Electromagnetic Design and Dynamic Characteristics Considering Instantaneous Inductance According to Mover Position of Permanent Magnet Linear Oscillating Machines

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MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

CHUNGNAM NATIONAL UNIVERSITY

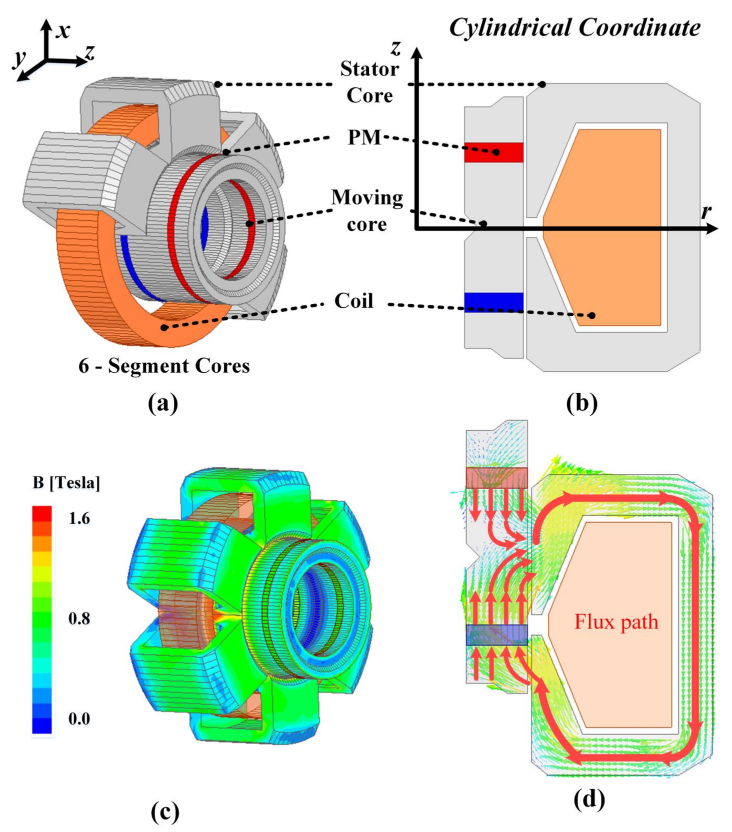
N.E.E New electrical Energy Lab.

Introduction

Linear oscillating actuators (LOAs) are machines that control the linear reciprocating motion through stroke cycles at a specific frequency. Owing to their advantages, such as their high transmission efficiency, simple structure, and low noise characteristics, LOAs are more suitable than conventional actuation methods, which make use of rotatory motors and crankshafts, for devices such as electro-medical machines, electric hammers, linear pumps, refrigeration compressors . LOA can be divided into three types: moving-magnet, moving-coil, and moving-core types. The moving-magnet type has an advantage that the weight of the mover is small; however, the increase in the output power density is limited. In the moving-coil type, although the control of stroke and displacement is easy, this type of LOA is difficult to manufacture. In contrast, the moving-core type is easy to manufacture and can increase the output power density. For a moving-core type, Zaid S et al. proposed the interior permanent magnet (IPM)-type LOA to improve the output power density. However, the magnetic flux flow of IPM-LOA generates a strong eccentric side force. This could lead to system failure, resulting in replacement cost. Therefore, IPM-LOA should be preceded by research to reduce electromagnetic eccentricity.

In this study, the structure and operating principle of the IPM-LOA were examined, and the electromagnetic characteristics of the IPM-LOA were analyzed. Next, we confirmed that the electromagnetic side force can be reduced by changing the shape of the permanent magnet (PM). Electromagnetic design has been carried out taking into account the thickness and position of the bridge of the PM. Next, the dynamic characteristics of the IPM-LOA were analyzed, considering the mechanical system such as spring coefficient, damping coefficient. It is confirmed that the inductance changes according to the position of the mover, and more accurate dynamic analysis was performed by analyzing the dynamic characteristics considering instantaneous inductance.

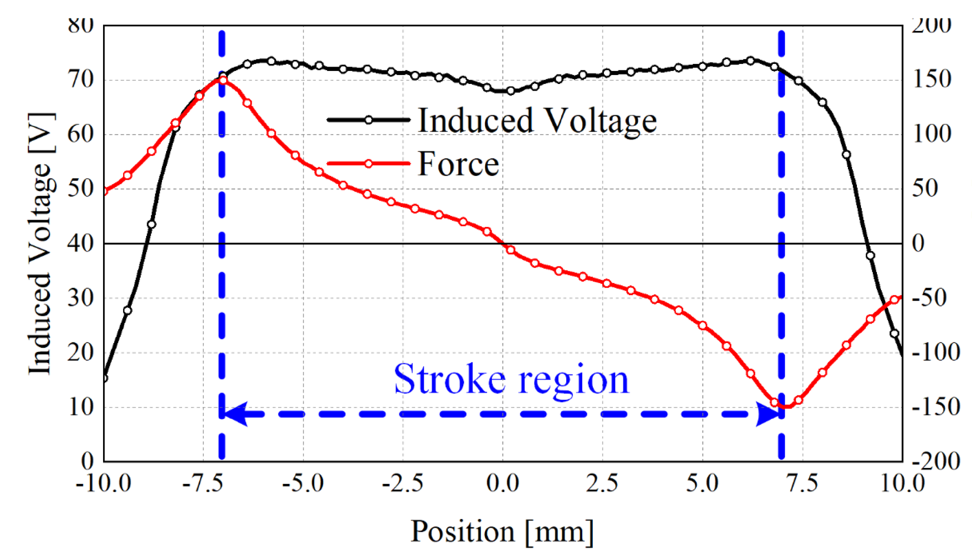
Analysis Model



➢ Fig. 1. (a) Analysis model of the IPM-LOA
(b) the magnetic flux density and flux path

❖ Specifications of IPM LOA

Parameter	Value
Output	100 W
Frequency	60 Hz
Stator Dia.	110mm
Moving Core Dia.	56mm
Air gap	0.5mm
Axial length	44mm
Stroke	±15 mm
Material of PM	N42SH

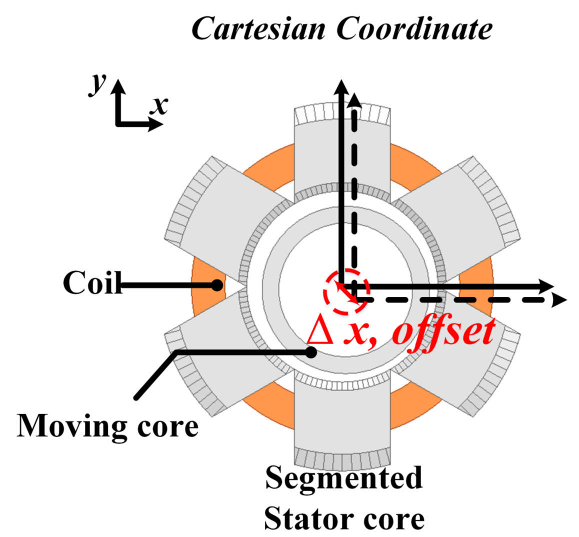


➢ Fig.2. Back EMF and magnetic force according to mover position

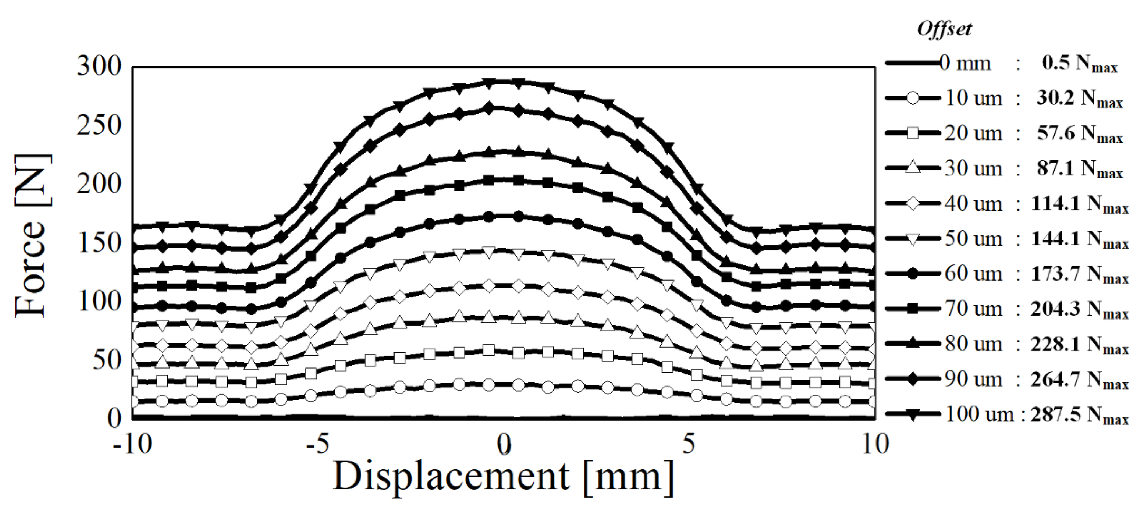
✓ Fig. 1 (a) shows the structure of the IPM-LOA, which consists of segmented stator cores, coils, and moving cores. Further, the PMs magnetized in the +z and −z directions are embedded in the moving core, which reciprocates in the z-axis direction.

✓ The IPM-LOA should be designed to produce a constant stroke. The stroke is determined by the distance between the PMs

Side Force Analysis



➢ Fig. 3 Definition of offset



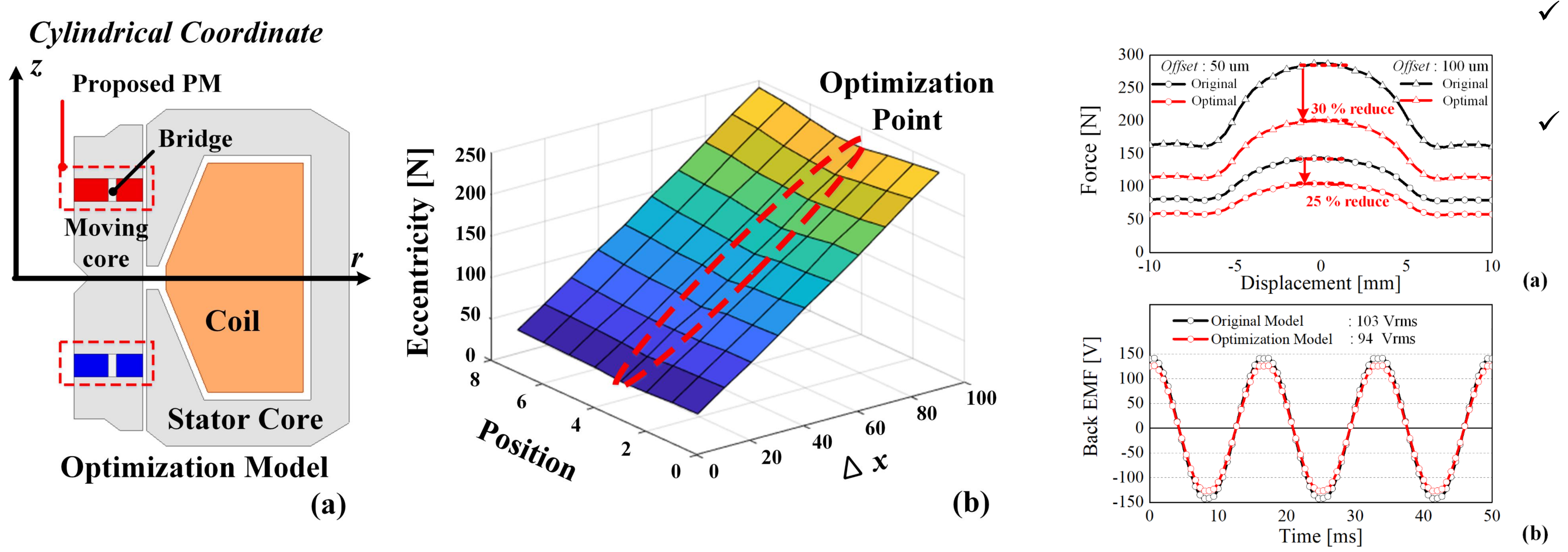
➢ Fig. 4. Electromagnetic side force according to mover position and off-set

✓ Fig. 3 shows the definition of the offset

✓ Fig. 4 shows the electromagnetic side force according to the mover position and offset. As shown, the side force generated from the center is the largest, and the greater the offset, the greater is the side force.

✓ The mover side force, which can be described as an offset between the center of the mover and stator, is a serious defect in electric machines

Optimization Design

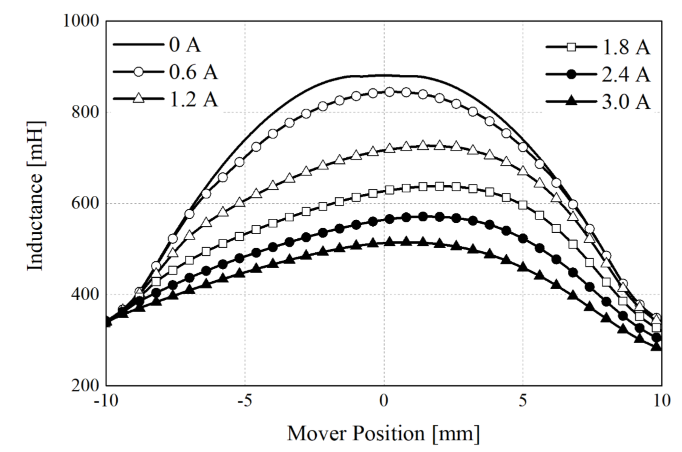


➢ Fig. 5. (a) Proposed IPM-LOA model, (b) side force optimization point

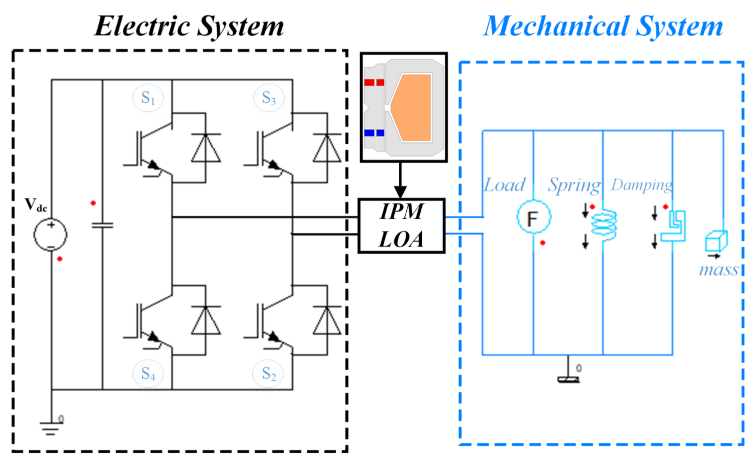
✓ We propose a PM shape with a bridge, as shown in Fig. 4 (a).

✓ Fig. 5 (a) shows the eccentricity reduction of the optimal model. The force of eccentricity was reduced by approximately 25%–30%. Furthermore, the back EMF wave form is shown in Fig. 5 (b), and the back EMF reduction amount is approximately 9%.

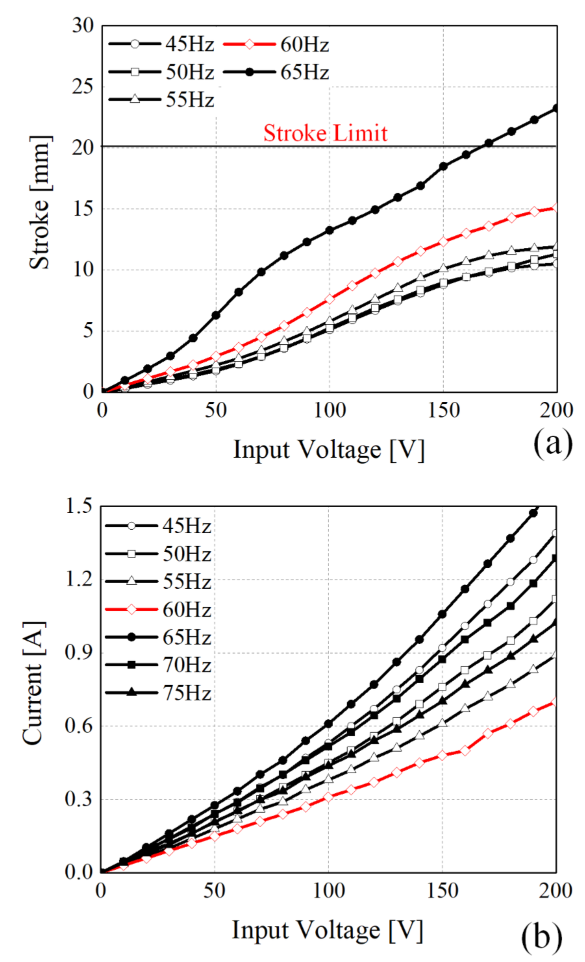
Dynamic Analysis considering Inductance and Mechanical system



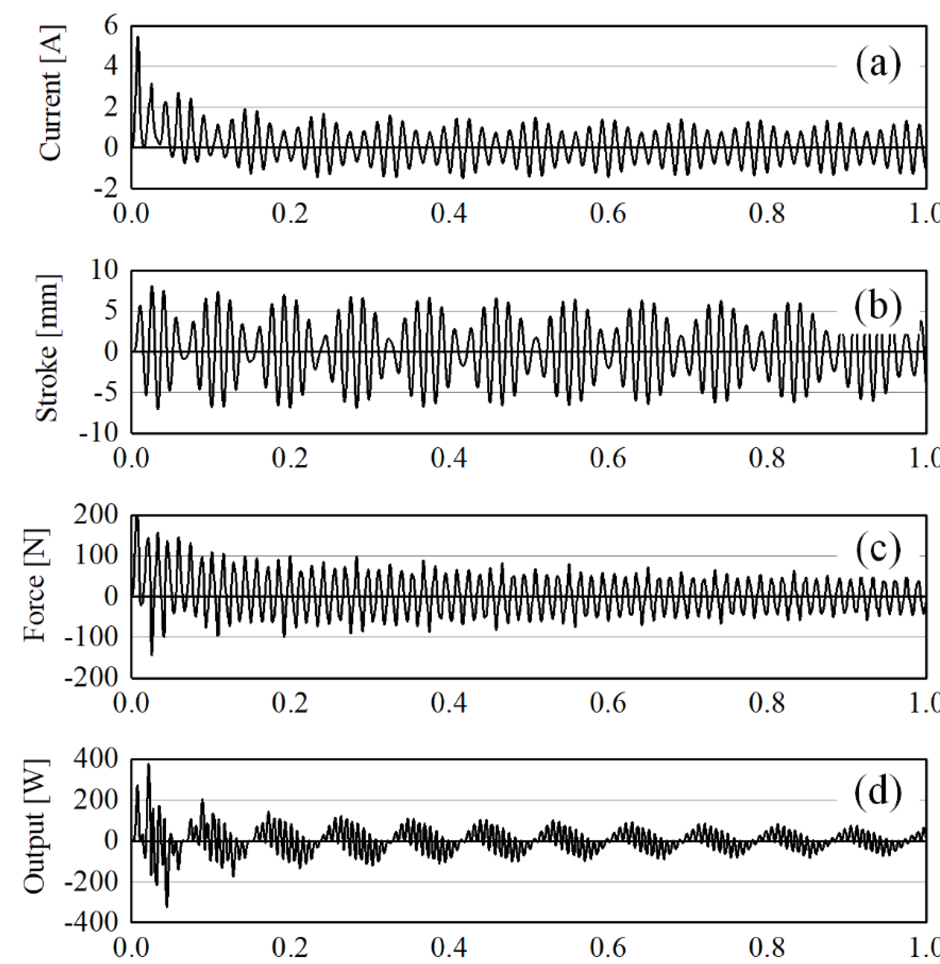
➢ Fig. 7. Instantaneous inductance according to mover position and current



➢ Fig.8. Analysis model including mechanical system of LOA



➢ Fig. 9. Dynamic analysis according to input voltage and frequency; (a)stroke, (b)current



➢ Fig. 10. Dynamic analysis results at rated condition; (a)current, (b) stroke, (c)force, (d) output

✓ Fig. 8 shows the analysis model considering the mechanical and electrical system of IPM-LOA. Through this, the dynamic characteristics analysis of IPM-LOA according to the input voltage and frequency was performed.

Conclusion

This study performed electromagnetic analysis considering mechanical systems of IPM-LOA. This paper described the structure and operation principle of IPM-LOA. We showed that a typical IPM-LOA generates a strong side force, which causes eccentricity. The side force can be minimized by changing the PM shape. An optimized design of the PM shape was also proposed. In addition, for accurate analysis, dynamic analysis was performed considering instantaneous inductance. The current and stroke characteristics were analyzed according to the applied voltage and frequency, and the electromagnetic characteristics at rated conditions were checked. It was confirmed that the most efficient operation was possible in the rated condition

Presented at the 26th International Conference on Magnet Technology , 2019 Tracking ID: Tue-Mo-Po2.11