Analytical modeling of passive electrodynamic levitation systems

Abstract: In this paper an analytical model for an electrodynamic levitation system is presented. The system consists of a moving permanent magnet piece levitated over a conducting plate. The width of conducting plate is assumed to be considerably greater than magnet. The permanent magnet piece is modeled by two equivalent current sheets, inducing eddy currents in the moving plate. The resultant magnetic field due to the permanent magnet and the eddy currents are then calculated. The drag and lift forces are also computed and their variations with system specifications are investigated. Finally a finite element method is employed to verify the validity of the analytical model, confirming the desirable accuracy of the model. The system modeling by the proposed analytical method is fast enough to be used in iterative design and optimization procedures.


Keywords: Electrodynamic Levitation, Magnetic levitation, Passive, Analytical modeling, Magnetic fields, Finite Element Method

Introduction

Maglev transportation uses magnetic fields to create lift, thrust and guidance forces without physical contact. There are two types of magnetic levitation systems: attractive and repulsive [1].

In attractive levitation or electromagnetic suspension (EMS), a ferromagnetic body is attracted to a source of magnetic flux, as a piece of steel is attracted to a permanent magnet. This type of levitation is unstable without feedback control [2]. In repulsive levitation or electrodynamic suspension (EDS), eddy currents are generated in a moving conducting body (guideway) when it experiences a magnetic field provided by superconducting coils [3]. Passive electrodynamic suspension (PEDS) in which the magnetic field is provided by permanent magnet (PM) has recently gained increasing attention due to its simplicity and cost saving merits [4]. It does not need power supplies, power conversion, power transmission means, superconducting coils and cooling facilities.

An optimal design of PEDS systems needs proper modeling and simulation of these systems and accurate predictive of lift and drag forces. Different modeling methods have been presented for electrodynamic suspension systems. A method based on dynamic circuit theory models a guideway by resistances and inductances and the motion by a mutual inductance between the source of magnetic field and the guideway [5-8]. The mathematical equations are then derived and solved using Laplace method. This method of modeling cannot accurately model the systems with a continuous sheet guideway. Karratmaker has used a simplified formula derived by Reitz for calculation of lift and drag forces of PM pieces above a rotating disc [9-10]. However, these formulas have some approximation resulting in a reduction in accuracy of computations. An analytical method based on Maxwell equations has been presented for PEDS, assuming a sinusoidal current distribution located above the moving conducting body [11]. However, this is not the case for usual EDS systems which use PM pieces or DC coils as the source of magnetic field.

Finite element method (FEM) as a powerful numerical method has been widely used to model different types of electrodynamic suspension systems. Two dimensional (2D) FEM has been used to calculate life and drag forces in the PEDS [4]. A PEDS system including Halbach magnets and a conductive wheel has been successfully analyzed by 2D and 3D FEM [12]. The parameters affecting the performance of this system have been studied using a 2D steady-state FEM [13]. Also a 2D complex steady-state FEM for calculating the lift and thrust or breaking forces created in an electrodynamic wheel [14]. A 3D FEM model using a magnetic charge boundary has been proposed for accurate and fast modeling of the electrodynamic wheel [15]. Although the FEM based models of PEDS systems presented so far accurately predict the performances of the systems, like most numerical methods, is time consuming and hard to be used in iterative procedures needed for the system design and optimizations. Therefore, an accurate and fast method for modeling of PEDS systems is to be worked out.

This paper proposed a novel and accurate analytical method to model magnetic fields, eddy currents and forces in PEDS systems. A PM piece is modeled by two equivalent current sheets at the ends of the PM. A guideway is divided to several segments and the induced eddy currents are calculated in each segment. The magnetic fields due to the PM and eddy currents are then calculated and used to compute lift and drag forces. This method is fast enough to be used in iterative system design and optimization procedures. The results obtain by the proposed method is finally compared with the ones obtained by FEM. The comparison confirms validity and accuracy of the proposed method.

System Structure

The structure of a PEDS system consisting of a moving PM Piece of dimensions $L \times D \times K$ over a conducting aluminum plate is shown in Fig. 1. The PM piece moves with a constant speed with respect to the aluminum sheet along the $x$-axis direction as shown in the figure. An air gap of $g$, along the $y$-axis, exists between the PM piece and the plate.