2-D Equivalent Modeling and Analysis of Quadratic Electromagnetic Linear Actuator

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Abstract — The purpose of this paper is to analyze the quadratic electromagnetic linear actuator which has many advantages such as no need of addition energy conversion system, space-saving and low power consumption as a component of the intelligent car. The dynamic performance of the linear actuator is verified by finite element analysis (FEA). However, proposed quadratic actuator is not an axis-symmetric model. So it should perform 3-D full model simulation. In order to perform 3-D full model simulation, it requires high performance computer and also takes tremendous amount of time. Therefore, to save the simulation time, we make the equivalent 2-D model of the linear actuator and calculate the effective coil length.

I. INTRODUCTION

Nowadays, intelligent car and green care are becoming an increasingly important trend of modern cars as people realize the value of lower fuel consumption and comfort driving. One of the core components used to improve riding comfort is an active engine mount in green cars. Currently, an active engine mount using electromagnetic actuator is under research to reduce engine vibration. Many studies have been conducted to improve the dynamic performance of the active engine mount because this will bring advancement passenger's riding comfort. [1]-[3] In this research, we present a small but a powerful quadratic electromagnetic linear actuator. Dynamic finite element analysis is performed by using combined magnetic, mechanical and electric subsystem. However, to characterize the performance of quadratic actuator, it requires high performance computer and also takes tremendous amount of time. Therefore, to save a simulation time and get the efficiency, 2-D equivalent model is necessary. In this research we make the equivalent 2-D model of the quadratic actuator and calculate the effective coil length. Finally, through a comparison of simulation results by 2-D equivalent model and 3-D full model, we verify the performance of the 2-D equivalent model.

II. STRUCTURE AND OPERATION PRINCIPLE OF ELECTROMAGNETIC LINEAR ACTUATOR.

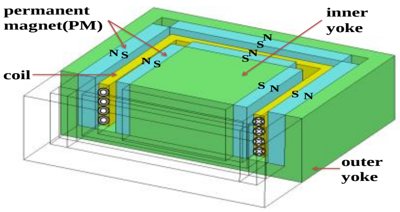


Fig. 1. Schematic diagram of linear actuator.

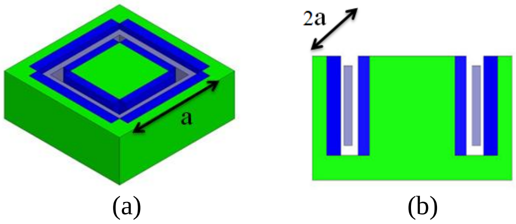
Figure 1 shows a schematic diagram of the quadratic linear actuator. It consists of a moving inner and outer yoke, a permanent magnet (PM), coil, spring, and coil housing around the coil.

In this research, we applied the moving magnet method. While coil and the coil housing are fixed, the yoke and PM are constantly moving.

The yoke and the PM are one rigid body and it moves up and down by using both of the stored spring energy and the magnetic force while the coil is fixed. The Lorentz Force, which explains the relationship between the PM and the current applied to the coil, is used to make a movement of the actuator. The direction of its motion is determined by the direction of the current flow in the coil. During this process, the PM and the yoke reciprocate rapidly with regular strokes. The maximum displacement of the yoke and the PM are designed to move ±20 mm. The spring force depends on the displacement of the yoke and the PM.

III. 2-D EQUIVALENT FE MODEL

In order to simulate the linear actuator, we made 3-D model in figure 2-(a). We assume the length of inner magnet or coil or outer magnet to '**a**' in 3-D model. As 3-D model transient simulation takes a tremendous amount of time, the equivalent 2-D model is required. Therefore, we created the cross-sectional 2-D FE model as shown in figure 2-(b) for transient simulation. In 2-D equivalent model, we also can assume the depth of equivalent model to '**double a(2a)**' to consider disappeared front and back part in the 3-D model. The original outer permanent magnet length is 50mm in 3-D model and equivalent model length is 100mm. However, there is a lot of error using this method. Therefore, we present how to determine the depth which means the effective coil length of cross-section to make an equivalent model.



(a) (b)

Fig. 2 Simulation model (a) 3-D model (b) equivalent 2-D model

The lorentz force to drive the actuator, it is expressed by a cross vector between a flux density and coil length as the equation below (1)

$$F_{magnetic} = ni\vec{B}_g \times \vec{l} \qquad (1)$$

So when the flux density is perpendicular to coil length, the Lorentz force is maximum. Figure 3 shows the direction of the flux density at part1 and part2.

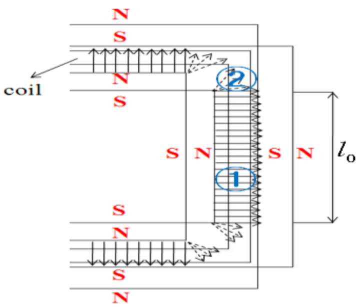


Fig. 3 The direction of the flux y at part1 and par2

Looking at the flux density of the inner magnet, at the part1, it has a horizontal direction to the outer permanent magnet within a inner magnet length. But like the part2, at an edge of the inner magnet, the flux density has a diagonal direction. In order to calculate the effective coil length, we divided an edge part of the inner magnet into five parts.

Figure 4 shows the direction of the flux divided into five parts at edge part.

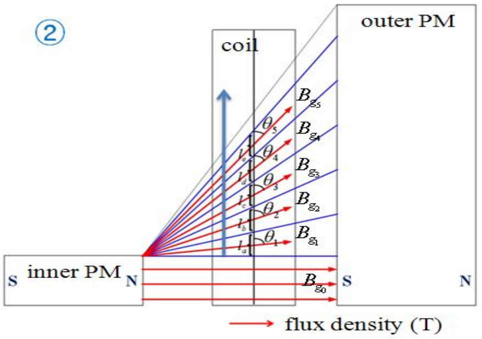


Fig. 4 The directions of the flux in five divided edge parts

Figure 5 shows the flux density of an edge part versus distance. The magnitude of diagonal flux density from B_{g1} to B_{g5} are different.

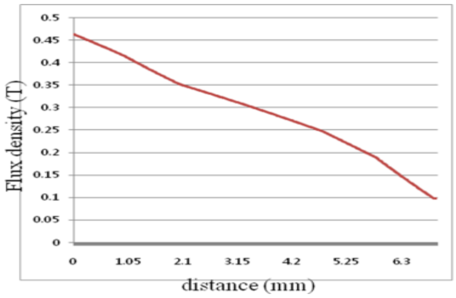


Fig. 5 the flux density at an edge part versus distance.

So the equation for calculating the effective coil length according to the distance due to changes in magnetic flux density is required weight $w\left(\frac{B_{gn}}{B_{g0}}\right)$. The equation for calculating the effective coil length is expressed as the equation below (2)

$$l_n = l_k \sin\theta_n \times w_n \qquad n = 1,2,3,4,5$$
$$k = a,b,c,d,e \qquad (2)$$

Therefore, when considering all the remaing edges the final effective coil length was determined as the equation below (3)

$$l_{eff} = \{l_0 + 2(l_1 + l_2 + l_3 + l_4 + l_5)\} \times 2 \qquad (3)$$

IV. RESULT AND DISCUSSION

Table 1 shows results of the static analysis versus input current and the error ratio.

TABLE I
Result of the static analysis and lumped parameter analysis versus input current and the error ratio.

	simulation		
	3D full model	2D equivalent model	
current (A)	magnetic force(N)	magnetic force(N)	error(%)
		70mm	Simulation
3	40.25	41.3	2.5
4	54.8	55.12	0.58
5	69.4	68.9	0.7

Figure 6 shows the excitation force of the actuator at input frequency 50hz.

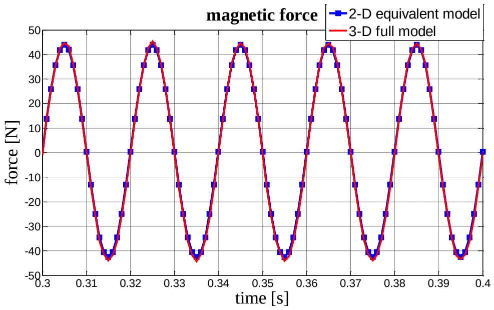


Fig. 6. The excitation force of the actuator at input frequency 50hz.

Through the simulation results, We can verify error about 2.5% when we compared the simulation results of the 3-D full model and 2-D equivalent model. Therefore, the proposed method to calculate the effective coil length is shown to be effective.

V. REFERENCES

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