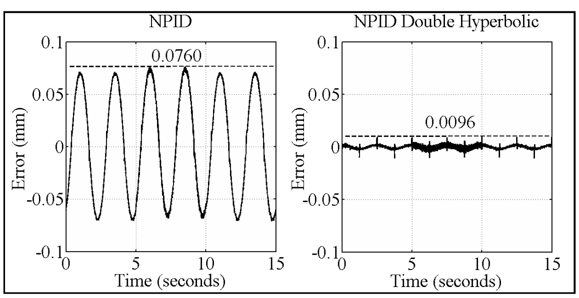

Figure 3: Experimental Result for Speed of 0.4 Hz

Table 1 Maximum Tracking Error

	Maximum Tracking Error (μm)	
	NPID controller	**NPID Double Hyperbolic controller**
0.2 Hz	45.80	6.12
0.4 Hz	76.00	9.66

Table 2 RMSE

	RMSE (μm)	
	NPID controller	**NPID Double Hyperbolic controller**
0.2 Hz	27.70	1.00
0.4 Hz	51.00	1.80

4. CONCLUSIONS

In conclusion, the NPID Double Hyperbolic produced a better tracking performance with smaller maximum tracking error and RMSE value compared to NPID controller for XY Table Ball-screw drive system. The usage of two nonlinear components in the controller is more applicable to use for this system.

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