Disturbance compensation using a state observer-based controller for precise tracking performances in machine tools application

M. Maharof [1,*], Z. Jamaludin[1], M.Minhat[1]

[1]Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[*]Corresponding e-mail: madihah.maharof@yahoo.com.my

Keywords: Observer, Disturbance force observer controller, Disturbance force

ABSTRACT – In milling cutting process, two most common types of disturbance forces are the resulting cutting forces and friction forces, both acting on the workpieces either directly or indirectly. These disturbance forces if left unattended could reduce the accuracy and precision of the process. This paper focuses on cutting force compensation using disturbance force observer (DFO) for precise tracking performances in XY milling table ball screw driven system. This paper presents numerical results of the two designed control configurations performed on an XY milling table using different input harmonics cutting force disturbance signal. Cutting force were using in the form of sinusoidal-based signal. Two control configurations were considered, namely; cascade P/PI and cascade P/PI with DFO. The root means square error (RMSE) results showed that cascade P/PI controller with DFO outperformed the stand-alone cascade P/PI controller. The percentage error reduction for single harmonic, double harmonics and triple harmonics was recorded about 93.83%, 94.16% and 92.70% respectively compared to the stand-alone cascade P/PI controller.

1. INTRODUCTION

Cutting force is natural behaviour of material removal process and arises during the milling cutting process. The high frequency dynamics of cutting force must be damped to enhance the tracking performance and accuracy of machine tool. In literature, various control techniques have been developed, validated and evaluated to address suppression of disturbance force in milling process. An advances controller and algorithms were applied for disturbance forces suppression [1]. The estimator was designed in [2] to compensate cutting force while [3] had suggested a repetitive controller to achieve high precision positioning for a ball screw driven stage. The objectives of this paper is to compensate the high frequency dynamic and negative effect of cutting forces in milling cutting process using disturbance force observer (DFO) controller.

2. TEST SETUP

Figure 1 demonstrates the schematic diagram of the test setup. The setup comprises of four main components, namely, a personal computer with MATLAB/Simulink and ControlDesk software, dSPACE DS1104 Digital Signal Processing (DSP) board, an amplifier and a XY milling table ball screw driven unit. The XY milling table is connected to a servo amplifier linked to a DS1104 DSP board. The personal computer that is connected to the DSP board applies the controller design and managed the data communication and collection. From the single-input single-output (SISO) signal, FRF of each drive system was estimated using H1 estimator. A model was fitted on the measured FRF for the system transfer function using *Fdident* toolbox in MATLAB Simulink software. Equation (1) shows a second order transfer function for a single axis of the ball-screw driven system;

$$G(s) = \frac{Y(s)}{U(s)} = \frac{A}{s^2 + Bs + C} e^{-sT_d} \quad (1)$$

Where U is the input voltage in volt (v), T_d is the time delay in second (s) and Y is the table position in millimetre (mm). The system parameters identified are; A=78020mm/Vs^2, B=163s^{-1}, C=193.3s^{-2} and T_d=0.0012s.

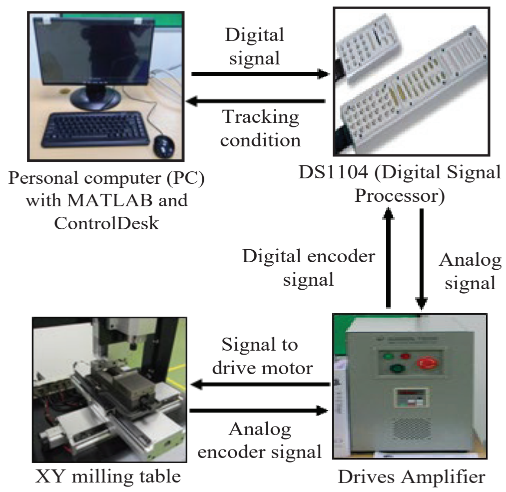

Figure 1 Schematic diagram of test setup for system identification

3. CUTTING FORCE IDENTIFICATION

A straight-line milling cutting process was performed onto an aluminium block. Cuts were performed at spindle speed of 1500rpm. The spindle speed rotation were selected based on the general recommendation made by [4]. The cutting force was extracted using Kistler Dynamometer. Figure 2 shows the FFT analysis for frequency domain perspectives.

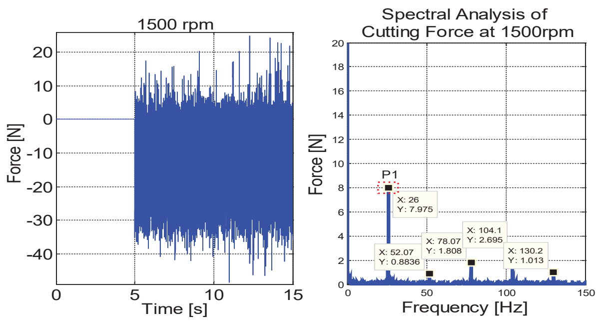

Figure 2 FFT of cutting forces at 1500 rpm spindle speed rotation

4. POSITION CONTROLLER AND OBSERVER

Figure 3 shows control scheme of a cascade controller. The controller gains of cascade P/PI were designed using frequency domain method based on gain margin and phase margin of the open loop transfer functions [5]. Table 1 lists the parameters of the cascade P/PI controller.

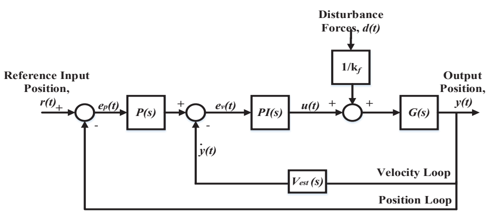

Figure 3 Control scheme of the cascade P/PI controller

Table 1 Parameters of the cascade P/PI controller

Parameters	Values
K_p	0.00661 Vs/mm
K_i	0.12075 Vs^2/mm
K_v	225s^{-1}

Figure 4 shows control scheme of a cascade P/PI controller and a disturbance observer.

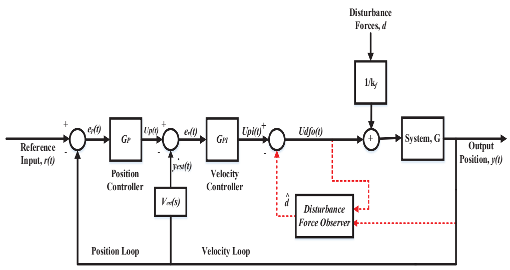

Figure 4 Control scheme of a cascade P/PI controller embedded with a disturbance observer

5. RESULT AND DISCUSSIONS

The performances of cascade P/PI positioning controller with DFO were numerical validated for two different cases, namely; (i) tracking error without disturbance observer and (ii) tracking error with disturbance observer. Three types of input disturbance force were considered in the form of sinusoidal-based, namely; (i) single harmonic (0.2Hz), (ii) double harmonic (0.2Hz and 0.5Hz) and (iii) triple harmonics (0.2Hz, 0.5Hz and 0.8Hz). Table 2 summarizes the RMSE values for cases with and without the disturbance observer. The results showed improvement in RMSE tracking error performance of the control system with the presence of the DFO. In numerical validations, errors reduction about 93.83%, 94.16% and 92.70% is observed compared with cascade P/PI controller for a single, double and triple harmonics frequency respectively.

Table 2 Summary of RMSE values of the system with and without disturbance observer

Harmonic frequency contents	Root mean square error (RMSE) (µm)		Error reduction (%)
	Cascade P/PI	Cascade P/PI with DFO	
1 harmonic	16.20	1.00	93.83
2 harmonic	29.10	1.70	94.16
3 harmonic	38.40	2.80	92.70

6. CONCLUSIONS

As conclusion, cascade P/PI controller with DFO was successfully numerical validated. The proposed control structure was superior in disturbance rejection when compared to conventional position controller. As future work, the DFO can be apply in actual milling cutting process as a forward strategy of this techniques to improve and enhance the quality of the final product.

ACKNOWLEDGEMENT

The authors would like to thank Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for the facilities provided.

REFERENCES

[1] Z. Jamaludin, J. Jamaludin, T. H. Chiew, L. Abdullah, N. A. Rafan, & M. Maharof, Sustainable cutting process for milling operation using disturbance observer, Procedia CIRP, vol. 40 pp. 486 – 491, 2016.

[2] S. Huang, K. K. Tan, G. S. Hong and Y. S. Wong, Cutting force control of milling machine, *Mechatonics*, vol. 17, no. 10, pp. 533 – 541, 2007.

[3] H. Fujimoto, and T. Takemura, High-precision control of ball-screw-driven stage based on repetitive control using n-times learning filter, IEEE Trans. on Ind. Elec., vol. 61, no. 7, pp. 3694 - 3703, 2014.

[4] S., Kalpakjian, and S. R., Schmid, 2013. Manufacturing Engineering and Technology, 7th ed., New Jersey: Prentice-Hall.

[5] S., Skogestad, and I., Postlethwaite, 2010. Multivariable Feedback Control Analysis and Design, 2nd ed., Chichester : J Wiley & Sons, Inc.