Characteristic Analysis of a Rotary Model of a Linear Induction Motor used for an Urban Railway Transit

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ABSTRACT: A linear induction motor for an urban railway transit is accompanied with the end-effect and large air-gap comparing with a rotary induction motor. These cause a large amount of discrepancy between simulation results and experiments. In order to figure out the difference, experiments based on a real-scale test bed are indispensable, however building a test-line and a test vehicle is so difficult that authors are going to make a small-scale model and simulate it for comparison. In this paper, a rotary-type small-scale model of a linear induction motor is designed. Thrust and normal force of the model have been analyzed with the variation of frequency and speed by using a Finite Element Method (FEM).

1 INTRODUCTION

As demands for cost-effective, less susceptible to weather, and reliable means of public transportation have increased, Korean government has taken into account the linear electric railway system (Linear metro) since the late twenty century. Linear metro gets the propulsion force from a liner motor different from a conventional rotary motor and it produces thrust force electromagnetically without using any friction force. Therefore, it does not use any mechanical coupling for the rectilinear movement.

The linear electric railway system is called as non-adhesion drive system, where as conventional railway system is called as adhesion drive system which gets the propulsion force from the friction between wheel and rail. This non-adhesion drive system has lots of advantages over the adhesion drive system as follows; (1) Excellent acceleration and deceleration, (2) Lower construction cost due to the small tunnel cross-section, (3) Capability of climbing steep gradients, (4) Enable flexible route planning (travel through sharp curves), (5) Less susceptibility to weather conditions, (6) Quiet and smooth running (No mechanical couplings), (7) Less maintenance cost. Consequently, the linear electric railway system is already in use in all over the world and continuously being extended.

Figure 1 shows the concept of a linear motor derived from a rotary motor. It is a conventional rotary motor whose stator, rotor and windings have been cut open, flattened, and placed on the guide way [1].

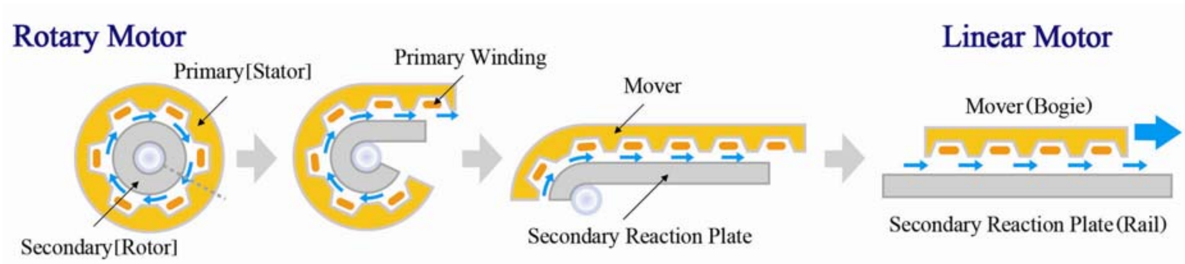

Figure 1. Concept of a linear motor from a rotary motor [4].

Even though the operating principle is exactly the same as a rotary motor, the linear motor has a finite length of a primary or secondary part and it causes ‘end effect’ and ‘transverse edge effect’. Moreover, the large airgap lowers the efficiency. However, the linear motor is superior to the rotary motor in the case of rectilinear motion, especially for a railway transit.

Among many kinds of linear motors, linear induction motor (LIM) is preferable to the urban railway transportation system because the construction cost is much lower than that of a linear synchronous motor (LSM), even though the efficiency and performance is little bit poor. The operating principle of a LIM is identical to a rotary induction motor. Space-time variant magnetic fields generated by the primary part cross the airgap and induce the electromotive force (EMF) in the secondary part, a conducting sheet. This EMF generates the eddy currents, which interact with the airgap flux and so produces thrust force known as Lorenz’s force [1]-[3].

The Short-Primary (SP) type which is generally applied for a low-medium speed urban lightweight transit, is very easy to lay conducting sheets on the guideway and thereby reduces construction costs. However, the SP type has low energy efficiency because of the drag force and the leakage inductance caused from the end effect [1]. Figure 2 represents a practical application for railway systems.

The end-effect and large air-gap comparing with a rotary induction motor cause a large amount of discrepancy between simulation results and experiments. In order to figure out the difference, experiments based on a real-scale test bed are indispensable, however building a test-line and a test vehicle is so difficult that a rotary-type small-scale model of a linear induction motor is designed and authors are going to simulate it for comparison with experiment.

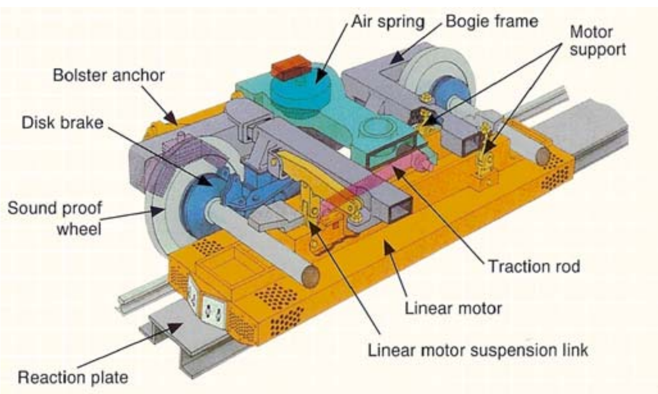

Figure 2. Practical application for railway systems [5].

2 ANALYSIS OF A ROTARY-TYPE SMALL-SCALE MODEL

2.1 Rotary-type Small-scale LIM Model

Figure 3 shows the rotary-type small-scale model for a LIM. As shown in the figure, the secondary unit is designed as a body of rotation with 1 m diameter. The airgap is 5 mm which is different from a real-scale model. For a reaction plate, 5 mm of aluminum and 22 mm of back-iron are used.

As the pole number affects to the end-effect significantly, it should be designed so as for the end-effect to be less than 10 %. For a real-scale model, the number of pole is eight but for a small-scale model, it is chosen as four considering of the length of the primary unit.

3-way load cells are also installed to measure the thrust force, lateral force and normal force.

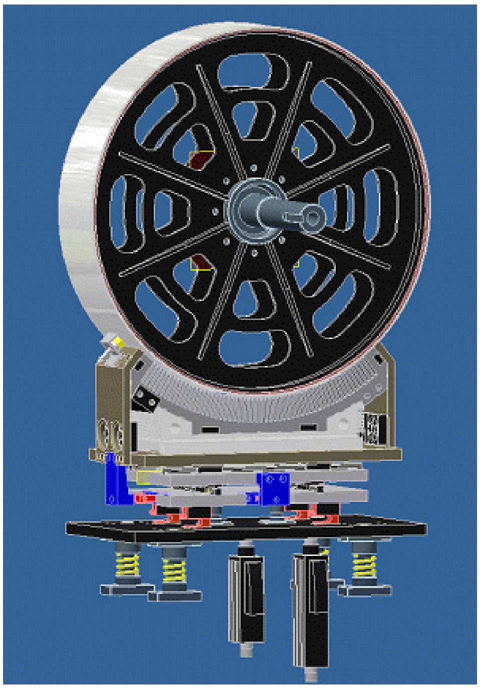

Figure 3. Rotary-type small-scale LIM model.

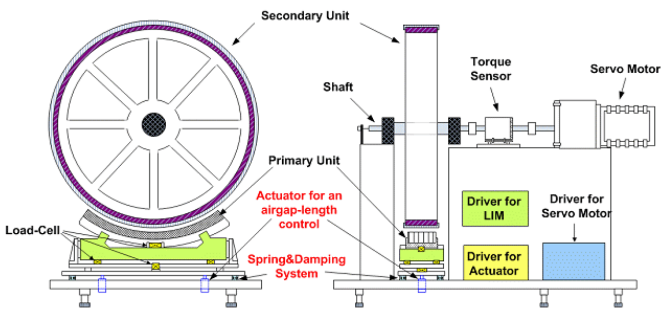

Figure 4. Test-bed of a rotary-type small-scale LIM model.

Figure 4 shows the test-bed of a rotary-type small-scale LIM model. As a load and brake system, a servo motor is connected with the shaft of the wheel through a torque sensor. Each driver for the LIM, actuator and servo motor is laid down in the surface plate. The other specifications are chosen by considering of efficiency and practicability. Table 1 represents the specifications of the small-scale model.

Table 1. Specifications of the rotary-type small-scale model.

Rated Power	10 kW	Number of Pole	4
DC Input Voltage	445 V	Primary Weight	56 kg
Rated Frequency	37 Hz	Number of slot per pole per phase	4
Rated Speed	8.52 m/s	Mechanical Airgap	5 mm
Rated Slip	0.2	Aluminum Thickness	5 mm

2.2 *Characteristic Analysis of the Model using Finite Element Method (FEM)*

Eddy current problem which has a two-dimensional traveling magnetic field, in general, has some assumptions as follows; (1) Every current has only z-direction, (2) It is a quasi-steady state neglecting displacement current, (3) Conductivity of the primary side is zero, (4) Permeability of the primary and the secondary back-iron is constant, (5) The primary moves x-direction only.

The governing equation of the two-dimensional analysis model which neglects the displacement current is as Equation 1.

$$\frac{1}{\mu}\left(\frac{\partial^2 A}{\partial x^2}+\frac{\partial^2 A}{\partial y^2}\right)=-J_o+\sigma\left(\frac{\partial A}{\partial t}+v_x\frac{\partial A}{\partial t}\right) \qquad (1)$$

Here, A = z-directional magnetic vector potential; J_o = exciting current density; σ = conductivity; μ = permeability; and v_x = moving speed of LIM.

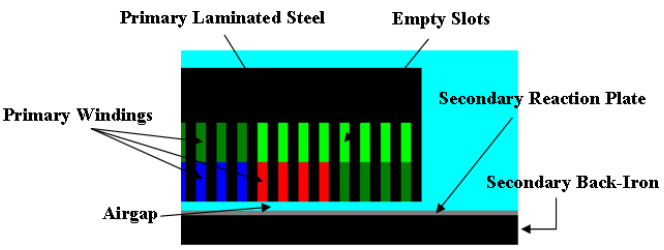

Figure 5. Two-dimensional analysis model (End part).

For the characteristic analysis of the model, a commercial magnetic analysis program, MAXWELL 2D, is used.

Even though there are so many types of the secondary reaction plate, semi-cap type is used in a real-scale and rotary-type small-scale model for better performance. As the semi-cap type of the secondary has inherently 3-dimensional shape, the equivalent secondary conductivity is applied for the 2-D analysis [6].

2.3 *Simulation Results*

Figure 6 shows the thrust and normal forces of the model in the state of 5 mm airgap. As the input frequency increases, the thrust force decreases as expected. For the normal force, as the input frequency increases, the repulsive force replaces the attraction force.

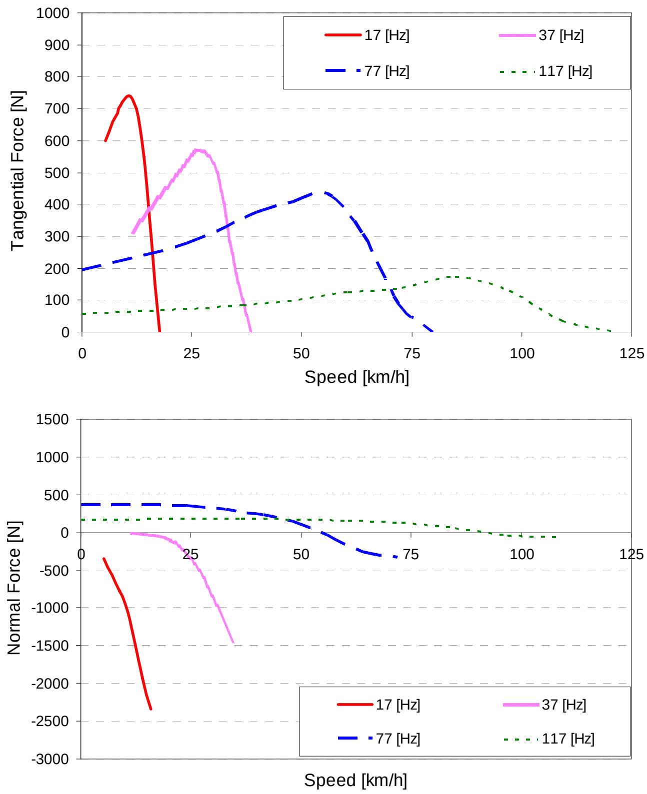

Figure 6. Thrust and Normal forces of the model.

3 CONCLUSIONS

Analysis of a linear induction motor which has a large airgap is inaccurate quantitatively. Therefore, real-scale model should be built, measured and compared with a simulation. However building a test-line and a test vehicle is so difficult that authors designed a rotary-type small-scale LIM model and simulate it for comparison. Thrust and normal force of the model have been analyzed with the variation of frequency and speed by using FEM. In the near future, the model will be made and experimented. The comparison between simulation and experiment will be followed.

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