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Vibration control of Feed Drive Systems by Nonlinear Relative Velocity Feedback

Kangkyu LEE, Atsushi MATSUBARA*, Soichi IBARAKI, Yoshiaki KAKINO

Department of Precision Engineering, Graduate School of Engineering, Kyoto University

***Yoshida-honmachi, Sakyo-ku, Kyoto 606-8317 Japan**

Phone: +81-75-753-5863, Fax: +81-75-771-7286

E-mail: matsubara@prec.kyoto-u.ac.jp

1. Introduction

High speed feed drives are generally designed by rotary servomotors with high lead ball screws. In such feed drives, a torque is transmitted to a table via a coupling and a ball screw. Therefore, the dynamics of feed drives includes internal vibration mode. Guideways with linear roller and ball bearings are usually adopted, which don't have sufficient damping to suppress the vibration.

It was reported by Imagi et al. that the feedback of relative velocity and position between the servomotor and the table to the servomotor torque can improve vibration characteristics in electric discharge machine [1].

Matsubara et al. reported that dual actuation with the main ball screw drive with small-size linear motors can enhance the servo performance of the feed drive by velocity feedback [2]. But it generates the small damping force when the relative velocity and feedback gain are small because the damping force is linearly proportional to the relative velocity.

In this paper, two methods are used to modify relative velocity feedback (RVFB) based on nonlinear control to solve above problem. The damping control performance of nonlinear RVFB is examined and compared with RVFB by experiments.

2. Theory of damping control

2.1 Dynamic model of feed drive

Fig. 1 shows the dynamic model of feed drive. In Fig.1, J_r :Inertia of rotational body [kg·m^2], θ_r :angular position of the servomotor [rad], D :viscous damping coefficient of rotational motion [Nms/rad], K_T :stiffness of feed direction [N/m], M_t :table mass [kg], x_t :table position [m], F_t :feed force to the table [N], C_t :viscous damping coefficient of linear motion [Ns/m], R :transformation coefficient from θ_r to x_t [m/rad]

The equation of motion can be described as follows:

$$M\ddot{x} + C\dot{x} + Kx = f \qquad (1)$$

where,

$$M = \begin{bmatrix} M_r & 0 \\ 0 & M_t \end{bmatrix}, C = \begin{bmatrix} C_r & 0 \\ 0 & C_t \end{bmatrix}, K = \begin{bmatrix} K_T & -K_T \\ -K_T & K_T \end{bmatrix}$$

$$x = \begin{bmatrix} x_r & x_t \end{bmatrix}^T, f = \begin{bmatrix} F_r & F_t \end{bmatrix}^T,$$

$$M_r = J_r / R_2, C_r = D/R^2, x_r = R\theta_r, F_r = T/R$$

2.2 Control rules of RVFB

A linear type in RVFB can be written as follows:

$$F_t = -C_z \times (\dot{x}_t - \dot{x}_r) \qquad (2)$$

where, C_z :damping gain [Ns/m]

An arctangent type is decided by the maximum value of the damping force. The equation can be expressed as follows:

$$F_t = -C_z \times \alpha \times \arctan\left(\beta \times (\dot{x}_t - \dot{x}_r)\right) \qquad (3)$$

where, α, β :constants.

A bang-bang type generates the control output by the sign of the relative velocity and the force scale. The equation can be described as follows:

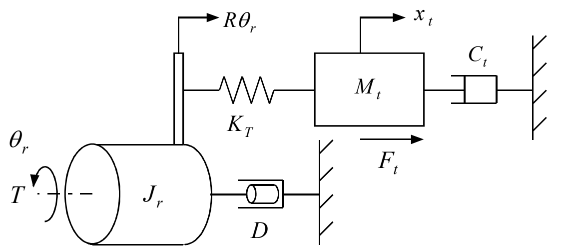

Fig. 1 Dynamic model of feed drive

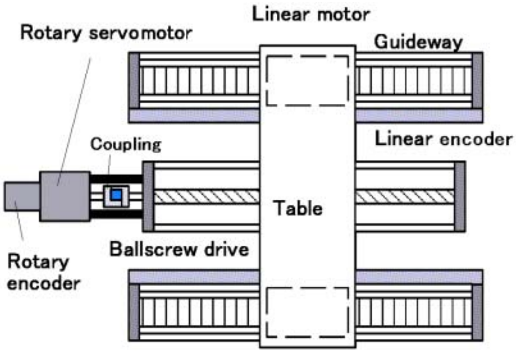

Fig. 2 Schematic view of the test stand

$$F_t = \begin{cases} -F_z & if\ (\dot{x}_t - \dot{x}_r) > 0 \\ 0 & if\ (\dot{x}_t - \dot{x}_r) = 0 \\ F_z & if\ (\dot{x}_t - \dot{x}_r) < 0 \end{cases} \quad (4)$$

where, F_z :force scale in the bang-bang type

3. Experiment

Fig.2 shows a schematic view of the test stand. The test stand mainly employs a ball screw drive as a main feed drive and two small-size linear motors are attached in parallel with the main feed drive to supply the damping force directly to the table.

Fig. 3 shows the frequency responses from the voltage command of servomotor torque to servomotor's velocity. At the anti-resonance frequency, the gain valley of the bang-bang type is recovered more than those of the linear and arctangent types. Similarly, at the resonance frequency, the gain peak of the bang-bang type can be lowered more than those of the linear and arctangent types.

The position and velocity feedback loops are closed and time responses are measured. Fig. 4 shows the table position of each type. The

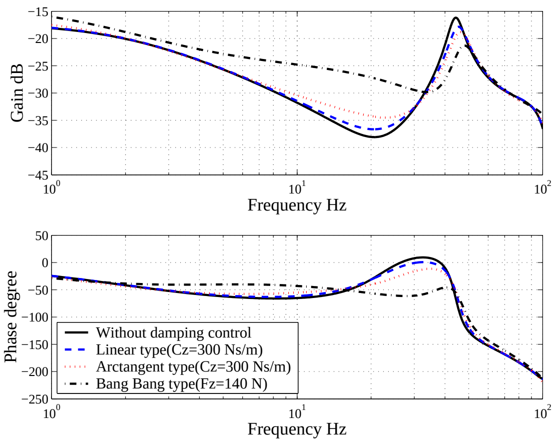

Fig. 3 Measured frequency responses

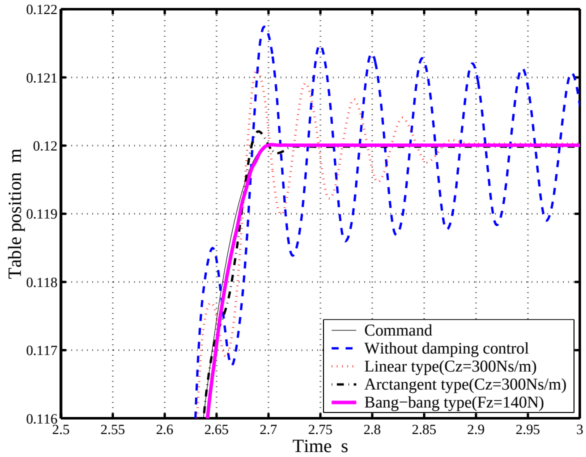

Fig. 4 Measured time responses of the table

linear type shows the vibration at positioning since the sufficient damping force is not provided to the table. The arctangent type shows that the table position reaches the steady-state after only one vibration. The bang-bang type shows the smooth response with no vibration due to the sufficient damping force.

4. Conclusion

Nonlinear RVFB is proposed to solve the problem that the damping force is small in the low relative velocity. Nonlinear RVFB was validated through the experiment of frequency and time responses. The bang-bang type had the best performance to suppress the vibration than the arctangent type and the linear type.

Reference

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[2] A. Matsubara, S. Ibaraki, Y. Kakino, M. Endo, M. Umemoto: Vibration Control of Feed Drive in NC Machine Tools by Dual Actuation (1st report)-Damping Control of 2 Mass System by Relative Velocity Feedback-, Journal of Japan Society for Precision Engineering, 69(3), pp. 442-426 (2003) [in Japanese].