Dynamic Analysis Method of Linear Resonant Actuator with Multi-Movers Employing 3-D Finite Element Method

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Introduction

Recently, linear resonant actuators (LRA) have been used in a wide range of applications because they have a lot of advantages; high efficiency, simple structure, easy control, and so on, however, they have a problem that the amplitude severely decreases in response to an external load.

To control this, a feedback control is adopted where the back EMF of the coil is detected to control the current duty .

We propose the numerical analysis method for predicting dynamic characteristics of LRA with two movers under PWM feedback control employing the 3-D FEM. And, the effect of a link-spring on each mover motion is clarified when a single mover is operated with load.

Analysis method

Motion analysis

This actuator is composed of two movers linked together by link-springs, and the motion equations and the spring forces are given as follows:

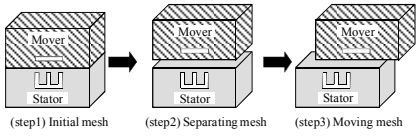
$$M_1 \frac{d^2 z_1}{dt^2} + C_1 \frac{dz_1}{dt} + F_{k1} = F_{z1}$$

$$M_2 \frac{d^2 z_2}{dt^2} + C_2 \frac{dz_2}{dt} + F_{k2} = F_{k2}$$

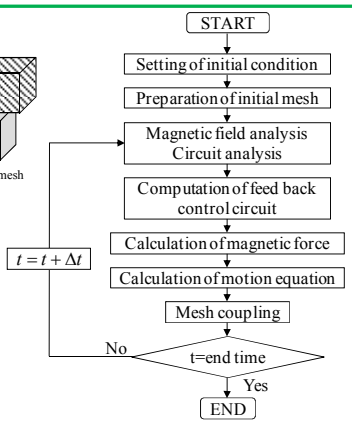
$$F_{k1} = k_m z_1 + k_l (z_1 - z_2)$$

$$F_{k2} = k_m z_2 + k_l (z_2 - z_1)$$

M_1 , M_2 : The mass of movers
z_1 , z_2 : The displacement of movers
F_{z1} , F_{z2} : Trust
F_{k1} , F_{k2} : Spring force
C_1 , C_2 : Viscous damping coefficient
k_m : Main spring constant
k_l : Link-spring constant

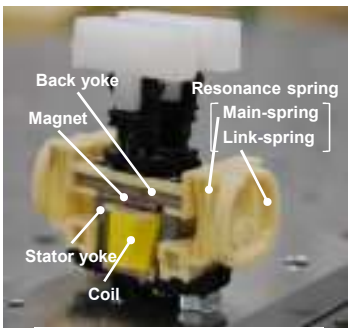


Mesh coupling method

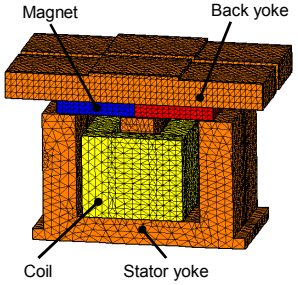


Flowchart of analysis

Analyzed Model and Condition



Basic structure of the LRA

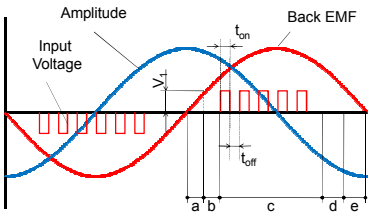


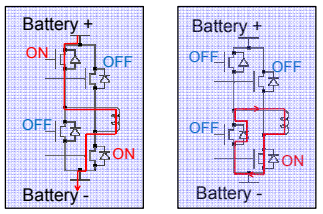
FEM model

Discretization date and CPU time

Number of elements	668,934
Number of edges	792,175
Number of unknown variables	768,815
Number of steps	1,300
Time division [μsec]	10
CPU time [h]	300
Computer used : Core2 Duo 3.0GHz PC	

Advanced PWM Feedback Control





c: Excitation mode d: Circulation mode

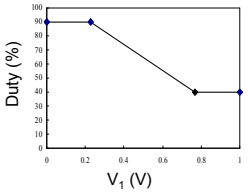
a: Voltage sensing mode
The coil detects the back EMF V_1 when a constant time passes after the back EMF is reduced to zero

b: Delay mode
The coil is excited with a delayed time.

c: Excitation mode
The coil is excited under PWM according to the duty determined by the back EMF V_1.

d: Circulation mode
Current circulates through a diode.

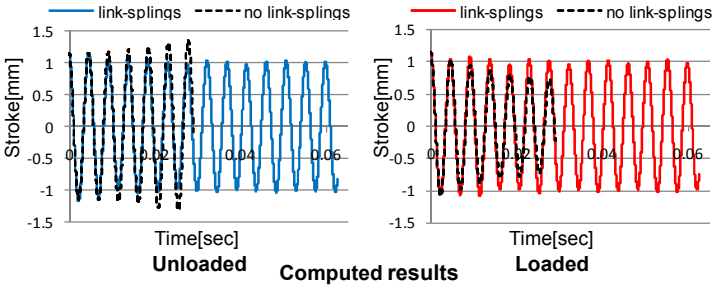
e: Circuit opening mode



Control function

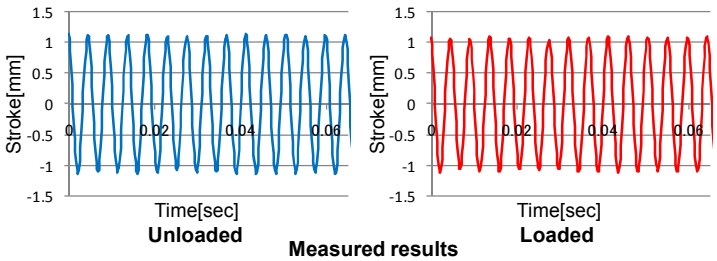
Effect of Link-Spring

Link-springs recover the amplitude by the motion of the other mover while the amplitude of one mover is decreased by an external load.
The horizontal load of 0.4N is applied to a single mover under unloaded steady-state condition.



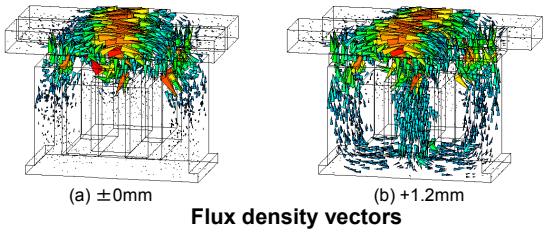
Unloaded **Computed results** **Loaded**

A decrease in the amplitude of the loaded mover is controlled, and an increase in the amplitude of unloaded mover is also well controlled.



Unloaded **Measured results** **Loaded**

Both results are well in good agreement.



(a) ±0mm (b) +1.2mm

Flux density vectors

Conclusion

we proposed the dynamic analysis method of a linear resonance actuator with multi-movers under PWM control employing the 3-D FEM. The effectiveness of this method was shown by the comparison with the measured results. Moreover, the effect of link-springs on amplitude control was clarified.