Paper:

Dynamic Analysis of One-Link Robot Arm Driven by Stepping Motor Using Microstep Drive and Harmonic Reduction Gear

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In this paper, first, taking into consideration stepping motor torque and harmonic reduction gear flexibility, the equations of motion of a one-link robot arm driven by a harmonic reduction gear and a hybrid stepping motor using a microstep drive are derived. The stepping motor is excited by two-phase excitation. Then, the numerical simulations of the one-link robot arm's dynamic response for four-division microstep and full-step drives have been carried out, and it is confirmed theoretically that the amplitudes of the vibrating torque of the stepping motor for the microstep drive are considerably smaller than that for the full-step drive, and the transient vibrations of the stepping motor in acceleration and deceleration periods can be reduced using microstep drive. Furthermore, the experiments of the trajectory tracking control of the one-link robot arm have been carried out, and the effects of the microstep drive on the transient vibration reduction of the stepping motor are demonstrated.

Keywords: dynamic analysis, robot arm, stepping motor, harmonic reduction gear, microstep drive

1. Introduction

Stepping motors are widely used as digital actuators in automation equipments such as office automation instruments and productive facilities, and many studies on the dynamic characteristics of stepping motors have been carried out. For example, the studies concerning the development of the mathematical model of magnetic stepping motors [1], the stepping motor failure model [2], the analysis of the vibration phenomenon of stepping motors [3], and the dynamic characteristics of stepping motor system in consideration of elasticity of rotating shaft [4] have been reported. Then, the microstep drive of stepping motors were developed for stepping motors to improve the position resolution and solve the problems of overshoot and resonance, [5, 6]. On the other hand, desk robots and semiconductor wafer transfer robots using stepping motors are in practical use [7, 8]. Furthermore, the studies about the dynamic characteristics of two-link robot arm driven by stepping motors and the trajectory tracking control of three-link semiconductor wafer transfer robot arm driven by stepping motors have been reported [9, 10]. The theoretical study concerning the effects of the microstep technique on the vibration reduction of stepping motors seems to be important from the viewpoint of engineering system analysis. However, the studies like this seem to have been little investigated.

In this study, first, the equations of motion of a one-link robot arm driven by a stepping motor using a four-division microstep drive and a harmonic reduction gear are derived. Then, the numerical simulations of the trajectory tracking control of the joint angle have been carried out, and the effects of the microstep drive on the vibration reduction of the stepping motor are investigated. Furthermore, the experiments have been carried out, and the dynamic characteristics of the system are investigated experimentally.

2. Equations of Motion of One-Link Robot Arm Driven by Stepping Motor

Figure 1 shows the photograph and the production drawing of a one-link robot arm driven by a stepping motor and a harmonic reduction gear. The torque τ_s of the stepping motor driven by two-phase excitation method and the constant-current-type driver can be expressed as follows [11]:

$$\tau_s = \tau_{sA} + \tau_{sB} \quad \quad (1)$$

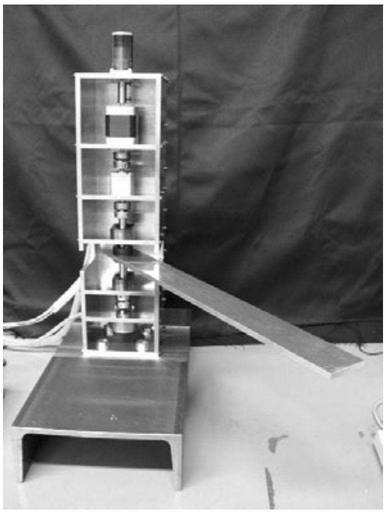
where

$$\tau_{sA} = -i_A K \sin\left(Z_R\phi - \frac{\pi}{4}\right) \quad \quad (2)$$

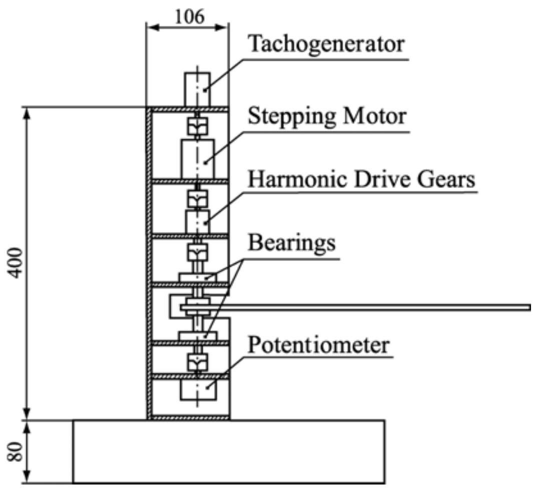
$$\tau_{sB} = -i_B K \sin\left(Z_R\phi - \frac{3\pi}{4}\right) \quad \quad (3)$$

$$Z_R = \frac{\pi}{2\phi_s} \quad \quad (4)$$

and τ_{sA} ,τ_{sB} are the torque components owing to the A-phase and B-phase windings, i_A, i_B are the exciting currents, Z_R is the number of the rotor teeth, ϕ is the rota-

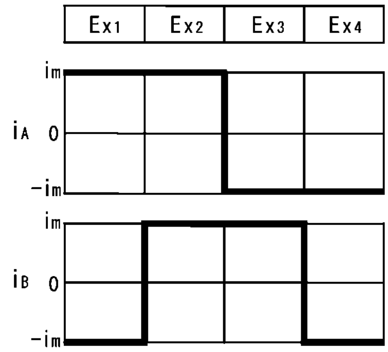


(a) Photograph

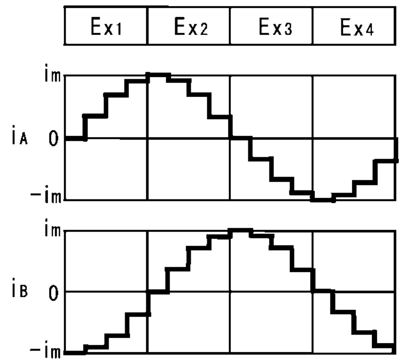


(b) Production drawing

Fig. 1. One-link robot arm driven with stepping motor and harmonic reduction gear.



(a) Full-step



(b) Microstep

Fig. 2. Two-phase excitation pattern.

tional angle, ϕ_s is the step angle of the stepping motor, and K is a constant.

Figure 2 shows the exciting currents of the A-phase and B-phase windings in two-phase excitation pattern for the full-step drive and the microstep drive. The exciting currents in case of the full-step drive are expressed as follows:

$$E_{x1}: \; i_A = i_m, \; i_B = -i_m \quad \ldots \ldots \ldots \quad (5)$$

$$E_{x2}: \; i_A = i_m, \; i_B = i_m \quad \ldots \ldots \ldots \quad (6)$$

$$E_{x3}: \; i_A = -i_m, \; i_B = i_m \quad \ldots \ldots \ldots \quad (7)$$

$$E_{x4}: \; i_A = -i_m, \; i_B = -i_m \quad \ldots \ldots \ldots \quad (8)$$

where

$$i_m = \frac{\tau_H}{K\sqrt{2}} \quad \ldots \ldots \ldots \quad (9)$$

and τ_H denotes the holding torque of the stepping motor.

The exciting currents (E_{x1}) of the first interval for the full-step drive are changed to the following four exciting currents for the four-division microstep drive.

$$E_{x1-1}: \; i_A = 0, \; i_B = -i_m \quad \ldots \ldots \ldots \quad (10)$$

$$E_{x1-2}: \; i_A = i_1, \; i_B = -i_3 \quad \ldots \ldots \ldots \quad (11)$$

$$E_{x1-3}: \; i_A = i_2, \; i_B = -i_2 \quad \ldots \ldots \ldots \quad (12)$$

$$E_{x1-4}: \; i_A = i_3, \; i_B = -i_1 \quad \ldots \ldots \ldots \quad (13)$$

where

$$i_1 = i_m \sin 22.5^\circ, \; i_2 = i_m \sin 45^\circ, \; i_3 = i_m \sin 67.5^\circ. \quad (14)$$

In the same way, the other exciting currents (E_{x2}, E_{x3}, E_{x4}) for the full-step drive can be changed to the exciting currents for the four-division microstep drive.

Figure 3 shows the nonlinear characteristics of the transmission torque τ of the harmonic reduction gear. Using the notations in **Fig. 3**, the transmission torque τ is expressed as

$$-\psi_A \leq \psi \leq \psi_A: \; \tau = k_A \psi \quad \ldots \ldots \ldots \quad (15)$$

$$\psi_A \leq \psi \leq \psi_B: \; \tau = \tau_A + k_B(\psi - \psi_A) \quad \ldots \quad (16)$$

$$(-\psi_B) \leq \psi \leq (-\psi_A): \; \tau = -\tau_A + k_B(\psi + \psi_A) \quad (17)$$

$$\psi \geq \psi_B: \; \tau = \tau_B + k_C(\psi - \psi_B) \quad \ldots \ldots \quad (18)$$

$$\psi \leq (-\psi_B): \; \tau = -\tau_B + k_C(\psi + \psi_B) \quad \ldots \quad (19)$$

where ψ, ψ_A, ψ_B are the torsional angles, τ_A, τ_B are the