Dynamic characteristics analysis of linear dc motor for the electric screen door

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Dynamic characteristics analysis of linear dc motor for the electric screen door

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In order to simulate the dynamic characteristics, we have developed a method of calculating the force of the linear dc motor screen door system which is using three-dimensional data of flux density in air gap from finite element analysis. We use the coil mesh data to calculate Lorentz forces of each coil. Then they are used for the dynamic characteristic analysis. The simulated dynamic characteristic is compared with experimental value. © *2006 American Institute of Physics*.
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I. INTRODUCTION

Recently, adopting linear dc motor (LDM) which is consist of moving coils and stator magnets for an electric door system replacing the oil pressure system is getting popular. This system has many merits such as easy control, maintenance free, relatively light weight, etc.[1,2]

LDM for the door control system is operating mainly in the transient state from the start to the stop. So the dynamic characteristic simulation of LDM is very important issue but the coil shape of the LDM which seems like a horse race track gives us difficulties of analyzing it by two-dimensional finite element analysis (FEA) simulation. Moreover, the transient simulation using three-dimensional FEA takes a very long time that it is hardly possible to get the satisfactory results.[3,4]

In this study, we suggest a method for the dynamic characteristic simulation for the LDM. In this type of motor, because the magnetic loading is dominant, the resultant force mostly depends on the product of the air-gap flux density and the armature current density. From the result of the three-dimensional FEA, we get the flux-density distribution in the air-gap area. The total force of LDM can be calculated by Lorentz force of the air-gap flux density and the coil current density.

To get the forces of the coils at arbitrary points, a three-dimensional (3D) tetrahedral mesh of the coil can be used. The cross product of the current density and the flux density in an element of the mesh give us the force density of the element. The summation of the element forces of three phase coils to the traveling direction becomes the thrust force of LDM.

The dynamic characteristics of the motor are determined by the equation of motion and the thrust force. The computed characteristics are compared with experimental values. For measuring the speed of the moving coil, we used a linear scale and an optical sensor and the experiment was done in open loop condition.

II. ANALYSIS OF STATIC FILED OF LDM AIR GAP

To calculate the thrust force of the LDM mover, we need to get the flux density of the air gap of the motor. The mover of LDM is comprised of three phase coils and plastic mold. Because of the air-core structure, the flux density of the air gap is mainly determined by the fluxes from magnets and the fluxes from the coils hardly affect on the air-gap flux density. So, we can use the static field analysis of 3D FEA for getting the air-gap flux density of the motor. Figure 1 shows the one-pole pair 3D FEM model of a LDM and the simplified model for calculating the air-gap flux density.

In the simplified model, the air-gap area shows the gray-scaled flux density plot on its surface. In the force calculation, we use just this area of the flux density. Figure 2 shows the simulated and measured flux densities at the magnet center and the magnet upper edge in the air-gap center according to the x positions of one pole. The positions are 10 and 50 mm the magnet left and right edges are located, respectively.

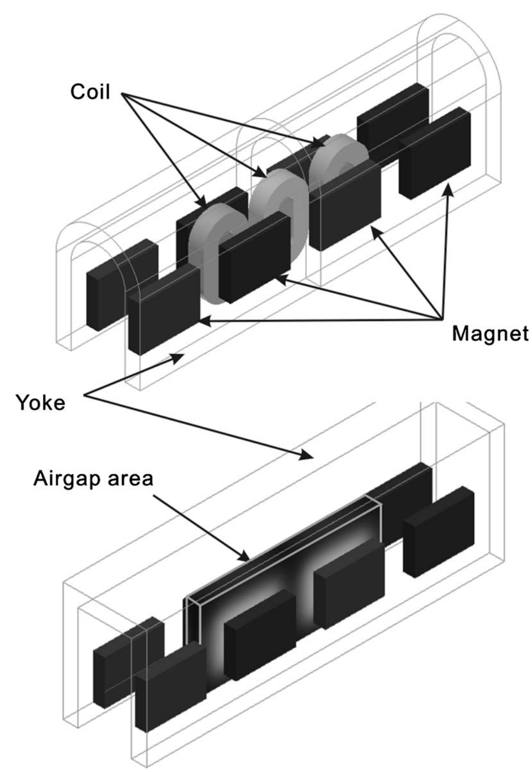

FIG. 1. The 3D FEM model and the simplified model.

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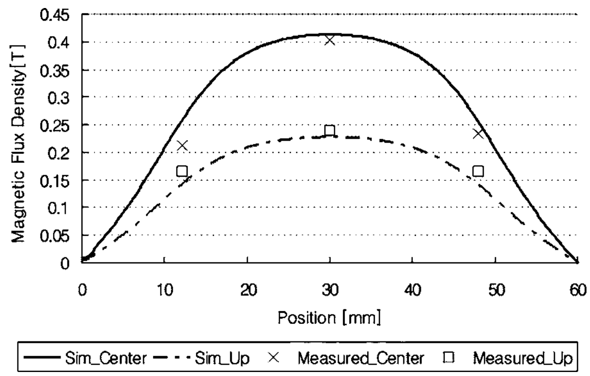

FIG. 2. The flux densities in the air gap.

TABLE I. Specifications of linear dc motor.

Name	Value
Maximum speed	1 m/s
Stroke	600 mm
Pole pitch	120 mm
Magnet width	40 mm
Magnet height	30 mm
Magnet thickness	8 mm
Magnet pole no.	10
Magnet material	NdFeB
Br	1.2 T
Coil turns/pole/phase	354
Total coil bundle number	15
Phase no.	3
Mass of the mover	1.65 kg

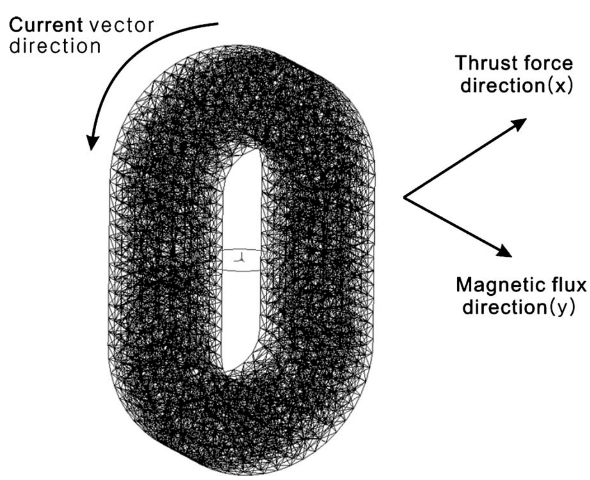

FIG. 3. A tetrahedral mesh for calculating the coil Lorentz force.

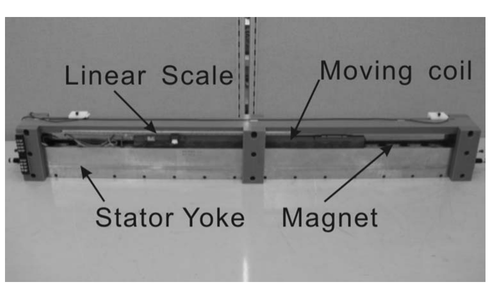

FIG. 4. LDM prototype.

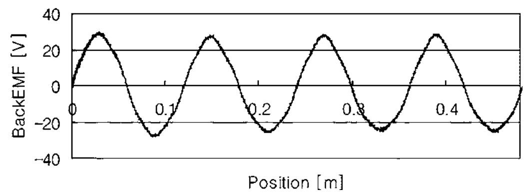

FIG. 5. Measured back emf vs position.

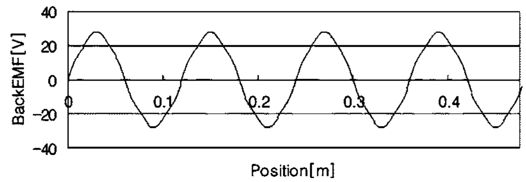

FIG. 6. Simulated back emf vs position.

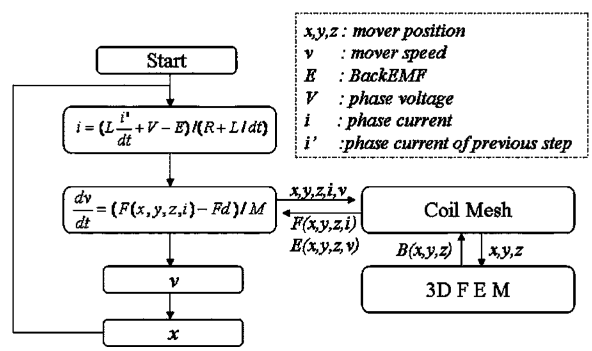

FIG. 7. Dynamic characteristic analysis process.

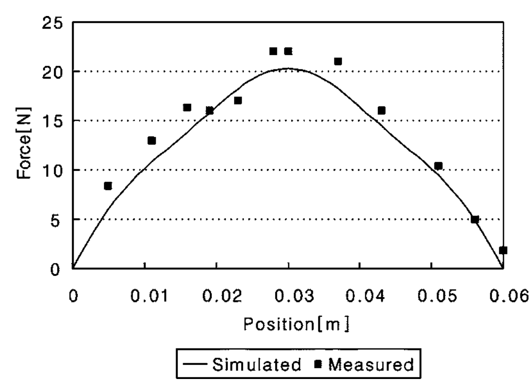

FIG. 8. Simulated and measured forces.

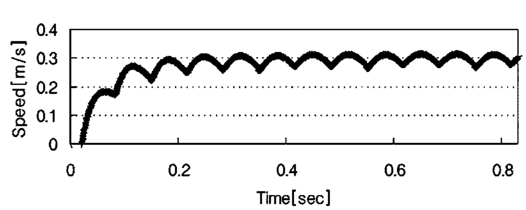

FIG. 9. Simulated speed curve.

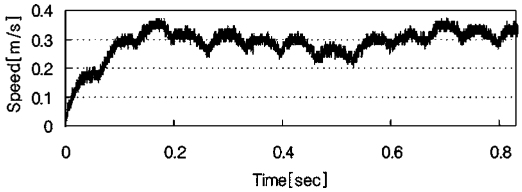

FIG. 10. Measured speed curve.

The prototype model of this motor has five-pole pairs, but for 3D FEM simulation the full model motor has to be simplified to one-pole pair. For minimizing the fringing effect, this model includes two-pole pairs of magnets. The specifications of LDM are shown in Table I.

III. CALCULATION OF COIL LORENTZ FORCE

Because the round edges of coils cannot be considered in analysis model in two-dimensional (2D) FEA, we need a 3D force calculation of coil parts. If 3D FEA is used for considering the edges of the coils, we need one model of LDM per position of the mover and it takes several hours to calculate. This means that it is almost impossible to do the dynamic characteristic simulation of LDM because for the dynamic characteristics simulation, at least thousands of the models of each position are needed. So we use another method to calculate the coil forces at arbitrary positions.

To calculate the thrust force on the phase coil at an arbitrary position in the air gap, it is very useful to divide the whole coil volume into small volume parts, where the Lorentz forces are calculated by the cross product of the current density vector and the magnetic-flux-density vector. For this, we use the tetrahedral mesh of a coil in Fig. 3.

IV. BACK EMF: CALCULATION AND MEASUREMENT

To verify this force calculation method, we simulate the back emf of coils which made up the LDM prototype and measured the back emf values of the motor. Figure 4 shows the manufactured motor. The total length of this motor is 1200 mm and the length of the mover comprising of phase coils and plastic body is 600 mm. So the maximum stroke of this motor became 600 mm.

Figure 5 shows the measured line to line back emf and Fig. 6 shows the simulated one. We can see that both results are well matched.

V. DYNAMIC CHARACTERISTIC ANALYSIS

For the dynamic characteristic analysis of LDM, we adopt the equation of motion,

$$\frac{dv}{dt} = [F(x,y,z,i) - F_d]/M, \tag{1}$$

where v, $F(x,y,z,i)$, Fd, and M are the speed of the mover, thrust force of the mover, friction force, and mass of the mover, respectively. Because we do not know the current value i, the voltage equation and a time differential method are used for calculating i.

$$i = \left(L\frac{i'}{dt} + V - E\right) \bigg/ \left(R + \frac{L}{dt}\right), \tag{2}$$

where L, R, i', V, E, and t are the coil inductance, resistance, phase current of previous time step, applied voltage, and phase back emf, respectively.

Whole process of the dynamic characteristic simulation is shown in Fig. 7.

The simulated and measured thrust forces of LDM are shown in Fig. 8. Because the dynamic forces are very difficult to measure when the mover is running, the static forces are compared in the condition of phase current of 0.6 A. Generally, because a LDM for the small size electric screen door system has to produce 60 N of maximum force, the manufactured LDM is applicable for the system. The result of the simulation is shown in Fig. 9 and the result of the measurement is shown in Fig. 10 in open loop condition with commutation speed=0.3 m/s. In the measured value, we can find some instabilities of the mover speed because the friction coefficient is not constant with respect to the running direction (x direction).

VI. CONCLUSION

The use of LDM used for the automatic door system is prospected to increase continuously because it has very simple structure thus needs low maintaining cost than the oil pressure door system and it is much easier to control and relatively light in weight.

For rapid development of LDM, the precise analysis is very important. Especially, the dynamic characteristic analysis of LDM is essential for the automatic door system because most of the operating time of LDM for the automatic door system is in transient state.

For this reason, the fast calculation of the thrust force of LDM is needed for the dynamic characteristic analysis. The presented method of the force calculation is very useful not only in the study of LDM and the automatic door system but also in the study of air-cored electric devices with three-dimensional structure. Especially, if there is eccentricity on the position of the mover in the air gap, the proposed force calculation method could make us save a lot of calculation times by substituting this calculation method for the 3D FEA of each position.

In further study, we will consider the inconstancy of the friction coefficient of the automatic door system with respect to the running direction.

ACKNOWLEDGMENT

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