A Study on Improvement of Operation Efficiency of Magnetic Levitation Train Using Linear Induction Motor

Sang Uk Park*, Chan Yong Zun*, Doh-Young Park**, Jaewon Lim** and Hyung Soo Mok†

Abstract

In this paper, a study on the efficiency improvement of the magnetic levitation train using the LIM (Linear Induction Motor) was presented. The maglev train has the advantage of being environmentally friendly since much less noise and dust is produced. However, due to structural limitation, compared to a rotating induction motor, linear induction motor, the main propulsion engine of the maglev train has a relatively greater air gap and hence has the lower operation efficiency. In this paper, the relationship between the operating condition of the train and the slip frequency has been investigated to find out the optimum slip frequency that might improve the efficiency of the magnetic levitation train with linear induction motor. The slip frequency is variable during the operation by this relationship only within a range that does not affect the levitation system of the train. After that, the comparison of the efficiency between the conventional control method with the slip frequency fixed at 13.5[Hz] and the proposed method with the slip frequency variable from 9.5[Hz] to 6.5[Hz] has been conducted by simulation using Simplorer. Experiments of 19.5[ton] magnetic levitation trains owned by Korea Institute of Machinery and Materials were carried out to verify the simulation results.

Keywords: Linear induction motor, Propulsion control, Slip frequency, railroad car, ATO, Auto train operation

1. Introduction

The concentration of jobs in metropolitan area and the distribution of population to satellite cities is still on going. Accordingly, medium-distance and short-distance transportation systems became important parts of modern society. Magnetic levitation train, which has the advantages of low noise, less dust and environmental friendly is being developed actively. In this paper, study deals with the improvement of the efficiency of the magnetic levitation train with linear induction motor.

The linear induction motor is similar in fundamental principle but different in structure to the rotary induction motor. Unlike conventional induction motor which has round, cylindrical shape, the linear induction motor has a straight arrangement where the rail takes the role of the rotor and the train takes the role of stator. In such arrangement, several problems occur which is not the case in rotary motor structure. Linear induction motors have finite primary and secondary length, which generates end-effects. While the operation, normal force is created perpendicular to the rail and counteract the levitation force,
makes levitation difficult and unstable. Thus, the slip frequency, the factor that decides the normal force is fixed to 13.5[Hz] to minimize the effect of the normal force and this further decreases efficiency.

To minimize the disadvantages of the linear induction motor, this paper proposed variable slip frequency drive control strategy which allows the slip frequency to vary within a certain range but doesn’t affect the levitation control too much. There are some works associated with improvement of efficiency of linear induction motor for maglev train have been done by varying slip frequency. But few of them deals with slip frequency that is constantly changing according to operating condition.

In this paper, with in a range that doesn’t affect the levitation system, the optimum slip frequency at each operating point is proposed based on rms current control. By applying ATO (Auto Train Operation) system, the cumulative power consumptions of both fixed slip frequency operation and variable slip frequency operation are calculated and compared to prove the efficiency improvement.

## 2. Structure and Operation Characteristics of Maglev Train

### 2.1 Structure of maglev train

As shown in Fig 2, a magnetic levitation train using LIM is mainly consists of a levitation system that generates levitation force to allow train to leviate and propulsion system which generates both propulsion force horizontal to the rail and normal force perpendicular to the rail at opposite direction to levitation force. The levitation force must powerful enough to overcome and balance the weight of the train plus the normal force, otherwise the levitation fails. The normal force must be controlled with in a range that doesn’t affect the levitation system.

### 2.2 Operating condition and slip frequency

#### 2.2.1 Notch command

The propulsion force of the maglev train with LIM is controlled by stator current and the current reference is given by the notch command. As shown in Table 1 and Table 2, the notch commands have 4 levels for acceleration and 7 levels for deceleration. The notch number goes higher with greater propulsion force or braking force. In this manner, the operating condition of the train can be controlled notch commands.

#### 2.2.2 Slip frequency

Fig. 3 (a) illustrated the relationship between slip frequency and normal force. For the same notch command, the normal force increases with decreasing slip frequency, and, the normal force increases when the notch level steps up. Fig. 3 (b) shows the relationship between slip frequency and efficiency. Efficiency goes higher with lower slip frequency under the same notch command, and goes lower when notch command steps up.

Fig. 4 shows the actual experiment result of train a traveling at 50[km/h] with slip frequency changed by notch command based on relationship shown in Fig. 3. Under the same operating condition[P4_B7], the cumulative power consumption was 1,352[kWh] for 13.5[Hz] slip frequency and 1,142[kWh] for 10.5[Hz] slip frequency. The 0.21[kWh] of energy saving by lowering slip frequency implies 15.5[%] of efficiency improvement, verifies the conclusion that efficiency can be improved by lowering the slip frequency.

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<th>Table 1. Notch pattern for propulsion force</th>
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![Fig. 2. Structure of the linear induction motor](image-url)
2.2.3 Speed

Fig. 5 (a) shows the relationship between the speed of train and the normal force with slip frequency fixed at 12.5[Hz]. Normal force increases with the speed decreases and at a certain speed, normal force increases when the notch level steps up. Fig. 5 (b) shows the relationship between speed and normal force under the same condition as Figure (a). The efficiency decreases with speed decreases.

From Figs. 3, 4 and 5, we can draw a conclusion that:
- Small slip frequency brings better efficiency
- Efficiency can be changed by operating condition.

Based on these two conclusions, it is possible change the slip frequency according to operating condition during the operation in order to make the train running with best efficiency. Note that the slip frequency must be restricted within a range that doesn’t affect the levitation system.

3. Simulation

3.1 Simulation condition

The train in this experiment was ran by ATO (Auto Train Operation) system. The ATO system, which is adopted in actual operation, automatically controls the train to accelerate, decelerate and stop between each station, respond to continuous change of operation pattern. Fig. 6 shows the speed pattern and notch command pat-
tern of actual experiment, where the blue curve represents speed and the black curve represents the notch command pattern.

Two simulations have been conducted to compare cumulative power consumption between fixed and variable slip frequency drive. The fixed slip frequency is 12.5[Hz], while the variable slip frequency ranges from 6.5[Hz] to 9.5[Hz]. At the same time, the normal force is limited to -2.5[kN], which does not affect levitation even with full capacity.

3.2 Variable slip frequency during the operation

Fig. 7 illustrates the simulation results. The right side of the figure shows that when slip frequency varies between 6.5[Hz]-9.5[Hz], the normal force changes under -2.19[kN]. It means the normal force didn’t reach the critical value where it could threat the levitation of the train. Fig. 8 simplifies the comparison of the cumulative power consumption. When slip frequency varies between 6.5[Hz]-9.5[Hz], power meter counts 4.25[kWh], and when slip frequency is fixed at 12.5[Hz], it counts 5.34[kWh].

The proposed method saved 1.09[kWh] of energy, improved 20.41[%] efficiency shows better performance over conventional method in terms of energy efficient.

4. Conclusion

This paper proposed a new control method to improve operation efficiency for magnetic levitation train with linear induction motor. Linear induction motor gets better efficiency with lower slip frequency. Thus, within a certain range, changing slip frequency according to notch command during operation can improve overall efficiency. Simulation result shows that compared to 13.5[Hz] fixed slip frequency, the proposed control method saved 1.09[kWh] of energy, and improved efficiency by 20.41[%], proves better performance over conventional method in terms of energy efficient.

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References

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