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A novel design of active accelerator pedal using linear electromagnetic actuator†

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Abstract

This paper describes a novel design of an active accelerator pedal(AAP) using a linear electromagnetic actuator that transfers warning messages recognized by the automobile from the sensors to the driver. In an emergency driving situation, the electromagnetic actuator creates additional pedal forces such as active pedal force and vibration force. In a passive situation however, the actuator does not produce additional force. In the past, a system with a rotary actuator was developed for AAP but was found to have critical drawbacks such as inaccurate movement by backlash and torque occurrence due to the high gear ratio. This research, therefore, aims to solve these drawbacks and maximize car safety by optimizing the electromagnetic linear actuator. Finite element analysis is performed to analyze the coupled system of electric, magnetic, and mechanical subsystems, and to characterize the dynamic performance of the proposed actuator system. A novel design of the AAP system with the optimized electromagnetic linear actuator is developed. The dynamic characteristics of the AAP system are simulated by a 3D dynamic analysis software program. Satisfactory results were obtained. Finally, the test result and the simulation result of the AAP system are compared.

Keywords: Active accelerator pedal; Electromagnetic linear actuator; Finite element method; Magnetic field analysis; Mechanism design; Permanent magnet

1. Introduction

Traffic accidents occur frequently and often lead to casualties. Collision comprises a high percentage among the many types of accidents. According to the 2006 statistics, collision comprised 20% of all accidents in the United States, 44% in Europe, 57% in Japan, and 46% in Korea [1, 2].

These accidents are largely attributable to human factor. In 85% of the cases, human error was a decisive determinant of accidents. The reasons are usually inappropriate speed, inadequate vehicle distance, insufficient attention, and so on.

The most important interaction between the driver and the vehicle is the method by which the driver is warned of a hazardous situation and is made fully aware of the information provided.

The active accelerator pedal (AAP) works by warning the driver directly through sensory stimulation; the hazard warning is felt directly by the driver's foot, making the driver aware of the situation in the quickest and most reliable way. Thus, the AAP offers an opportunity to lower the number of traffic fatalities.

This paper introduces the electromagnetic linear actuator for the AAP system, which transfers warnings to the driver. In an emergency driving situation, the electromagnetic linear actuator creates an additional pedal force, such as an impact or vibration, and transmits the force to the driver's foot so that the vehicle reduces speed quickly.

In the past, an AAP system with a rotary actuator was developed, but it had critical drawbacks such as inaccurate movement by backlash and torque occurrence due to the high gear ratio. Therefore, this research aims to solve these drawbacks and maximize car safety by optimizing the electromagnetic linear actuator. Finite element analysis (FEA) is performed to analyze the coupled system of electric, magnetic, and mechanical subsystems and to characterize the dynamic performance of the proposed actuator system. Fig. 1 shows the operating structure of the AAP system.

2. Analysis of the actuator for AAP

2.1 Active accelerator pedal system

When the AAP system is operating, the accelerator pedal has to transmit a counterforce so that the driver could feel the impact or the vibration. Drivers generally press the accelerator pedal at about 30 N~40 N. The AAP system should be able to produce the same force or more; otherwise, the driver would not feel any warning force.

As shown in Fig. 2, the counterforce is composed of two

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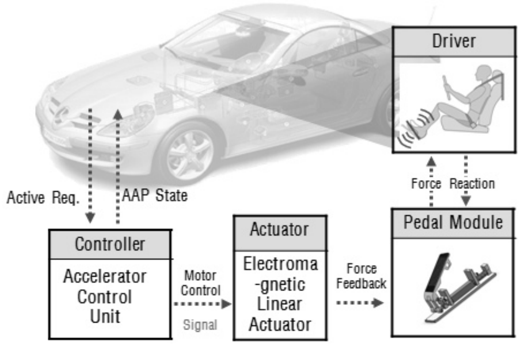


Fig. 1. Schematic diagram of the development of the actuator for active accelerator pedal system.

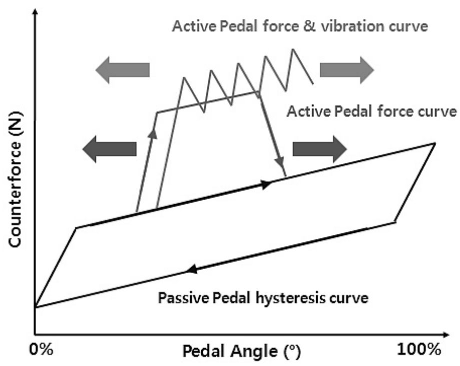


Fig. 2. Active and passive pedal curves of the active accelerator pedal system.

forces, namely, the passive spring force and friction, which produces hysteresis and the active force, which gives the additional counterforce of the active pedal force and vibration force.

The spring and friction in the pedal system has to produce hysteresis because hysteresis makes the pedal return to the original position with lower force than pressing force on the pedal.

Until now, a rotary type actuator has been used to produce the active pedal force. Two types of rotary actuators transmit the actuator force to the driver: cable and geared. The cable type does not produce the vibration force, while the geared type has drawbacks such as inaccurate movement by backlash and torque occurrence due to its high gear ratio. Therefore, in this study, an electromagnetic linear actuator is considered to resolve these shortcomings.

2.2 Magnetic analysis of the optimized electromagnetic linear actuator

The designed electromagnetic linear actuator is shown in Fig. 3. Using an electromagnetic analysis software, Maxwell 2D, we carried out a FEA to determine the size of the actuator. Fig. 3(a) shows the axial cross-section of the complete actuator, and Fig. 3(b) schematically illustrates the multiphase stack of the stator. The concentrated type stator winding was used because it was easy to manufacture [3-5].

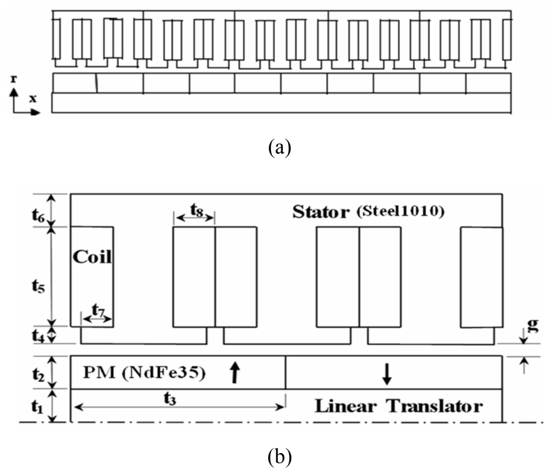


Fig. 3. (a) Axial cross-section of the electromagnetic actuator: (a) the complete actuator and (b) the axial cross-section of one pole pair of the linear actuator.

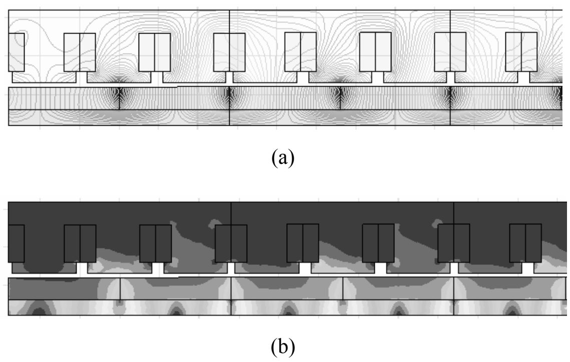


Fig. 4. Electromagnetic analysis result of the linear actuator obtained by finite element analysis: (a) flux distribution and (b) magnetic intensity distributions.

The design variables for optimization and boundary conditions constituting a realistic design are as follows:

- The space inside cars is limited; thus, the size of the actuator cannot be enlarged infinitely. Here, the length is assumed to be 140 mm, and the outer diameter of the stator is 30 mm.
- The current used in a car is limited to a maximum of 10 A. Thus, the excitation current in the coils is less than 10 A.

As shown in Fig. 4, the linear actuator under the upper constraints yields 40 N of the axial moving force of the shaft at a 5 A current.

2.3 Dynamic simulation of the AAP system

As shown in Fig. 5, the AAP system is simulated by the RecurDyn dynamic analysis engineering software. When the force of the driver's foot is applied to the pedal and the actuator is in the passive mode, the AAP system does not operate except by active force. Fig. 6 shows that the actuator produces forces according to AAP condition, depending on whether they are passive or active forces.

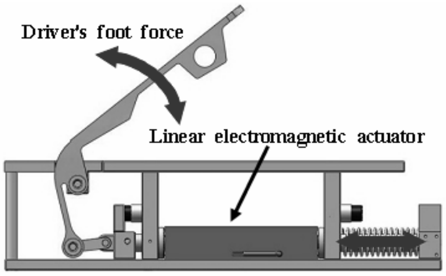
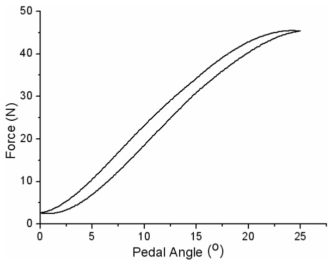
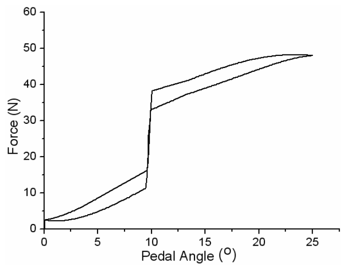


Fig. 5. Novel design of an AAP system with the electromagnetic linear actuator, the shaft with the spring moves in the axial direction when the pedal is rotated by the driver.



(a)



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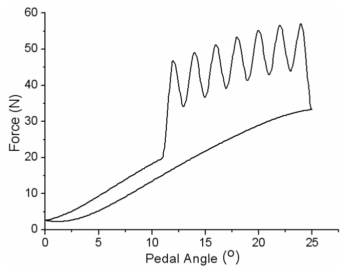


(c)

Fig. 6. Dynamic simulation reaction force according to pedal angle: (a) hysteresis curve in passive mode, (b) hysteresis curve upon active pedal force, (c) hysteresis curve upon active vibration force at the pedal rotating angle of 25.5° .

2.4 Development and experiment of the AAP System

The novel design of the AAP system is based on the concept that a rotary actuator is changed to a linear actuator to generate simple motion [6]. Fig. 7 shows the developed AAP. The pusher with the force sensor applies a condition of constant velocity movement to the pedal from which the linked linear actuator moves left and right. When an emergency occurs, the actuator adds the additional force. Fig. 8 shows that the result of the test for each condition is the same as that of the simulated condition.

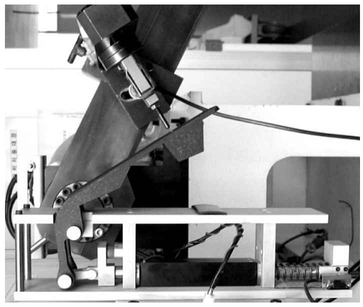
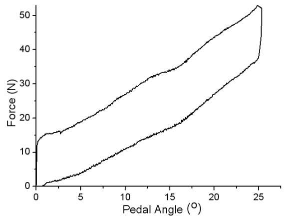
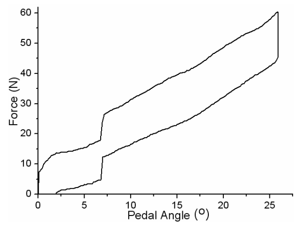


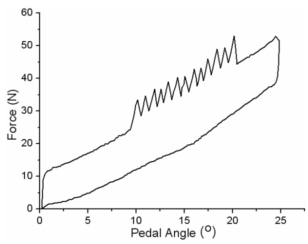
Fig. 7. AAP experimental setup.



(a)



(b)



(c)

Fig. 8. Experimental results: (a) passive condition, (b) active pedal force applied, and (c) active vibration force applied.

In the simulation shown in Fig. 6, the hysteresis is 6 N; otherwise, the experimental hysteresis is 17 N. The simulation result differs from the experiment result because the simulation does not consider the exact material constant and friction characteristics. Despite this difference, the trend of the force curves between the experiment and the simulation is almost the same at the same force condition.

3. Conclusions

This paper described a novel type of AAP system using an electromagnetic linear actuator for applications requiring active pedal motion.

The additional active force produced by the electromagnetic linear actuator for the AAP was analyzed. The result of the electromagnetic analysis was shown and compared with the result of the experimentation of the novel AAP system. The curves of the pedal angle and sensing force on the pedal with the force sensor showed the same trend depending on the condition, passive, active pedal force, and active vibration force.

Therefore, this research reveals the possibility of replacing a rotary actuator with a linear actuator to develop a novel design of the AAP system.

In this research, the cogging force is not considered, although it may exist due to the material characteristic of the stator. Future work will consider the amount of cogging force and its effect on the performance of the actuator to develop a new actuator with reduced cogging force.

Acknowledgment

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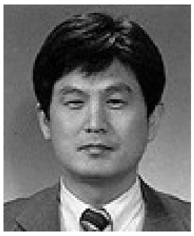

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