Research on Inductance Characteristics of the Linear Synchronous Motor with Various Air Gap Range

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ABSTRACT: This paper presents the leakage inductance of linear motor with various air gap ranges. Due to the three-phase winding configuration, which is hired in linear motor, self and mutual inductances according to air gap are also calculated. To figure out the transversal side effect, 3D simulations are performed with finite element analysis.

1 INTRODUCTION

Linear synchronous motor with high speed transporting system has large air gap to guarantee the safety operation. Especially, in the maglev system, air gap can be varied during operation despite of the highly developed gap control techniques. Large and varying air gap could cause the huge leakage fluxes and induce the large leakage inductances. Those leakage components could effect on the propulsive thrust and efficiency of the linear motor operations. Also, both sides of the linear motor usually have limited length and those transversal edges and winding overhang could cause the 3D leakage components [1]-[4].

This paper presents the leakage inductance of linear motor with various air gap ranges. Due to the 3 phase winding configuration, which is hired in linear motor, self and mutual inductance according to air gap are also calculated. To figure out the transversal side effect, 3D simulations are performed with finite element analysis.

2 STRUCTURE OF THE MOTOR

The geometry of the linear synchronous motor which is used for inductance analysis is shown in Figure 1. The stator consists of four field windings, building up 2 sets of N-S field system. The three-phase winding in mover is configured as shown in Figure 1. End windings of phase A and phase B are bended up and down in order to avoid overlap between windings. The cross section of the motor in y-z plane is shown in Figure 2.

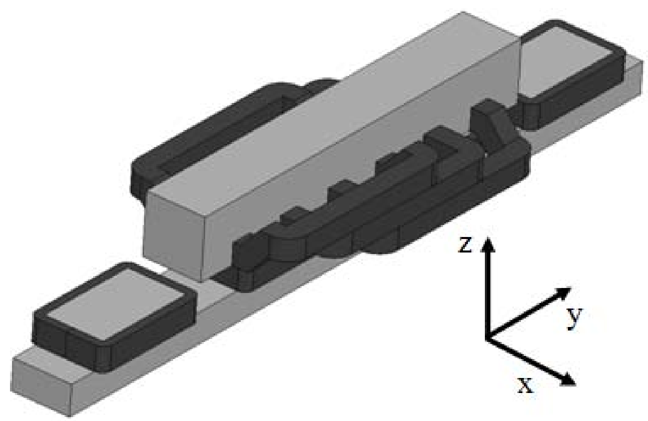


Figure 1. The geometry of the linear synchronous motor.

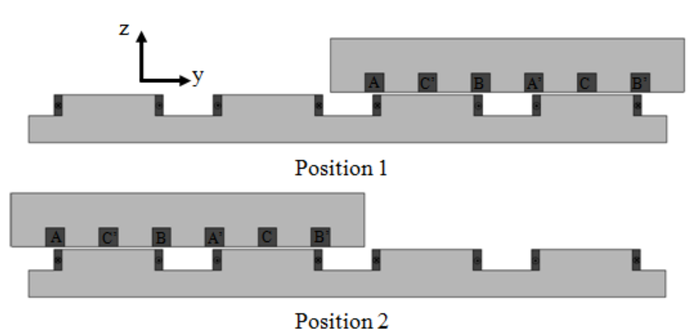


Figure 2. Cross section of the motor.

The dimension of the motor is specified in Table 1. The depth of the model and the air gap length change during the simulation, so they are not specified. The end winding configuration of mover windings and the dimension are shown in Figure 3. During the analysis procedure the mover moves from position 1 to position 2 in Figure 2, thus the moving distance is 120mm. Figure 4 is 3D mesh of the simulation model for finite element analysis. The elements are tetrahedrons, and the elements are mostly concentrated in air gap between the stator and the mover.

Table 1. Dimension and material data of the motor.

	Width/ y-direction (mm)	Length/ z-direction (mm)
Stator back iron	240	10
Pole	35	8
Teeth	13	7
Slot	7	7
Mover back iron	133	13
Field winding	3	8

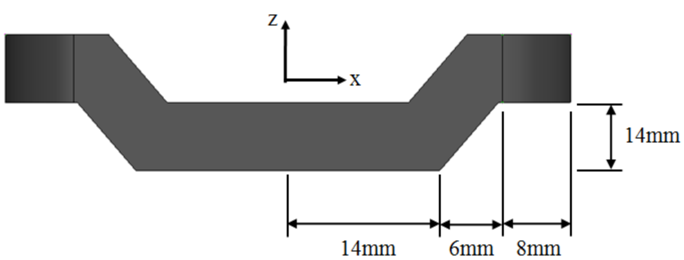


Figure 3. The end winding configuration of phase A winding. Phase B winding configuration is opposite in z direction.

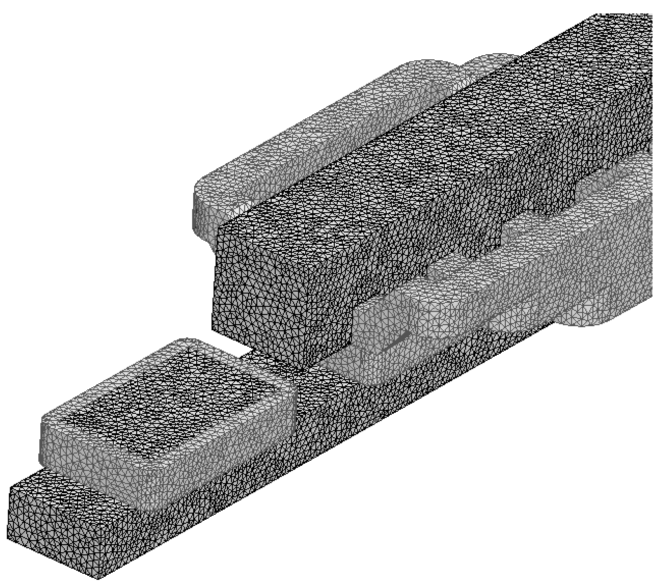


Figure 4. Mesh of the simulation model for finite element analysis.

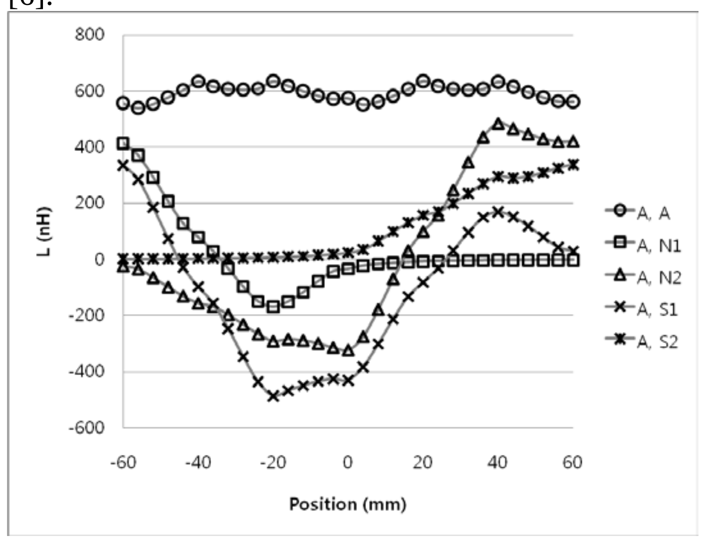
3 INDUCTANCE ANALYSIS

3.1 3D Finite element analysis

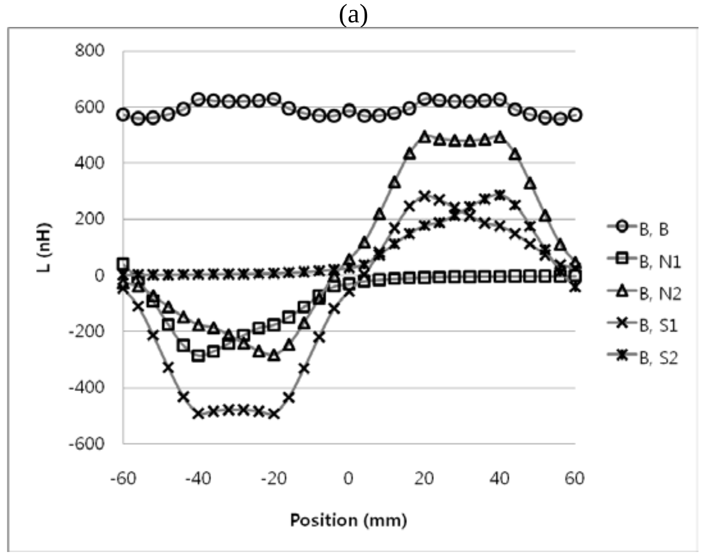
For the inductance calculation 3D magnetostatic finite element analysis is performed. In order to observe the inductance variation throughout the mover motion, the magnetic field is calculated in every step of mover displacement, which is size of 4mm. Therefore 60 times of the magnetostatic computation is performed for every model.

3.2 Inductance difference between mover windings

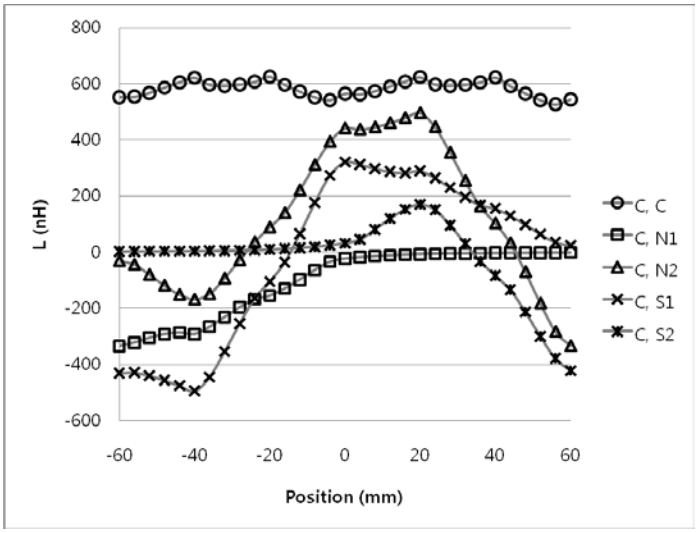
Because of the difference between 3D configuration of three mover windings, there inductance characteristics are also different from each other. Figure 5 shows the self and mutual inductance of the three mover windings when air gap is 1mm and depth is 20mm. The leakage inductance of each winding is calculated from the result and shown in Figure 6 [5]-[6].



(a)



(b)



(c)

Figure 5. Self and mutual inductance of mover windings. (a) Phase A winding. (b) Phase B winding. (c) Phase C winding

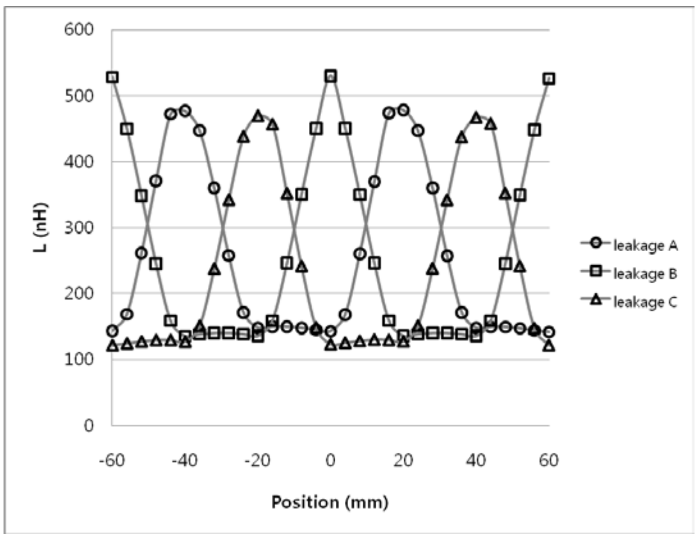


Figure 6. Leakage inductance of mover windings.

The inductance characteristics of the three-phase windings are similar to each other, with minor differences. As shown in Figure 6, the leakage inductances of phase A winding is slightly larger than phase B winding, while the phase C winding is slightly smaller than phase B winding.

3.3 Inductance characteristic due to the air gap variation

Self inductance and leakage inductance largely depends on air gap. Therefore understanding not only the trend, but also the exact value of inductance change due to the air gap variation is essential.

The depth of the motor is fixed on 20mm, and the simulation is run with air gap varied from 1mm to 5mm. The simulation result is shown in Figure 7 and Figure 8. Only inductance of phase C winding is shown as a representative sample, in order to maintain clarity of the data and the graph. The inductance variation trend of three phase windings is almost same.

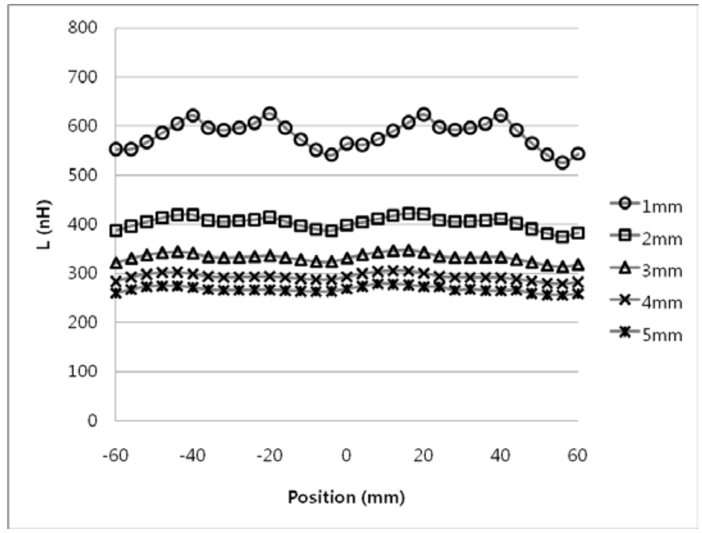


Figure 7. Self inductance of mover winding with different air gap.

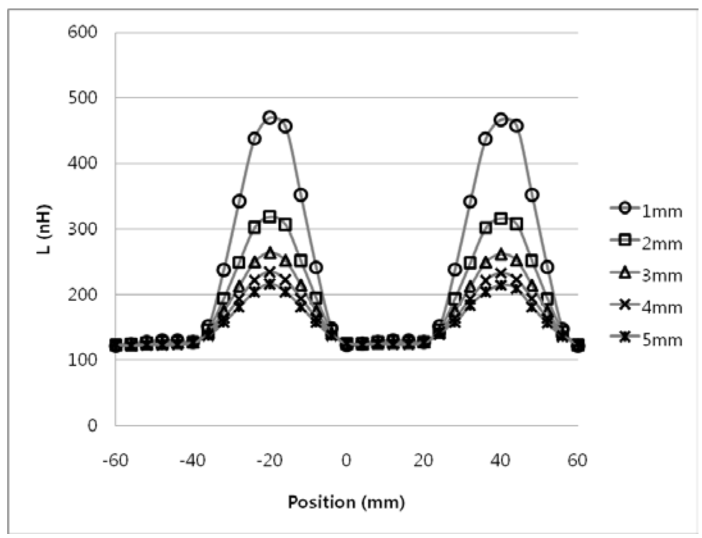


Figure 8. Leakage inductance of mover winding with different air gap.

Table 2 compares the self and leakage inductance when the mover is at position -52mm. Self inductance sharply decreases, and the leakage inductance increases in small amount.

Table 2. Self and leakage inductance at position -52mm with different air gap.

Air gap (mm)	Self inductance (nH)	Self inductance change (%)	Leakage inductance (nH)	Leakage inductance Change (%)
1	567.30	-	121.59	-
2	404.98	-28.61	123.12	1.26
3	337.32	-40.54	123.42	1.51
4	298.19	-47.43	123.43	1.51
5	273.09	-51.86	123.78	1.80

3.4 Inductance characteristic due to the depth variation

Increasing motor depth is one of the most straightforward ways to increase the performance of the motor. In this process the leakage inductance variation is still an issue, because it can lead to motor efficiency decline.

The air gap of the motor is fixed on 1mm, and the simulation is run with depth varied from 20mm to 40mm. The simulation result is shown in Figure 9 and Figure 10.

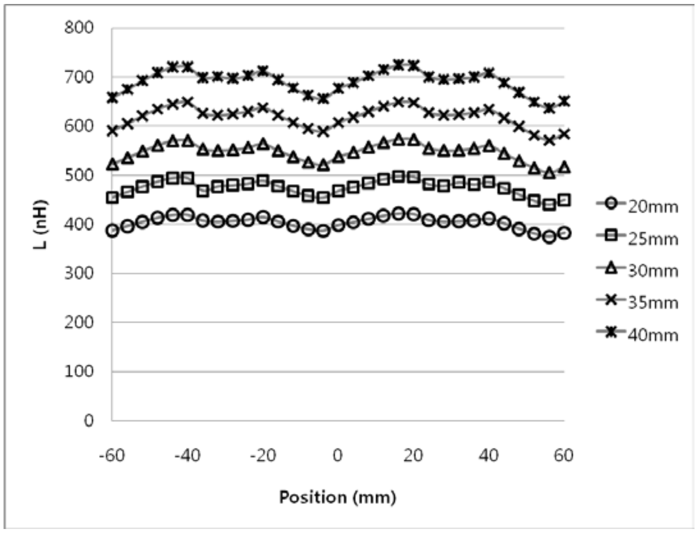


Figure 9. Self inductance of mover winding with different depth.

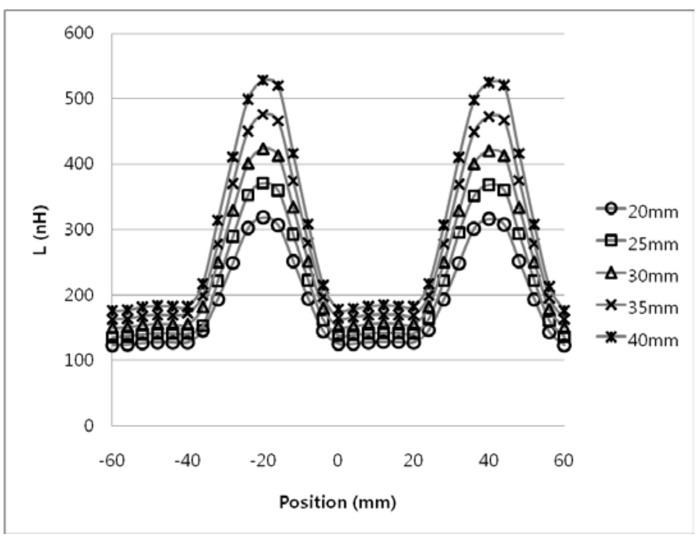


Figure 10. Leakage inductance of mover winding with different depth.

Figure 9 clearly shows that the self inductance is directly proportional to depth of the motor. Similar to Table 2, Table 3 compares the self and leakage inductance when the mover is at position -52mm. The self inductance is increased by about 17% when the depth is increased by 5mm, and the leakage inductance is also increased proportionally.

Table 3. Self and leakage inductance at position -52mm with different depth

Depth (mm)	Self inductance (nH)	Self inductance change (%)	Leakage inductance (nH)	Leakage inductance Change (%)
20	404.98	-	126.36	-
25	476.70	17.71	139.87	10.69
30	548.77	35.50	153.84	21.75
35	620.43	53.20	167.54	32.59
40	692.42	70.98	181.46	43.60

4 CONCLUSION

In this paper, various inductance characteristic differences due to 3D configuration and dimension change are observed. 3D finite element analysis is performed to calculate the inductance, and diverse simulation data is obtained. From this data a certain pattern is observed through different air gap size and depth of the motor.

5 REFERENCES

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