Modeling of a Maglev Vehicle Considering Flexibility

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ABSTRACT: In an EMS-type Maglev vehicle, the flexibility of the bogie frame may affect the acceleration of the electromagnet that is input into the control system, which could lead to instability in some cases. For this reason, it is desirable to consider bogie frame flexibility in air gap simulations, for the optimization of bogie structure. The objective of this paper is to develop a flexible multibody dynamic model of 1/2 of an EMS-type Maglev vehicle , and to compare the air gap responses obtained from the rigid and the flexible body model. The feedback control system and electromagnet models that are unique to the EMS-type maglev vehicle must be included in the model. With this model, dynamics simulations are carried out to predict the air gap responses from the two types of models, and the air gaps are compared. Such a comparative study could be useful in the prediction of the air gap in the design stage, and in designing an air gap control system.

1 INTRODUCTION

In an EMS (Electromagnetic suspension)-type Maglev (Magnetically-levitated) vehicle, the feedback control system typically uses the measured air gap and the vertical acceleration of the electromagnet attached to the bogie frame on the vehicle to maintain the air gap, which is the distance between the electromagnet and the guiderail within an allowable range. The flexibility of the bogie frame may affect the acceleration of the electromagnet that is input into the control system, which could lead to instability in some cases. For this reason, it is desirable to consider the flexibility of the bogie frame in the air gap simulation, in order to optimize bogie structure. The objective of this paper is to present a flexible multibody dynamic model of an EMS-type Maglev vehicle, and to compare the air gap responses obtained from the rigid and the flexible body model. The basic modeling procedure is almost the same as in other applications. However, the feedback control system and electromagnet models that are unique to the EMS-type maglev vehicle must be included in the model. With this model, dynamics simulations are carried out to predict the air gaps obtained from the two types of models, and the air gaps are compared. This type of comparative study could be useful for prediction of the air gap in the design stage, and in designing an air gap control system.

2 MODDEL

2.1 Vehicle

The 1/2 vehicle in Figure 1 was manufactured for functional testing of levitation and propulsion. The experimental vehicle is composed of 2 bogies, of which has 8 electromagnets.

2.2 Modeling Procedure

The flow and structure of the technique employing flexible multibody dynamics is shown in Figure 2. Equations of motion of a constrained system with a flexible body and its features are presented in reference [3-4]. Vibration and static correction modes from a finite element code are used to account for the linear elastic deformation of flexible bodies. This theory has already been incorporated into some general-purpose spatial dynamics codes. The study uses LMS Virtual.Lab Motion as a dynamic analysis code for generating and solving equations of motion. The bogie is modeled as a flexible body through modal superposition. ANSYS is used to carry out both vibration and static analysis, interfacing with LMS Virtual.Lab Motion. Important issues addressed in the modeling and simulation process shown in Figure 2 are as follows:

- LMS Virtual.Lab Motion performs the modeling of bodies and their geometries, joints, suspensions, and levitation control systems, and specifies the initial conditions of dynamic simulation. The equations of motion of the system are then integrated in the program using a variable-step, variable-order numerical integration algorithm.
- Equations of the magnetically-levitated system that will be given in the next section are defined in the user-defined subroutine of LMS Virtual.Lab Motion. The user-defined subroutine senses the air gap (i.e. the distance between the electromagnet and the guideway), its derivative, and the absolute vertical acceleration of the electromagnet. The subroutine then evaluates the system of differential equations of the levitation system, and calculates the levitation forces. The forces are then applied to both the electromagnet and the guideway in the subroutine.
- The ANSYS software is used to create finite element models for the guideway, and to carry out both vibration and static analysis. Boundary conditions for vibration and static correction mode analysis must be properly chosen in order for gross motion and local deformation modes in operation to be considered in the analysis. Here, the boundary conditions and load cases are automatically generated, using LMS Virtual.Lab Motion in ANSYS format.

Figure 1. Experimental 1/2 Maglev vehicle.

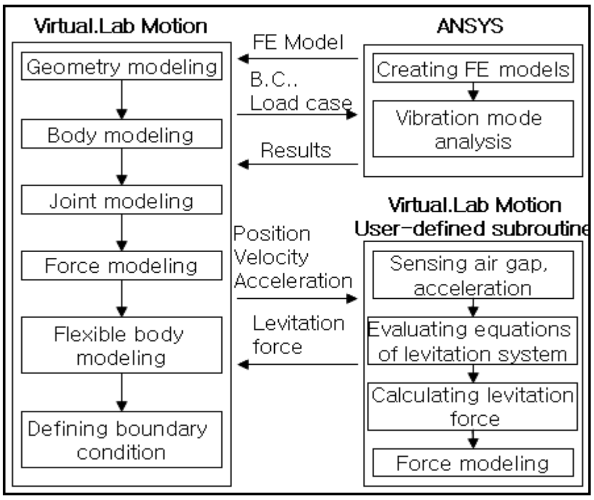

Figure 2. Modeling and simulation process of the rigid vehicle and flexible bogie model.

2.3 Electromagnet

The principle of the electromagnet is illustrated in Figure 3. The levitation force or lift force $F_z(t)$ and guidance force $F_y(t)$ are functions of the air gap $c(t)$, lateral air gap or displacement $d(t)$, and current $i(t)$.[2]

$$F_z = F_0 \times \left[1 + \frac{2c(t)}{\pi w_m} + \frac{2d(t)}{\pi w_m}\tan^{-1}\left(\frac{c(t)}{d(t)}\right)\right] \tag{1}$$

$$F_y = F_0 \times \left(-\frac{2c(t)}{\pi w_m}\tan^{-1}\left(\frac{d(t)}{c(t)}\right)\right) \tag{2}$$

where F_0: idle levitation force (N); F_y: guidance force (N); F_z: levitation force (N); d: lateral air gap (m); c: air gap (m); w_m: magnet width (m).

To more accurately calculate the levitation and guidance forces in consideration of the relative position and orientation, the electromagnet's pole face is piecewised along the length of the pole face, as shown in Figure 4.

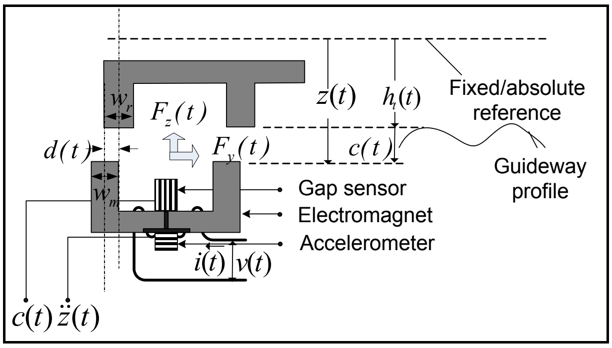

Figure 3. Principle of electromagnetic suspension.

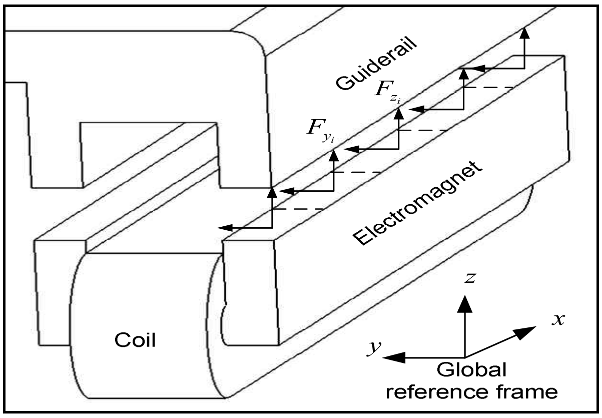

Figure 4. Piecewise electromagnet model.

The vehicle employs the 5 states feedback control law to maintain the change in air gap within an allowable magnitude [1]. Using the control law, the controlled voltage is determined by

$$\Delta v(t) = k_1 \Delta\hat{\ddot{z}}(t) + k_2 \Delta\hat{\dot{z}}(t) + k_3 \Delta\hat{z}(t) + k_4 \Delta\hat{\dot{c}}(t) + k_5 \Delta\hat{c}(t) \tag{3}$$

where $\Delta\hat{\ddot{z}}(t)$: *acceleration;* $\Delta\hat{\dot{z}}(t)$:*velocity;* $\Delta\hat{z}(t)$: *position,* $\Delta\ddot{e}(t)$: *air gap velocity;* $\Delta\ddot{o}(t)$: *air gap;* k_1, k_2, k_3, k_4, k_5: *control gains.*

2.4 Integrated Model

Except for the electromagnet, the flexible multibody model for the vehicle is created in a normal manner in the multibody dynamics field. The resulting model is shown in Figure 5. The frames of the bogies are all modeled as flexible bodies. For this study, as the attention is on the bogie, the carbody and guideway are represented as rigid bodies. As stated in the previous section, all calculations and tasks required for the electromagnet are processed in the user-defined subroutine. The bogie consists of 2 side frames, 4 anti-roll beams, 2 linear induction motors, 4 air springs, and 2 traction rods, as shown in Figure 6 and 7.

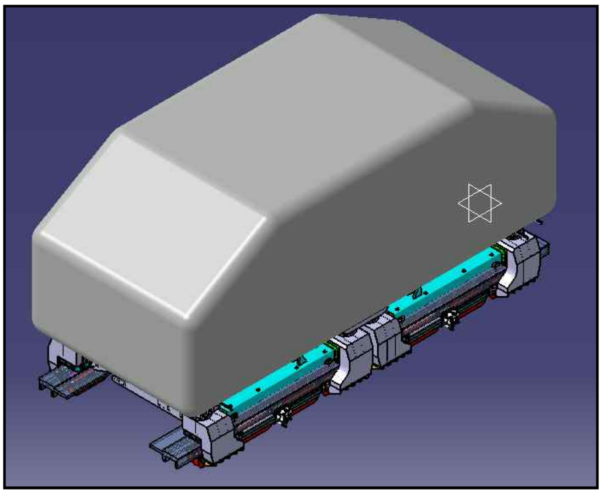

Figure 5. 1/2 Maglev vehicle dynamic model.

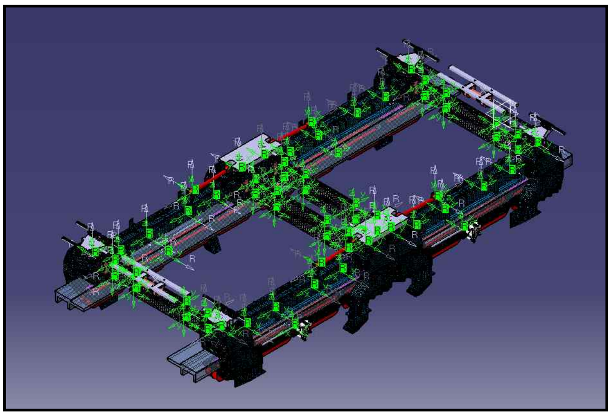

Figure 6. Flexible body model for the bogie.

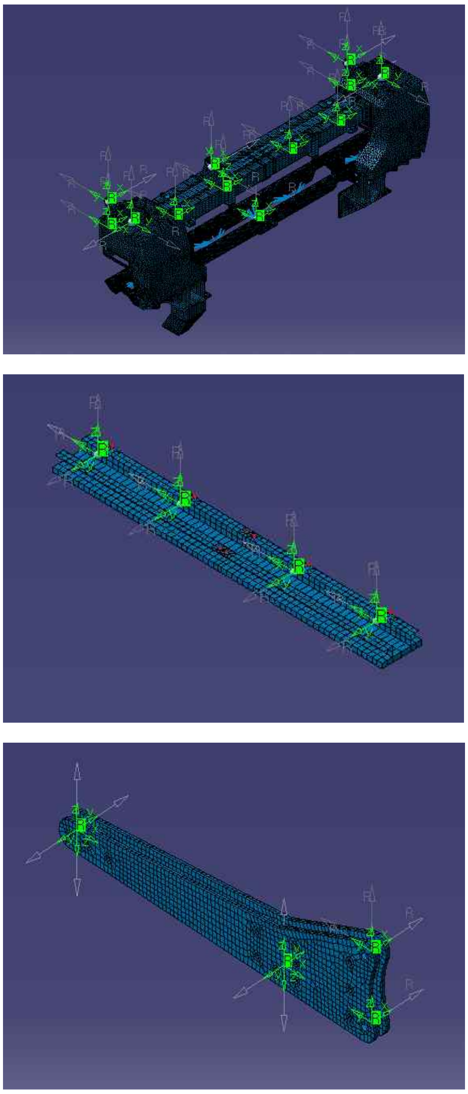

Figure 7. Flexible bodies of the bogie.

2.5 Guideway

The guideway is assumed to be stationary, with irregularities such as girder deflection and surface roughness.

3 AIR GAP SIMULATION

The air gap simulations are carried out using the model. The vertical air gaps are compared in Figure 8. The difference in air gap between the rigid and flexible body model is not clear. Consequently, it can be said that, in the case of the vehicle, the effects of the flexibility of the bogie structure on the vertical air gap are lower than we expected. For this reason, we can conclude that for the purpose of modeling the vertical air gap, a rigid body model could be more practical than a flexible body model. However, the lateral air gap obtained using the rigid body model is considerably different from the result of the flexible body model, with the largest difference between the two models being about 15%. In the entire simulation, the lateral air gaps obtained using the flexible body model were larger than those obtained using the rigid body model. Therefore, the selection of a body model must be considered in the lateral air gap simulation, which plays an important role in curving performance. We can infer several reasons for the difference between the two models. One of them is the flexibility of the anti-roll beam. The deformation of the body, as shown in Figure 10, is relatively greater than the deformation of other elements. To reduce the effects of the flexibility of the anti-roll beam on the lateral air gap, it is necessary to make it stiffer.

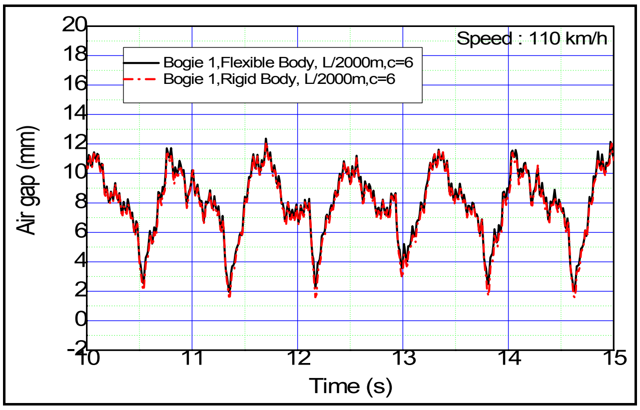

Figure 8. Vertical air gap.

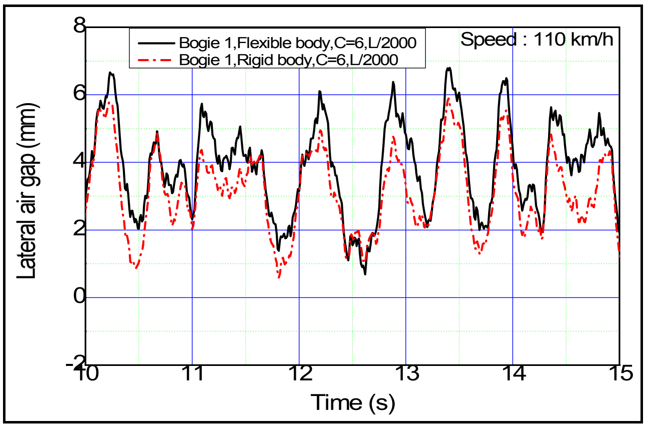

Figure 9. Lateral air gap.

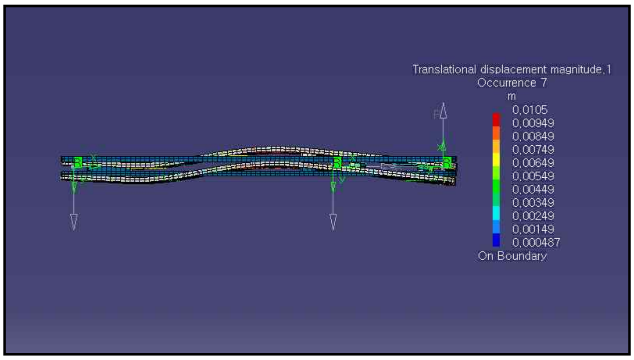

Figure 10. Deformation of the anti-roll beam(top view).

The reaction forces from both models on the air spring attachment points are plotted in Figure 11. The forces from the flexible body model are slightly less than from the rigid body model. A comparison of the reaction forces in the bracket joint between the side frame and the magnet is almost the same as on the air spring attachment points, as shown in Figure 12. It can be noted that, in dynamic load simulations, the rigid body model could be used with less difference from the flexible body model.

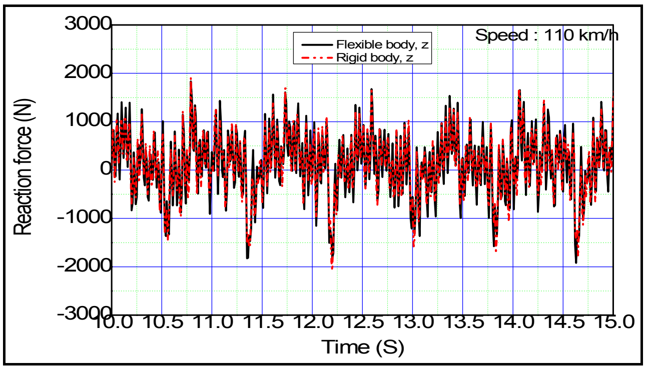

Figure 11. Reactions force on the air spring attachment.

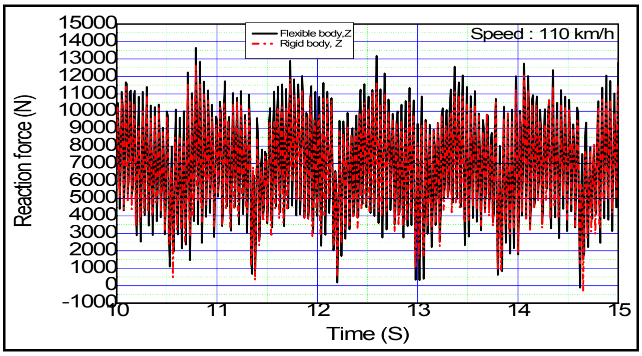

Figure.12 Reaction forces on the bracket joint between side frame and magnet.

4 CONCLUSIONS

A flexible multibody dynamic model of 1/2 of an EMS-type Maglev vehicle that is under testing is developed and compared with a rigid body model. In the case of the vehicle, the effect of the flexibility of the bogie structure on the vertical air gap was lower than we expected. However, the lateral air gap obtained from the rigid body model is considerably different from that of the flexible body model. The maximum difference between the two models was about 15%, and throughout the simulations, the lateral air gaps obtained from the flexible body model were larger than those obtained from the rigid body model. Therefore, the selection of a flexible or rigid body model must be considered in the simulation of the lateral air gap, which plays an important role in curving performance. This comparative study could be useful in the prediction of the air gap in the design stage, and in designing an air gap control system.

5 REFERENCES

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