Design of Electromagnetic Linear Actuator by Using the Equivalent Magnetic Circuit Method

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This paper is concerned with the design variations of electromagnetic linear actuator with divided coil excitation system such as colenoid (COL) and multipoler solenoid(MPS) by using the equivalent magnetic circuit (EMC). At first, the magnitude and direction of magnetic flux in each pole can be obtained by using the EMC method. And magnetic flux density of each pole region is calculated by the superposition principle. To make the magnetic flux density uniform in each pole, pole width is adjusted by the iteration method. Comparing with the initial model having equal pole distance, the generated clamping force of optimized model with EMC has increased and almost same force characteristics with the optimization results by the response surface methodology (RSM). Based on the results with EMC method, the characteristics of electromagnetic linear actuator are investigated with the variation of slot width. An electromagneic linear actuator is developed to produce clamping force of 40kN and the experimental results show that it can be used to hold workpiece firmly instead of the pneumatic cylinder in chucking system.

Index Terms **—Colenoid, electromagnetic actuator, equivalent circuit, multi polar solenoid.**

I. INTRODUCTION

Many variations on the linear actuator design have been created by applying hydraulic power to obtain large force over long stroke. However, the hydraulic actuation system necessarily should have too many components for proper operation such as hydraulic pump, valve module, connecting hose and so on. It is also commonly difficult to achieve continuous force control and get fast response time.

Electromagnetic linear actuators have been proposed to overcome the drawbacks of the hydraulic actuators. They are becoming more popular in automotive industries due to their improved dynamic response, high accuracy and high efficiency compared to the hydraulic or pneumatic systems. In addition, they are environmentally friendly design since they could keep the work area clean. And thus they have been developed in many applications such as engine valve actuator, chucking system, fast oscillating system and so on [1]. However, electromagnetic linear actuators have a relatively low force density and have been applied to the applications requiring short stroke in comparison to hydraulic actuator. To compenaste for these disadvantages, various coil excitation methods for electromagnetic linear actuator are proposed such as colenoid (COL) and multipoler solenoid (MPS), and their performances are analyzed based on the finite element analysis [2]. The table of orthogonal array and response surface methodology (RSM) are also applied to maximize the clamping force and analysis results reveal that the clamping force can be maximized when the magnitude and distribution of magnetic flux density is uniform at the air gap region of stator teeth [3]. However, this method requires many finite element analyses and is difficult to analyze the influences of slot and number of turns on the inductance as well as the clamping force.

This paper is concerned with the design variations of electromagnetic linear actuator with divided coil excitation system, COL and MPS. Using the equivalent magnetic circuit (EMC) method, the clamping force is analyzed with the variation of slot width and applied magnetomotive force (MMF). Based on the proposed method, an electromagnetic linear actuator with the clamping force of 40kN is developed.

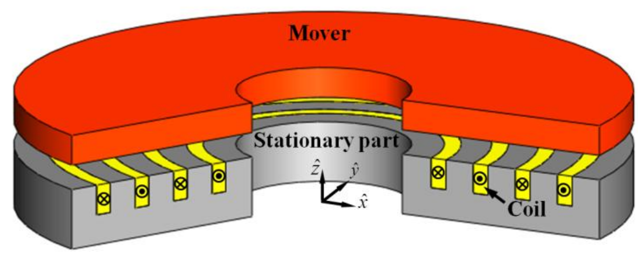

Fig. 1. 3-D view of electromagnetic linear actuator.

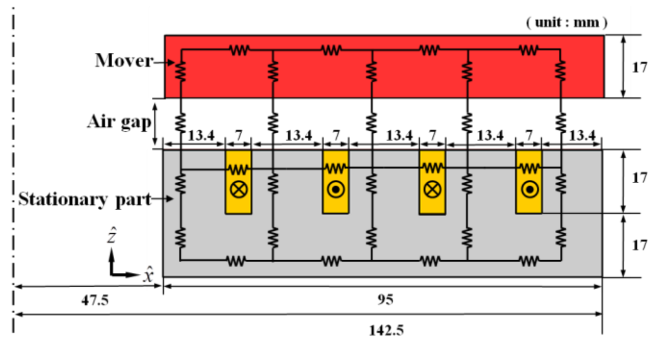

Fig. 2. Cross-sectional view of electromagnetic linear actuator.

II. DEVELOPMENT OF ELECTROMAGNETIC LINEAR ACTUATOR

A. *Design and analysis of linear actuator by EMC method*

Fig. 1 shows a 3-D view of electromagnetic linear actuator having COL excitation. It consists of a stationary part with coils having alternating polarity in adjacent positions and a mover. If the MMFs of the all coils have the same direction, it is called MPS excitation [2]. Fig. 2 shows a cross-sectional view of axisymmetric model and corresponding EMC of electromagnetic linear actuator [4]. When the number of slot and slot width are determined, each pole width should be adjusted to maximize clamping force. At first, when one coil is excited, the magnitude and direction of magnetic flux in each pole can be obtained by using the EMC method. And magnetic flux density of each pole region is calculated by the superposition principle. To make the magnetic flux density uniform in each pole, pole width is adjusted by the iteration method. Table I shows pole width by RSM and EMC method when the slot number is 5. Fig. 3 shows profiles of clamping force of the intial model having equi-distance pole width with ones by RSM and EMC method. Comparing with the initial model, the optimized model with EMC has increased force and almost same force characteristics with the results by RSM in every MMF region.

Based on the results with EMC method, the clamping force of electromagnetic linear actuator are investigated with the variation of slot width as shown in Fig. 4. The number of turns is changed by maintaining the slot fill factor. When the input current is small, the generated clamping force is mainly influenced by the applied MMF. However, as increasing the input current, the saturation level of the stator pole is dominant factor in the developed force.

TABLE I
COMPARISON OF POLE WIDTH AMONG INITIAL, RSM AND EMC MODEL

Design variables		Initial model	RSM model	EMC model
Width of pole (mm)	pole 1	13.4	8.6	9.1
	pole 2	13.4	16.7	17.1
	pole 3	13.4	16.7	17.9
	pole 4	13.4	16.7	16.0
	pole 5	13.4	8.2	6.9

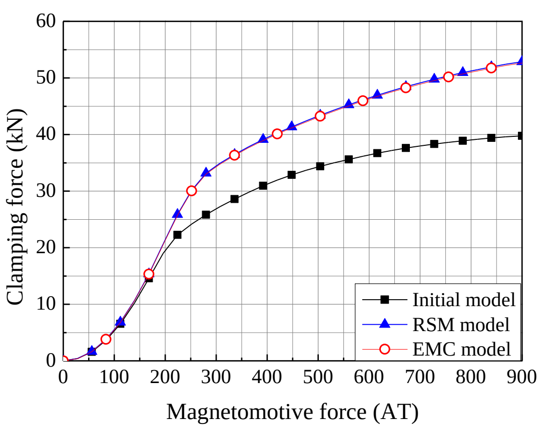

Fig. 3. Comparison of clamping force between initial model and the optimized model by using the RSM and EMC.

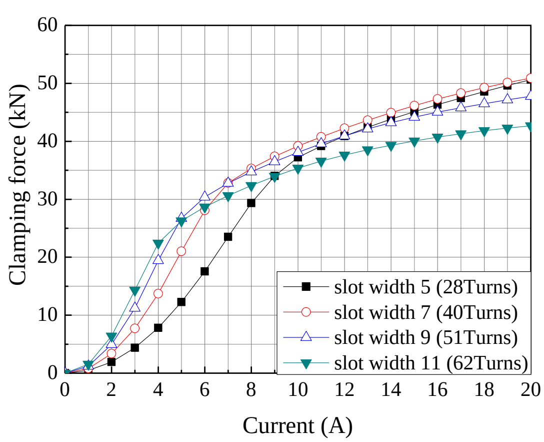

Fig. 4. Clamping force of electromagnetic linear actuator with the variation of slot width.

B. Development of linear actuator

In the lathe, the pneumatic cylinder is usually used to hold workpiece firmly. Even though the ranges of clamping force are different with the size of chuck, it requires very high force over 30kN up to 120kN. There is also constraint on the allowable diameter to produce such a big force. Therefore, it is very challenging to exchange the pnumetic system with electrical system. One possible solution is to combine chucking system having high force and linear motion device producing small thrust over relatively long stroke. Fig. 5 shows the developed chucking system with the divided coil excitation. It is designed to produce over 40kN with diameter of 285mm. As shown in Fig. 6, though the experiment results is different from the optimized model with EMC due to the manufacturing tolerances, the clamping force is generated more than 40kN. Therefore, the electromagnetic linear actuator can be used to hold workpiece firmly instead of the pneumatic cylinder in chucking system.

Fig. 5. Developed clamping device.

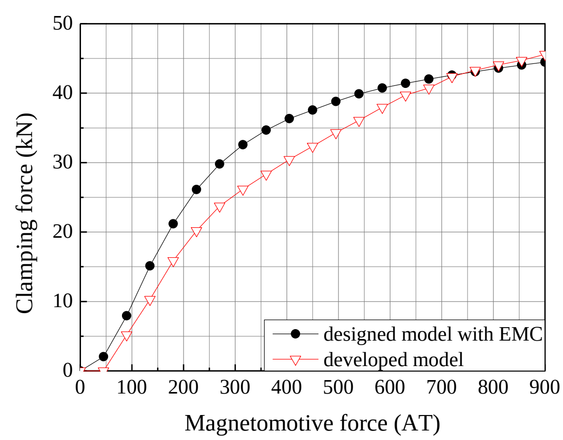

Fig. 6. Comparison of clamping force by anaylsis and experiment.

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