

DSP-BASED PRECISION MOTION CONTROLLER FOR IRON-CORE LINEAR MOTORS

Seung-Chul Kim¹, Kyung-Don Kim² and Sung-Chong Chung^{1*}

¹Hybrid System Design & Control LABORatory

Department of Mechanical Engineering

Hanyang University, SungdongGu, Seoul 133-791, KOREA

²Small Business Corporation, Gyeonggi Regional Headquarter, Suwon, KOREA

ABSTRACT

Precision motion controller using a digital signal process (DSP) is studied to apply for iron-core permanent magnet linear motor (PMLM) stages. Friction force, velocity and force ripples, and positioning errors are measured and analyzed on the linear servo according to various operating conditions. To improve transient characteristics as well as to minimize tracking error and disturbance, the perfectly matched feedback controller, feedforward controller, feedforward ripple compensator, and notch filter are combined together to make a precision motion controller for a stage equipped with iron-core linear motors. The controller is installed on the DSP, TMS320C. Experimental results verify the effectiveness of the developed system.

INTRODUCTION

Precision motion control is essentially required in the FPD (flat panel display), machine tool, robot, semiconductor, medical and packaging industries. Many processes requiring sub-micron resolution and control are applied to the measurement, manufacture and control of large, macro and/or micro components of display, optical, MEMS and/or semiconductor devices. Lithography, MEMS and FPD fabrications are three representative examples of nanofabrication processes. Precision machining such as cutting, grinding and super finishing are required to provide nano-precision surfaces such as ultra-precision bearings, spindles, memory disks, mirrors and lens for optical systems, and so on. Surface mounting, IC packaging, assembly of micro-machines, inspection of FPDs, SEM, AFM require nano-level motion control as well. In order to achieve such precision motion control, precision level of sensing and control technology is required [1, 2].

In this paper, a DSP-based precision motion controller is developed to apply for iron-core permanent magnet linear motor stages. To improve transient characteristics as well as to

minimize tracking error and disturbance, the perfectly matched feedback controller, feedforward controller, feedforward ripple compensator, and notch filter are designed and installed on the DSP, TMS320C. The force ripple compensation is performed through the adaptive feedforward compensation. The feedforward controller is included to reject servo lag. The perfectly matched feedback controller is applied to improve tracking performance and robustness of the control system. The notch filter reduces the power noise and rejects unwanted vibration due to natural frequency of the servo. In order to verify the performance of the developed system, Velocity and force ripples, frictions and positioning errors are measured on the linear servo according to various operating conditions. Experimental results verify the effectiveness of the developed system.

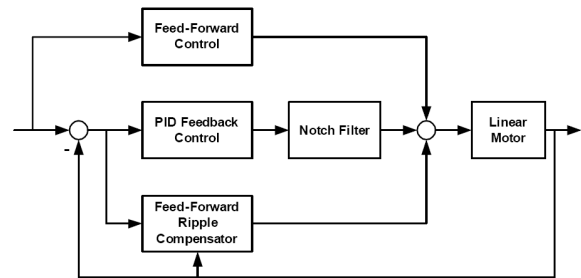


FIGURE 1 Overall structure of control system.

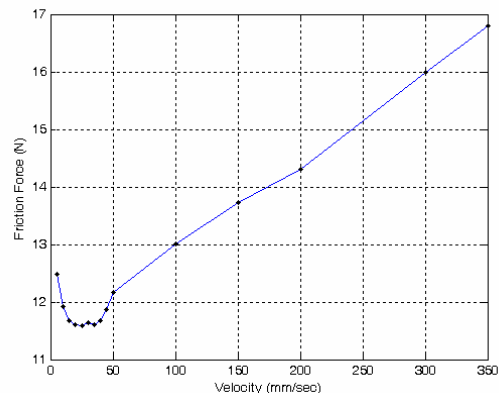


FIGURE 2 Friction force vs. velocity.

CONTROLLER DESIGN

Fig. 1 shows the overall structure of the control system. DSP controller constructed with the feedforward controller and feedforward ripple compensator are to be based on the mathematical models of PMLMs.[2,3]

Dynamics of PMLMs

Considering dominant effects of the mechanical and electrical dynamics of a PMLM, following models are given by [3]

$$F_m = K_m I_m = M\ddot{x} + B\dot{x} + F_f + F_{ripple} \quad (1)$$

$$K_e I_m + L_m \frac{dI_m}{dt} + R_m I_m = v$$

where F_M is the motor force, K_M is the torque constant, I_M is the motor current, F_{ripple} is the force ripple, and F_f is the friction force.

From precision motion control viewpoints, force ripples are highly undesirable but yet they are predominantly present in PMLMs.

In general, the most significant friction components distorting the identification results are the stiction and the Coulomb friction [4].

$$F_{friction} = \text{sgn}(\dot{x}) \cdot F_c + F_s N_s(\dot{x}) \quad (2)$$

where F_c is the Coulomb friction coefficient and N_s is a striction nonlinearity.

Friction in the linear motor is computed from average disturbance by unloading tests at 10 ~ 350 mm/s axis velocity. Fig. 2 shows observed friction force versus axis velocity to estimate the friction model.

Feedforward ripple compensator

Force ripples are described as sinusoidal functions according to position. However, as shown in Fig. 3, it is complex to make a mathematical model. The ripple consists of several sinusoidal functions with unknown frequencies and amplitudes. Fig. 4 shows velocity and force ripples according to the velocity command in the open loop system. The force ripple is described with a periodic sinusoidal signal depending upon the location, and with the amplitude depending upon the load velocity as follows:

$$F_{ripple}(x, v) = \sum_{k=1}^N A(x, v) \sin(\omega x + \phi) \quad (3)$$

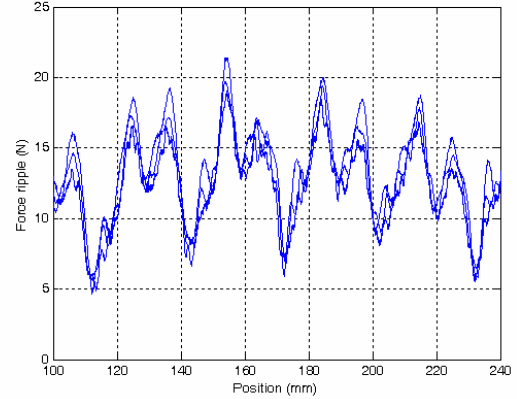


FIGURE 3 Force ripple signal via position

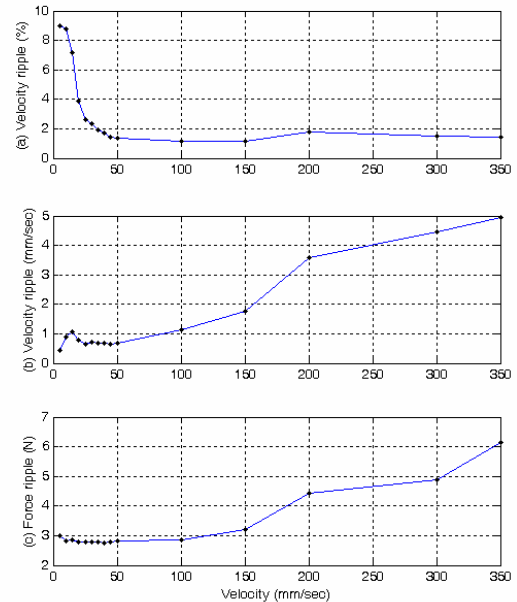


FIGURE 4 Force and velocity ripple for the open-loop system.

Feedforward controllers

Velocity, acceleration and friction feedforward controllers are designed to reduce tracking errors due to servo lag, friction and external disturbance as follows:

$$F_{FF} = K_{af} \ddot{x} + K_{vf} \dot{x} + F_{friction}(x) \quad (4)$$

Feedforward refers to the addition of open-loop information to the profile generator. Through injecting nominal control input to the servo system, it is possible to improve the bandwidth

of the feedback control loop and the tracking performance of the servo.

PID feedback controller

The servo control loop is essentially based on a three-term PID controller. And the perfectly matched feedback controller is applied to improve tracking performance and robustness of the control system. In this paper, the PID feedback controller is designed with the integrated design methodology to obtain optimal and robust performance of the nominal system [4-6].

Notch filter

Notch filters reduce the response of the power noise and resonance frequency of the servo. And, it is applied to reject instability at stop command. Using fast Fourier transform (FFT), the instability frequency is identified and adaptively feedback to manipulate the notch frequency.

Fig. 5 shows the frequency spectrum of the control system without the notch filter. From the spectrum, undesirable frequencies are 100Hz and 120Hz, etc. A narrow-band notch filter is applied to compensate for the undesirable vibration.

EXPERIMENTAL RESULTS

Fig. 6 shows an experimental setup constructed with linear motors (Anorad, LCK-S) and servo drives (Glentek, SMA 9815). In order to install the developed controller and compensators, TMS320C6713 DSP board is developed. Experimental results are shown in Figs. 7~11. Fig. 7 and 8 show control performances of velocity ripple in the steady-state. Velocity ripples with the ripple compensator are measured less than 0.4% at both 100 and 300 mm/sec. Tracking performances with respect to sinusoidal inputs are shown in Figs 9~11. Figs. 9 and 10 show position and velocity tracking performances according to the proposed PID control system. Fig. 11 shows control performances obtained from the proposed controller composed of the PID, feedforward and force ripple controllers. Comparing Figs. 9~11, it is confirmed that the proposed control system has excellent control performance.

CONCLUSIONS

Precision motion controller using the DSP is proposed to apply for iron-core permanent

magnet linear motor (PMLM) stages. Force ripple is compensated for through the developed Force ripple compensator. Perfectly matched feedback controller is developed through the previously developed integrated design methodology. The narrowband type notch filter is applied to reject unwanted vibration. Effectiveness of the proposed system is confirmed through experiments.

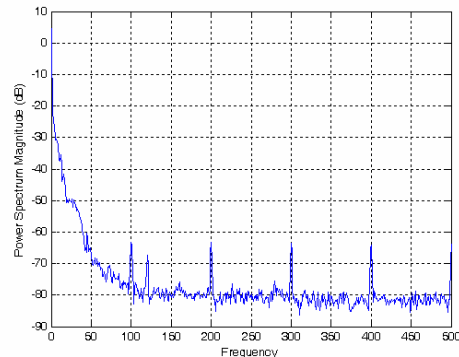


FIGURE 5 Power spectral density of the control system without the notch filter.



FIGURE 6 Configuration of the linear motor

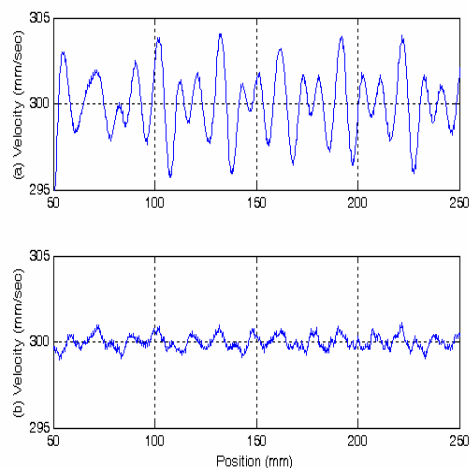


FIGURE 7 Performance of the force ripple compensator at 300mm/sec velocity: (a) without compensator; (b) with compensator.

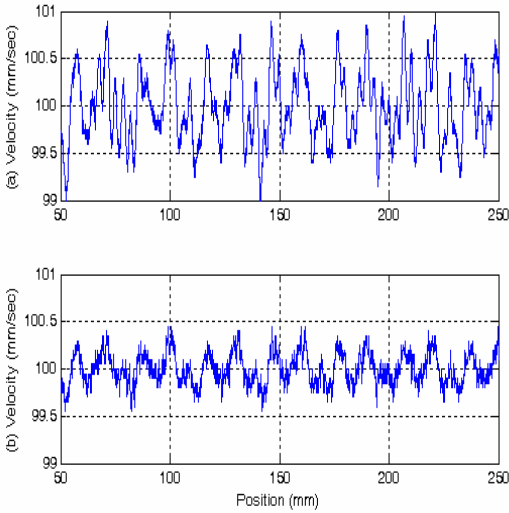


FIGURE 8 Performance of the force ripple compensator at 100mm/sec velocity: (a) without compensator; (b) with compensator.

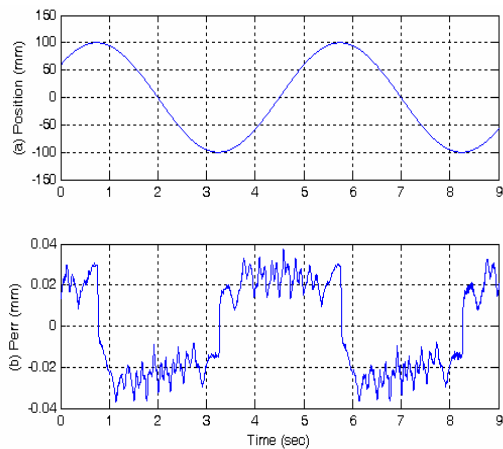


FIGURE 9 Position tracking performance of the PID control system

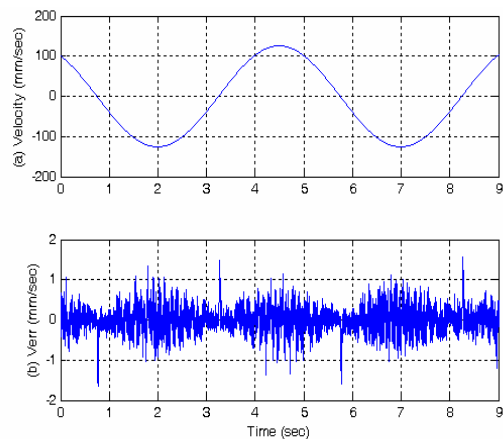


FIGURE 10 Velocity tracking performance of the PID control system.

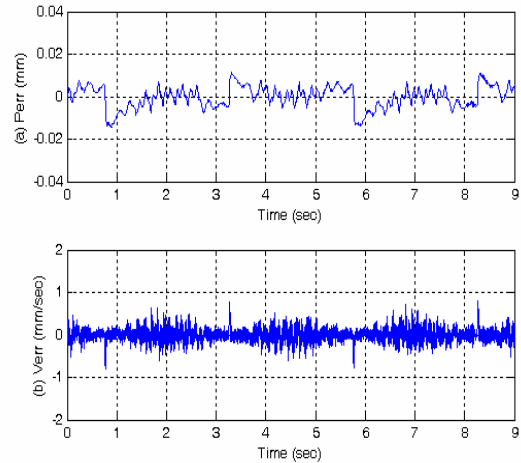


FIGURE 11 Tracking performance of the developed PID+FFC+FRC control system.

REFERENCES

- [1] Bae, H. K. and Chung, S. C. Optimal Tuning of Biaxial Servomechanisms using a Cross-Coupled Controller. Transactions of the North American Manufacturing Research Institution of SME, 2006; 34: 603-610.
- [2] Tan K.K., Tang K.Z., Dou H.F. and Huang S.N. Development of an Integrated and Open-Architecture Precision Motion Control System. Control Engineering Practice, 2002; 10: 757-772.
- [3] S. Zhao, and Tan, K.K. Adaptive Feedforward Compensation of Force Ripples in Linear Motors. Control Engineering Practice, 2005; 13: 1081-1092.
- [4] Kim, M. S. and Chung, S. C. A Systematic Approach to Design High-Performance Feed Drive Systems. International Journal of Machine Tools and Manufacture, 2005; 45: 1421-1435.
- [5] Kim, M. S., and Chung, S. C. Integrated Design of Feed Drive Systems using Discrete 2-Degree of Freedom Controllers (I). Transactions of the KSME(A). 2004; 7: 1029-1037.
- [6] Kim, M. S., and Chung, S. C. Integrated Design of Feed Drive Systems using Discrete 2-Degree of Freedom Controllers (II). Transactions of the KSME(A). 2004; 7: 1038-1046.