

Multifunctional Magnetic Vibration Simulator for EDS Maglev

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ABSTRACT: This paper proposes a magnetic vibration simulator with a new excitation coil arrangement. By controlling the current of excitation coils, the proposed simulator can generate alternating magnetic fluxes that simulate harmonic magnetic fluxes generated by not only 60-degree pitch levitation coils but also 120-degree pitch propulsion coils at the same time. Furthermore it can generate steady levitation and propulsion forces. It is useful for advancing the stationary test apparatus for EDS maglev.

1 INTRODUCTION

Concerning the development of railway vehicles of wheel-rail systems, stationary test apparatuses for bogies and car bodies have effectively been applied to evaluate their dynamic performance. One of them is the bogie dynamic simulator shown in Figure 1 that has rotating wheels that simulate track rails running backward while the vehicle runs forward. This test apparatus can simulate the dynamic behavior of vehicle running with a stationary vehicle.

As for the development of superconducting electro-dynamic suspension (EDS) maglev, it is difficult to use stationary test apparatuses such as the rotating track, because they would need to be large in scale to simulate ground coils which pass superconducting coils of wide surface area. Therefore an apparatus called a magnetic vibration simulator (Fig. 2) has been used to evaluate AC loss and vibration characteristics of the superconducting coils for EDS maglev (Suzuki 1994). The simulator generates magnetic flux that simulates harmonic magnetic flux while the vehicle runs by using three-phase excitation coils fed by inverters. But it can only generate one wavelength of magnetic flux, so that it can only simulate either the harmonic flux of the levitation system or that of the propulsion system (LSM: linear synchronous motor). Therefore it does not have enough functions as to be a complete stationary test apparatus for EDS maglev driven by LSM.

This paper discusses a method of realizing a stationary test apparatus for EDS maglev driven by LSM by improving a magnetic vibration simulator. One main task is to simulate harmonic magnetic fluxes of the levitation system and propulsion sys-

tem simultaneously. Another task is to generate steady levitation force, guidance force and propulsion force which act on the superconducting coils while the vehicle runs. Furthermore, a method of magnetic levitation on the test apparatus by controlling these steady forces is proposed. A new type of magnetic vibration simulator is proposed, and studied with respect to fundamental performance by numerical computation.



Figure 1: Stationary test apparatus for railway vehicles (Railway Technology Research Institute web site).

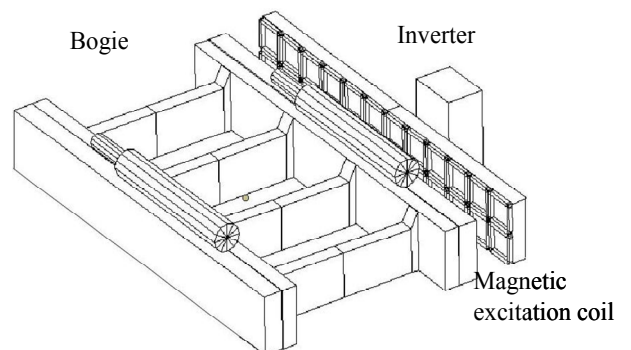


Figure 2: Magnetic vibration simulator for EDS maglev.

2 THE EDS-LSM SYSTEM AND THE EXISTING SIMULATORS

2.1 EDS-LSM system

Figure 3 shows the composition of superconducting maglev system, which is suspended by EDS and driven by LSM (Miyamoto et al. 2004). The superconducting maglev system is composed of superconducting coils on board and levitation coils for EDS and propulsion coils for LSM on the ground. The levitation coils are arranged with a 60-degree pitch and the propulsion coils with a 120-degree pitch. Superconducting coils are used for field poles of both EDS and LSM, so that they are applied by both steady levitation and propulsion forces and alternative forces caused by harmonic magnetic fluxes by levitation and propulsion coils.

Figures 4 a, b show spectra of x -direction wavelengths of magnetic fluxes generated by levitation and propulsion coils, respectively. The order of space harmonics n is the integer used in the expression for the wavelength $2\pi/n$.

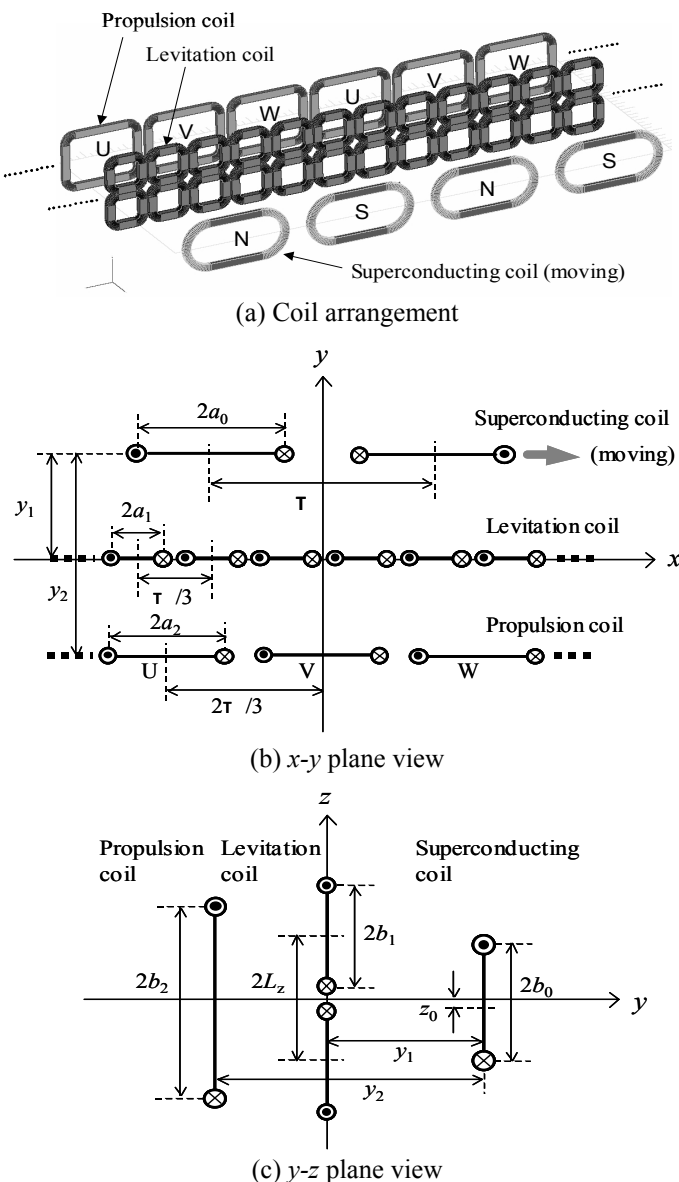
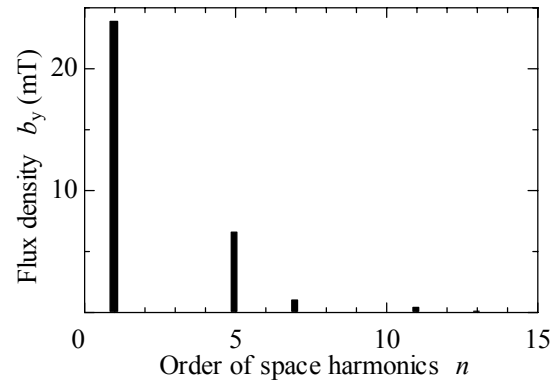
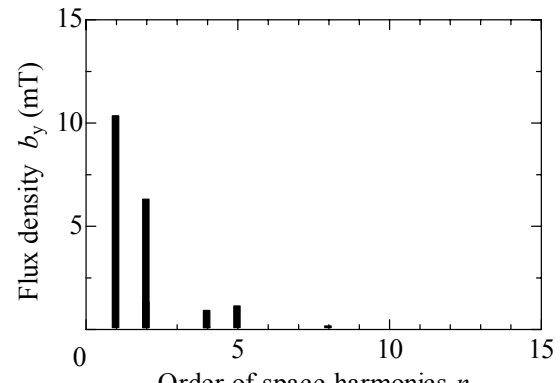


Figure 3: Composition of the combined EDS and LSM system.



(a) 60-degree pitch levitation coils



(b) 120-degree pitch propulsion coils

Figure 4: Spectra of magnetic fluxes generated by EDS and LSM system.

These figures show that main space harmonic fluxes are 5th component in 60-degree pitch levitation coils and 2nd component in 120-degree pitch propulsion coils. Since these harmonic fluxes are unsynchronized with the vehicle motion, they are observed as traveling fluxes from vehicle-based coordinates. The frequencies of the 5th space harmonic component of these traveling fluxes correspond to the 6th harmonic component, and those of the 2nd space harmonic component correspond to the 3rd harmonic component. And these traveling fluxes cause excitation forces oscillating at the frequencies of the 6th and 3rd harmonic components, respectively.

2.2 Existing simulators

Figure 5 a shows the excitation coil arrangement of the existing magnetic vibration simulator for 5th space harmonic component, and Figure 5 b shows the spectrum of magnetic fluxes generated by this simulator. This simulator has double layer excitation coils arranged with a $2\pi/15$ pitch, which is the wavelength of the 5th space component $2\pi/5$ divided by 3, the number of phases. This simulator generates the traveling magnetic flux of wavelength $2\pi/5$ as shown in Figure 5 b. By feeding excitation currents at the frequency of 6th harmonic, this simulator can simu-

late excitation forces that act on superconducting coils in EDS of 60-degree pitch levitation coils.

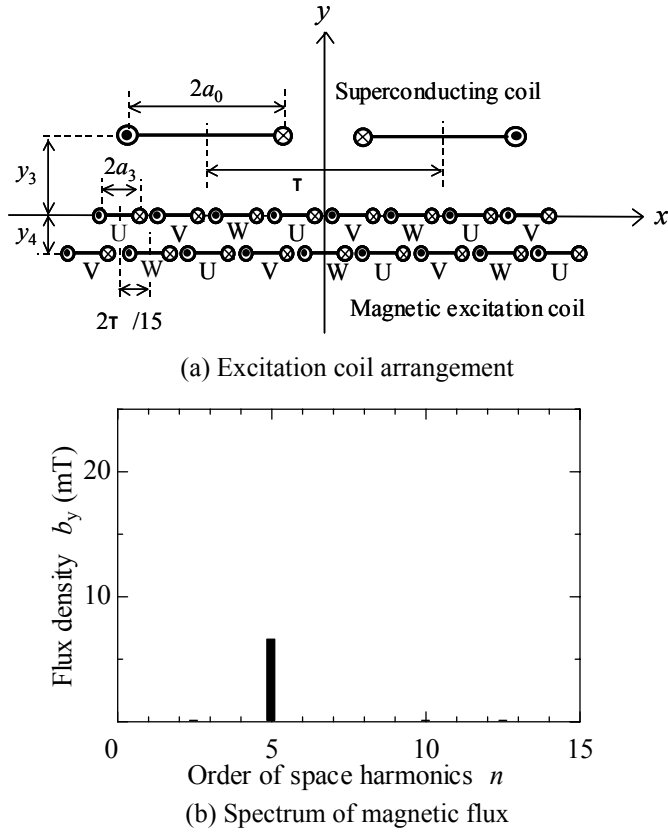


Figure 5: Existing simulator for 60-degree pitch levitation coils.

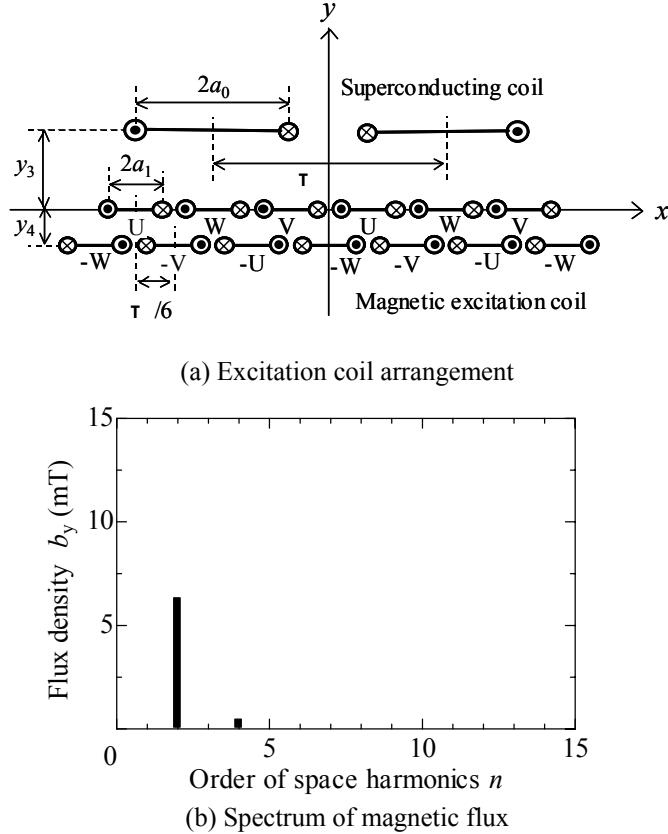


Figure 6: Existing simulator for 120-degree pitch propulsion coils

Figure 6 a, b show the excitation coil arrangement for 2nd space harmonic component and the spectrum of magnetic fluxes, respectively. This simulator has double layer excitation coils arranged in a $\pi/6$ pitch, which is the wavelength of the 2nd space component τ divided by 6, the number of phases. This simulator generates the traveling magnetic flux of wavelength τ as shown in Figure 6 b. By feeding excitation currents at the frequency of the 3rd harmonic, this simulator can simulate excitation forces in LSM with 120-degree pitch propulsion coils.

These simulators can simulate only one wavelength of magnetic flux, so that it is impossible to simulate plural harmonic magnetic fluxes simultaneously.

3 THE PROPOSED SIMULATOR

3.1 Magnetic vibration simulation

One way to generate plural harmonic magnetic fluxes simultaneously is to install additional excitation coils behind the existing coils. However, the coils would require large excitation currents because of the large gap between the additional excitation coils and the superconducting coils. And a multi-layer structure is inapt for setting excitation coils on the guideway sidewall. Therefore, a new simulator is proposed which can generate harmonic fluxes that simulate both levitation and propulsion coils.

3.1.1 Simulation for 60-degree pitch levitation coils

Figure 7 a, b show the excitation coil arrangement of the proposed simulator which is set up for 60-degree pitch levitation coils, Figure 7 c the excitation current vector diagram, and Figure 7 d the spectrum of magnetic flux generated by the proposed simulator. This simulator can generate the traveling magnetic flux of wavelength $2\tau/5$, shown in Figure 7 d, by the following principles,

[1] In the EDS system shown in Figure 3, 6-phase currents are induced in levitation coils while the vehicle runs.

[2] By feeding currents of the six phases U, -W, V, -U, W, -V to the front layer coils that have the same dimensions as that of the levitation coils, the simulator can generate the same magnetic fluxes as that of the EDS system. In this case, the fundamental flux is also observed as a traveling wave in a stationary coordinate system, but this fundamental flux is not needed for the simulation system.

[3] Adding currents of the six phases R, -T, S, -R, T, -S to the back layer coils can cancel the fundamental flux. By shifting the back layer coils forward

