Characteristics Comparison of Permanent Magnet Linear Synchronous Motor with Different Topology Structures for Ropeless Elevator System

Yu-Wu Zhu, Sang-Geon Lee, and Yun-Hyun Cho
Electrical Engineering, Dong-A University
840, Hadan 2-dong, Saha-gu, Busan, 604714, South Korea
zhuyuwu@gmail.com

Abstract — To make the ropeless elevator system become practical, one of the most important requirements is the high force density. The slotted iron core type permanent magnet linear synchronous motor (PMLSM) seems to be the best choice except the large detent force. Therefore, in this paper the characteristics of detent force, normal force, and propulsion force of PMLSM are investigated under different motor topology structures, such as different PMLSM topologies, different mover topologies, and different armature core topologies. Finally, the long stator double-sided slotted iron-core type PMLSM with fractional slot winding is selected for the best performance.

I. INTRODUCTION

Recently the multi-car ropeless elevator system (RLES) attracts much more attentions to improve the economic efficiency of high buildings. Compared with the traditional rotary machine the linear motor is more suitable to the multi-car RLES. However, there is no counterweight. To make this high efficiency RLES become practical, one of the most important requirements is the high force density.

In comparison of other type linear motors, for instance, linear switched reluctance motor (LSRM), linear induction motor (LIM), the permanent magnet linear synchronous motor (PMLSM) is most suitable for ropeless elevator system because of the high force density [1]. Some researchers had investigated on the core-less type PMLSM because there is no detent force and low normal force [2]. However, the force density is still relative lower compared with the slotted iron-core type PMLSM. Therefore, in this paper we focus on the force characteristics investigation versus different topology structures of the slotted iron-core type PMLSM.

To compare the characteristics among different topology structures of PMLSM efficiently, the combination of two dimensional (2-D) finite element analysis (FEA) and response surface methodology (RSM) is utilized, which can solve the problem effectively without much time consuming [3]. Furthermore, the window-zoom-in method is introduced to reduce the optimal region to obtain more accurate and near-optimum response value. The validity and effectiveness are verified by some numerical calculated and experimental results.

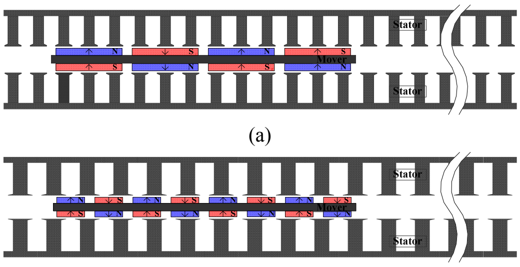
II. PMLSM TOPOLOGY STRUCTURES COMPARISON

A. Different PMLSM Topology Structures

The PMLSM can be divided into long- and short-armature types. For the short-armature type PMLSM, the armature is fixed on the mover. It is composed of iron core and windings of which the weight is large. Furthermore, the power has to be fed into the armature on the mover side, which needs the power cable. If the RLES can be achieved, the contactless power supply system has to be used to eliminate the power cable. However, this contactless power supply system is very expensive and contains some losses in the power transmission that will decrease the overall system efficiency. Whereas, for the long-armature type PMLSM, the armature is fixed to the elevator fit and the PM is fixed to the mover, thus, the contactless power supply system is not needed, and the weight of the mover is relative smaller. Therefore, the long-armature type PMLSM is more suitable for the RLES compared with the short-armature type one.

B. Different Core Topology Structures

Fig. 1 illustrates the two different winding types of PMLSM. Based on the PMLSM structure and the specifications shown in table I, the finite element models are made. For these two PMLSM models we try to keep same slot width and air-gap, and similar mover length with consideration of actual manufacturing. Here we optimize the structures of these two PMLSMs to investigate the detent force characteristics.



(a)

(b)

Fig. 1. PMLSM structure. (a) Integral-slot winding type, (b) Fractional-slot winding type.

TABLE I
SPECIFICATIONS OF DIFFERENT WINDING TPYES OF PMLSM

Items	Integral-slot winding type	Fractional-slot winding type
Pole pitch	60 mm	24.75 mm
Slot pitch	20 mm	22 mm
Slot width	12 mm	12 mm
Slot/pole/phase	1	3/8
Air-gap length	2 mm	2 mm
Mover length	600 mm	594 mm

In this paper the three factors: PM relative displacement SK_L, PM length PM_L, and slot opening length SL_OPL shown in Fig. 2, are screened as optimal factors. The optimization procedure is illustrated as the flow chart in Fig. 3. According to the specifications of PMLSM and the preliminary range of the three factors, fifteen independent combinations of factors generated by RSM can be obtained. Then the fifteen corresponding 2-D FEA models are made and the corresponding detent forces in one slot pitch are calculated. From the calculated results, the amplitude of detent force for each optimal factor combination is found. These amplitudes are used in RSM to calculate the coefficients of the quadratic approximation function and predict the global optimal value of the detent force.

For this first optimization, one predicted response surface is shown in Fig.4 and the quadratic approximation function is

$$\begin{aligned} F_{df} &= 119x_1^2 + 434x_2^2 + 43x_3^2 - 17x_1x_2 + 140x_2x_3 \\ &\quad + 8x_2x_3 + 74x_1 - 40x_2 - 192x_3 + 168 \end{aligned} \tag{1}$$

where, x_1, x_2, x_3 represent the optimal factors PM_L, PM_SFL, SL_OPL, respectively. F_{df} is the detent force.

In the first optimization the estimate error is too large to predict the correct global optimal value exactly due to the large range of the amplitude of the detent force. However, this RSM give a tendency for the reduction of the detent force. We can use the window-zoom-in method to select a new region in which the detent force is relative smaller. In this new region we repeat the upper optimization calculation process to find the global optimal point. For this integral-slot winding type PMLSM, this process is repeated two more times. The peak value of the detent force is reduced from 1487 N to 21.8 N.

For the fractional-slot winding type PMLSM, the detent force is optimized in the same way. The optimization calculation process is repeated twice. And the peak value of detent force is minimized to 4.2 N. The waveforms of the optimized detent forces for both integral-/fractional- slot winding type PMLSMs are shown in Fig.5. The peak value of detent force for this fractional-slot winding type PMLSM is only 19.3% of that for the integral-slot winding type PMLSM. This result shows that the amplitude of fractional-slot winding type PMLSM is smaller. Therefore, it is more suitable for the ropeless elevator system.

The propulsion force and normal force characteristics of the iron-core type PMSLM will be investigated in detail in the full manuscript, together with the consideration of the different core topology structure. Some experimental results will also be reported to verify the validity of our optimal designed slotted iron-core type PMLSM.

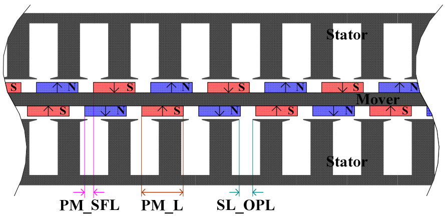


Fig. 2. Optimal factors in PMLSM.

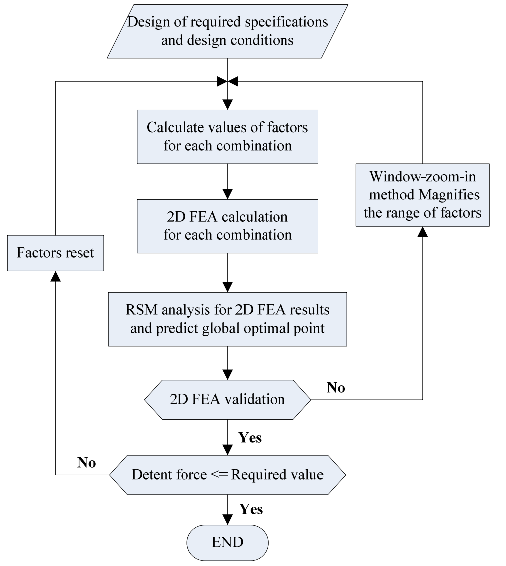


Fig. 3. Analysis flow chart using combination of RSM and FEA.

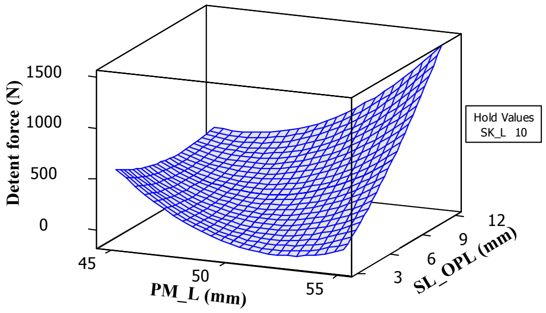


Fig. 4. Predicted response surface of detent force versus the PM length PM_L and slot opening length OPL.

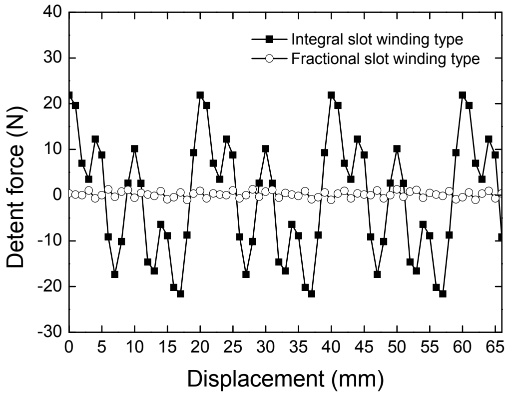


Fig. 5. Detent forces of two different winding types of PMLSMs.

III. REFERENCES

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