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Dynamic characteristic analysis of non-resonance type ultrasonic actuator by electronic circuit simulator

非共振型超音波アクチュエータの電子回路シミュレータによる動特性解析

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1. Introduction

In general, the electromechanical equivalent circuit of an ultrasonic actuator is useful for an intuitive understanding or design[1]. However, the equivalent circuit had not been simulated directly on a commercial computor software such as an electronic circuit simulator (ECS), because the nonlinear elements which expresses a friction or contact-separation were hardly expressed on the equivalent circuit. Hence it is necessary to write a computer program separately from the equivalent circuit for analysis of the ultrasonic actuator. If the nonlinear element had been defined on an ECS, the dynamics of ultrasonic actuator might be analyzed directly and easily on the ECS. Such a attemption was studied, however, a practical equivalent circuite was not obtained [2]. In this paper, the equivalent circuit model of a non-resonance type ultrasonic actuator which is created from the equation of motion and can simulated on a commercial ECS is proposed, and some simulated results by a commercial ECS are reported.

2. Dynamic model of ultrasonic actuator

Figure 1 shows the basic construction of an ultrasonic actuator which is composed of piezoelectric actuators as a stator and a rotor. A preload is applied by a spring between the piezoelectric actuator and rotor. The rotor rotates due to a friction when the piezoelectric actuator is in contact with the rotor. The top of the piezoelectric actuator has a non-linear motion by contact and separation with the rotor. Dynamic model of normal and tangential component of the ultrasonic actuator in contact surface are shown in **Figs. 2** and **3**, respectively.

In both figures, K is the spring constant [N/m], D denotes damping coefficient [N·s/m], and M is mass [kg]. The mass of the piezoelectric actuator which is divided equally can be placed at the both ends in dynamic model under the condition that the piezoelectric actuator is operated at lower frequency than its resonance frequency [3]. When the piezoelectric actuator is in contact with the transfer object, the normal force is applied at the contact surface. Meanwhile the friction force occurs in proportion to the normal force. In the dynamic model, it is assumed that the dynamic friction coefficient is equal to the static one for the simplification of an equivalent circuit.

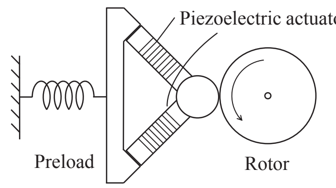

Fig. 1 Basic construction of ultrasonic actuator.

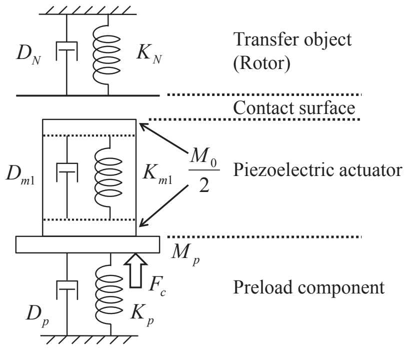

Fig. 2 Dynamic model of normal component of ultrasonic actuator.

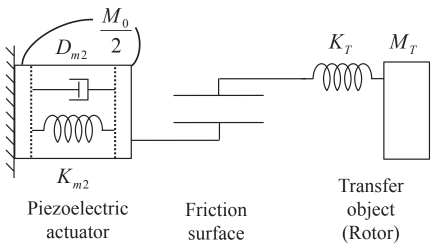

Fig. 3 Dynamic model of tangential component of ultrasonic actuator.

3. Equivalent circuit

The developed equivalent circuit of non-resonance type ultrasonic actuator is shown in **Fig. 4**. The equivalent circuit is drawn by electric circuit element and electronic one on the ECS. The voltage and electric current correspond to the force and velocity, respectively. In the normal component, the switch and diode are contact factors. Those factors enable the analysis of the non-linear normal contact force. In the tangential component, the voltage controlled voltage source (VCVS) and diode are friction factors. The non-linear tangential friction force can be simulated by those factors.

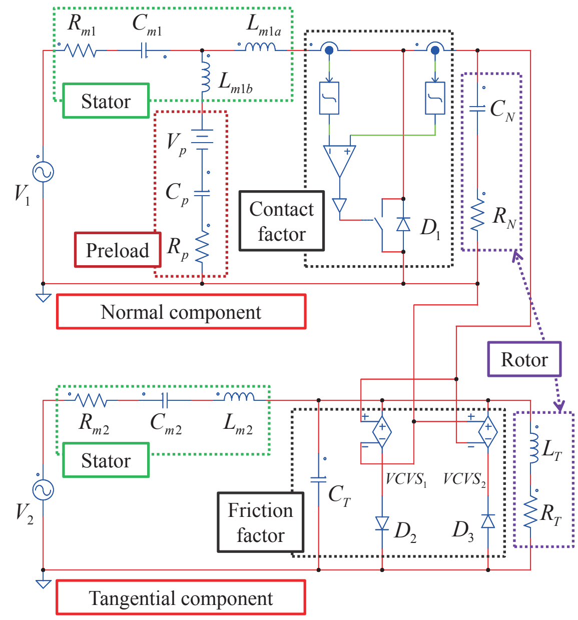

Fig. 4 Mechanical analogy equivalent circuit of ultrasonic actuator.

Table I Parameters of equivalent circuit and dynamic model.

Element	Dynamic model	Equivalent circuit
Force	f_{m1}, f_{m2}, F_c	V_1, V_2, V_p
Damping coefficient	D_{m1}, D_{m2}, D_p	R_{m1}, R_{m2}, R_p
	D_N, D_{loss}	R_N, R_T
Compliance	$1/K_{m1}$,$1/K_{m2}$	C_{m1}, C_{m2}
	$1/K_p$	C_p
	$1/K_N$, $1/K_T$	C_N, C_T
Mass	$M_0/2$	L_{m1a}
	$M_0/2+M_p$	L_{m1b}
	$M_0/2$, M_T	L_{m2}, L_T

The equation of circuit can correspond to the equation of motion. The correspondence with the parameter of the equivalent circuit and that of the dynamic model is shown in **Table I**. The resistance is the damping coefficient; the capacitance, the compliance; the reactance, the mass; f_{m1} and f_{m2}, forces of the piezoelectric actuator in normal direction and tangential one, respectively; and D_{loss}, the damping coefficient of a transfer object.

4. Simulation results

The ultrasonic actuator was simulated by the developed equivalent circuit and numerical analysis program for dynamic model. Runge-Kutta method was employed to solve the dynamic model of motion. The equivalent circuit simulation was carried out on the commercial ECS (PSIM, Myway Plus Co.) which is good at the analysis of the power electronics circuit. Sinusoidal forces were applied to stator sections in normal component and tangential one, respectively. The phase difference between the tangential force V_2 and the normal force V_1 was 90 degrees. Each parameter was set to actual values of the tested ultrasonic actuator. The time step of simulation Δt of 5ns was chosen. Even if Δt was smaller than 5ns, it was confirmed that simulated results were not changed.

The velocity of a transfer object and instantaneous value of driving force in steady state were simulated by both equivalent circuit and dynamic model, as shown in **Figs. 5** and **6**, respectively. The almost same simulated results were obtained by both simulation methods. Hence, the developed equivalent circuit can express the dynamic model of ultrasonic actuator, and that was able to be analyzed directly on PSIM.

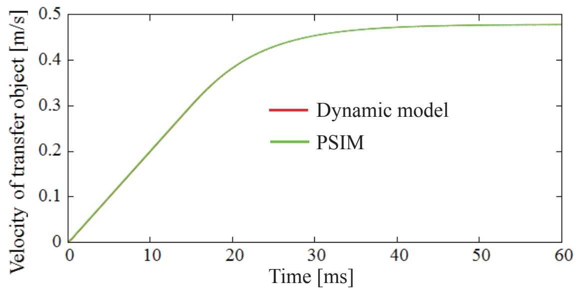

Fig. 5 Simulated results of velocity of transfer object.

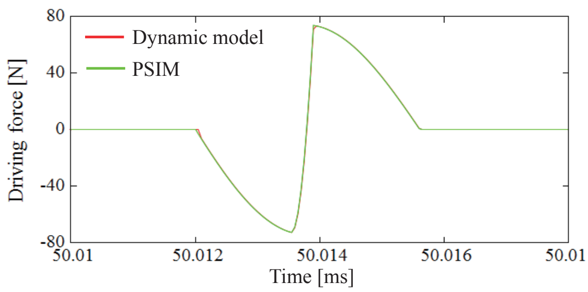

Fig. 6 Simulated results of instantaneous value of driving force in steady state.

5. Summary

The equivalent circuit of the ultrasonic actuator that is evaluable in a commercial ECS was developed. Simulated results of the equivalent circuit and dynamic model were almost equal. Therefore, the developed equivalent circuit for the analysis of ultrasonic actuator succeeded in the direct simulation on the commercial ECS.

References

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