INTRODUCTION

Linear oscillating actuators (LOAs) are machines that control the linear reciprocating motion through stroke cycles at a specific frequency. Owing to these advantages, such as their high transmission efficiency, simplicity in structure, and low noise characteristics, LOAs are more suitable than conventional actuation methods, which make use of rotary motors and crankshafts, for devices such as electro-medical machines, electric hammer, linear pumps, refrigeration compressors. LOA can be divided into two 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 easier to manufacture and can increase the output power density. For a moving-cores 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

- Specifications of IPM LOA
  - Output: 100 W
  - Frequency: 60 Hz
  - Stator Dia.: 110 mm
  - Moving Core Dia.: 55 mm
  - Air gap: 0.5 mm
  - Axial length: 44 mm
  - Stroke: ± 15 mm
  - Material of PM: N42SH

SIDE FORCE ANALYSIS

- Fig. 1: (a) Analysis model of the IPM-LOA, (b) the magnetic flux density and flux path
- Fig. 2: Back EMF and magnetic force according to mover position
- 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

DYNAMIC ANALYSIS CONSIDERING INDUCTANCE AND MECHANICAL SYSTEM

- Fig. 6: Instantaneous inductance according to mover position and current
- Fig. 7: Analysis model including mechanical system of LOA
- Fig. 8: Analysis model considering the mechanical and electrical system of IPM-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

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.