Design of nonlinear PID controller with conditional integrator for cutting force compensation

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ABSTRACT – Machine tools application requiring a high-precision and self-adjusting mechanism to be implemented in the system in order to withstand a variety of disturbance forces. The disturbance force can come in different form depending on the encountered circumstances. The aim of this paper is to propose a controller namely NPID with conditional integrator to control the positioning of the system. The stability of the controller will be tested by using Nyquist plot and bode diagram. The controller can be used to compensate the disturbance in machine tools application.

1. INTRODUCTION

A lot of controllers have been used in machine tools application. The controllers can used to compensate disturbance force such as mechanical structure, workpiece mass, friction force and cutting force [1]. Some popular controllers include PID, Cascade, Sliding Mode Control (SMC), Gain Scheduling and Fuzzy Logic Controller. These controllers also can be operated by combining other adaptive controller to cater different types of needs in various application. As an example, PID controller that usually faced problems to control the position and to provide good transient response [2], so the nonlinearity issue has already been solved by applying nonlinear function to the PID controller, making it a Nonlinear PID controller (NPID) [3]. Since PID is still relevant in industry today, the controller still can be used with the intact of other control mechanism.

In this paper, NPID with conditional integrator is proposed as a disturbance compensator for the XY table ball screw drive system. In general, integrator is used to remove the steady-state error of system response in a control system. However, it contains 90° phase lag at all frequency which may lead the controller to be unstable. Therefore, conditional integrator was designed to reduce phase lag while maintaining the steady-state error at minimum [4] and to prevent integration wind-up [5–7].

2. METHODOLOGY

The controller is designed by using Simulink software. The plant used is XY table ball screw drive system. The transfer function of the plant needs to be determined to represent the plant for simulation process. The transfer function of the plant was obtained through system identification process which has been done in [8]. There are a few steps for system identification. First, collect the time data to convert into frequency response function (FRF). Then, the FRF will be converted to a mathematical model which is the transfer function and finally the model will be validated. The system identification process was described in detail by [9]. The transfer function that was obtained is as follows:

$$G(s) = \frac{Z(s)}{U(s)} = \frac{78020}{s^2 + 163s + 193.3} e^{-0.0012s} \qquad (1)$$

A few tests can be done using MATLAB to get the Nyquist plot and bode diagram for the controller which prove its stability.

3. CONTROLLER DESIGN

The nonlinear algorithm of a controller is able to provide an action to the system based on error. Then, the integral part of the PID controller will be rearraged to make it conditional, thus reduce phase lag while maintaining the steady-state error at minimum and to prevent integration wind-up. The design of nonlinear PID controller with conditional integrator are proposed as shown in Figure 1.
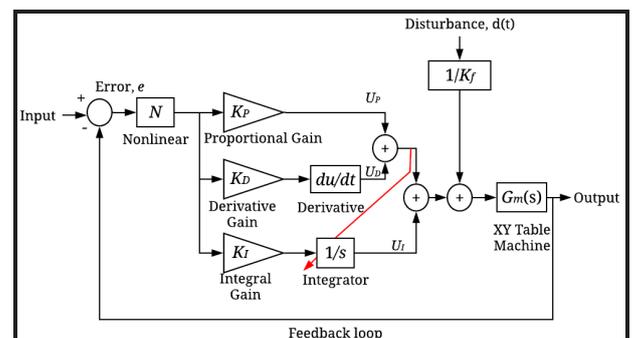

Figure 1 NPID Controller with Conditional Integrator

The stability analysis is satisfied if the gain margin (3

dB – 10 dB), phase margin (30° - 60°) and Nyquist plot at (-1, 0) is not encircled.

As for its original PID controller, the gain obtained for K_P, K_I, K_D are 1.12, 0.006 and 0.007, respectively with gain margin (8.29 dB at 209 Hz), and phase margin (54.4° at 80.8 Hz) as shown in Figure 2. Meanwhile, Figure 3 shows the Nyquist plot at point (-1, 0) is not encircled.
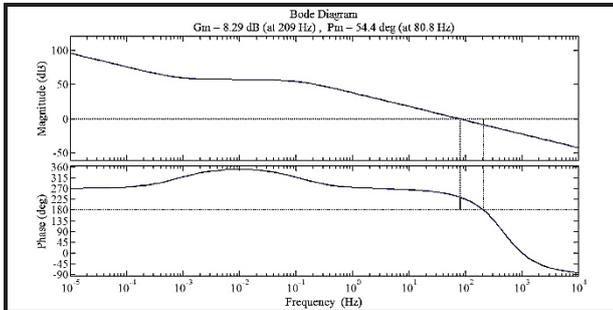

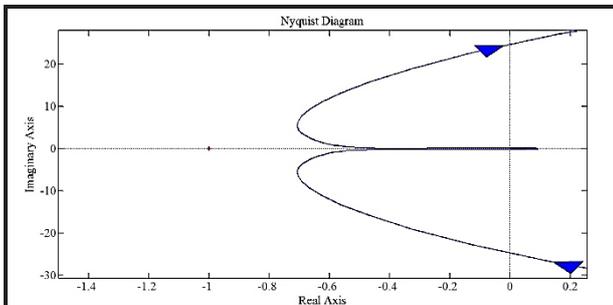Figure 2 Gain Margin and Phase Margin of PID controller

Figure 3 Nyquist plot of PID controller

4. DISCUSSION

Disturbance in a machine such as cutting force can be compensated and reduced by designing a new adaptive control algorithm. The proposed control algorithm is expected to compensate the disturbance force by reducing the error such as maximum tracking error, Fast Fourier Transform (FFT) error and root mean square error (RMSE). The new control algorithm should produce less error than the conventional PID controller and nonlinear PID controller. The result can be demonstrated by simulation, experimentation and tabulation of the data to show the differences between the error of each controller thus proven the new control algorithm.

5. CONCLUSION

The Nyquist plot and bode diagram obtained from the test on the controller should be in a good range of stability. It is recommended that other tests can be performed to further evaluate the controller performance. Then, the controller can be used to compensate the disturbance in XY table ball screw drive system. Thus, the precise positioning can be achieved.

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