Dynamic Characteristics of Linear Resonant Actuator Using Electrical Resonance

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IEEE CEFC 2016
The 17th Biennial Conference on Electromagnetic Field Computation
Miami, FL, USA - Nov 13-16, 2016

Introduction

Linear resonant actuators (LRAs) are actuators that reciprocate by alternating currents excitation and utilize mechanical resonance.

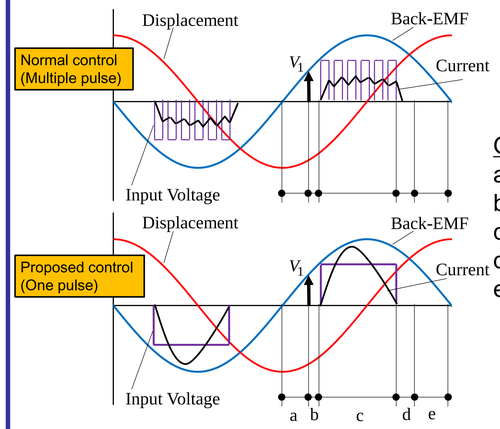
○Simple structure, easy control, direct drive

◆ Problem
When a large load is applied to LRA, its duty reaches maximum and the amplitude is not controllable as it is required

◆ Purpose

- Propose a new control method in which electrical resonance is coupled with mechanical resonance
- Verify the proposed control method through 2-D finite element analysis and measurement

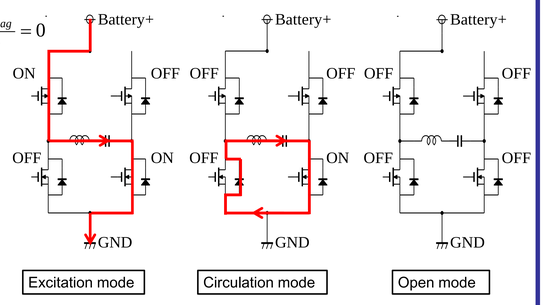
Control Method for Electrical Resonance



Operating mode
a : Voltage sensing mode
b : Delay mode
c : Excitation mode
d : Circulation mode
e : Circuit opening mode

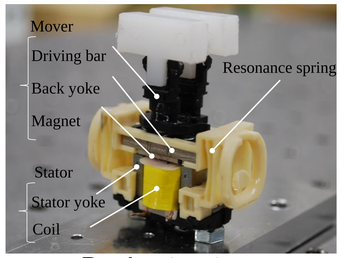
$$V - RI - \frac{1}{C}\int Idt - L\frac{dI}{dt} - \frac{d\psi_{mag}}{dt} = 0$$

$$f_e = \frac{1}{2\pi\sqrt{LC}}$$

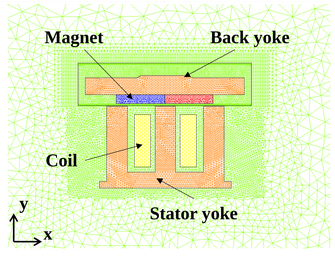


Electrical resonance is achieved by:
1. Connecting a capacitor with a coil in series
2. Matching f_e with frequency of input voltage

Analysis Model and Condition



Basic structure



2-D FEA model

DYNAMIC ANALYSIS CONDITION

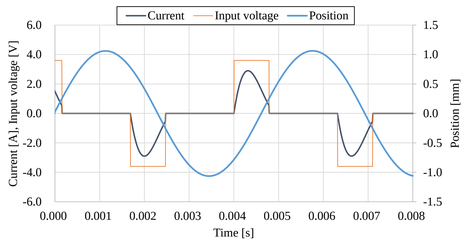
Coil	Input voltage (V)	3.6
	Resistance(on) (mΩ)	700
	Resistance(off) (mΩ)	580
	Number of turns (turn)	68
	Inductance (μH)	220
Remanence of magnets (T)		1.42
Mass of mover (g)		6.95
Spring constant (N/mm)		13.36
Viscous damping coefficient (N·s/m)		0.14
Forward diode voltage (V)		0.7
Length of interval c (μs)		800
Thickness of stator and mover (mm)		10.25

Dynamic characteristic analysis is conducted through 2-D finite element method.

Capacitance is substantially determined to 234 μF from input time and coil inductance.

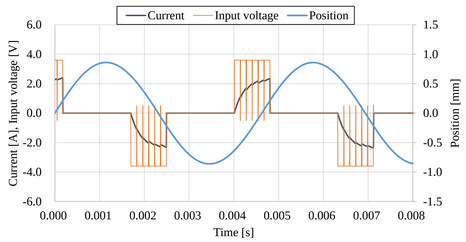
The full bride circuit is regarded as four ideal switches in this simulation.

Analyzed Results



Proposed control
Mechanical resonance
+Electrical resonance

Amplitude: 2.13mm
Peak current: 4.3A
Average current: 1.96A



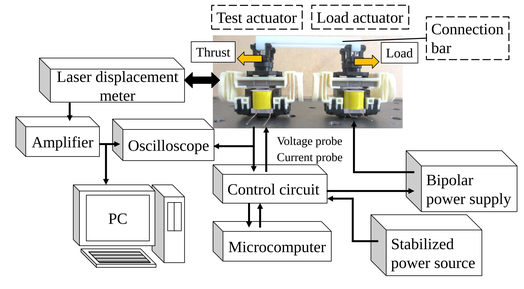
Conventional control
Only mechanical resonance

Amplitude: 1.72mm
Peak current: 2.35A
Average current: 1.72A

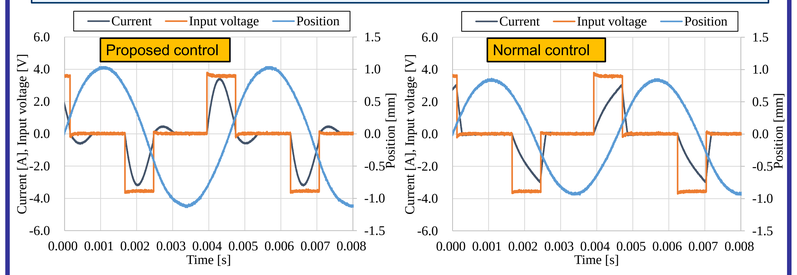
Current waveform is sinusoidal when the circuit is operated in excitation mode and the phase in voltage and current is the same.

Due to smaller impedance, the proposed control is successfully able to generate large current and consequently obtain large amplitude without any change in excitation time.

Measured Results



Two LRAs are connected and share their vibrating motion.
Polypropylene film capacitor (200 μF) is selected because of non-polarity.

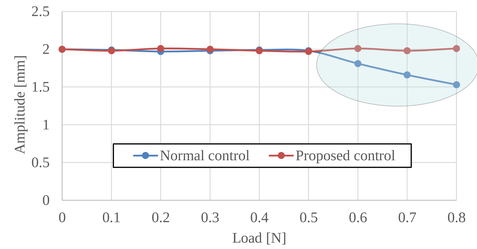


Amplitude: 2.18mm
Peak current: 3.21A
Average current: 2.09A

Amplitude: 1.81mm
Peak current: 3.0A
Average current: 1.87A

The proposed control is effective also on experiment.

Measured load characteristics under PID control



The proposed control is able to keep the target amplitude against larger load.

Conclusion

- ◆ This paper presented a new control method in which electrical resonance was applied to a normal PWM control.
- ◆ Electrical resonance occurred and larger current was generated because of smaller electrical impedance.
- ◆ Consequently, amplitude was kept constant against larger load under the proposed control.