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Dynamic response characteristics of high temperature superconducting maglev systems: Comparison between Halbach-type and normal permanent magnet guideways

B. Wang[a], J. Zheng[a,*], T. Che[a], B.T. Zheng[a,b], S.S. Si[a,b], Z.G. Deng[a,*]

[a] *Applied Superconductivity Laboratory, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, P R China*
[b] *School of Electrical Engineering, Southwest Jiaotong University, Chengdu 610031, P R China*

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ABSTRACT

The permanent magnet guideway (PMG) is very important for the performance of the high temperature superconducting (HTS) system in terms of electromagnetic force and operational stability. The dynamic response characteristics of a HTS maglev model levitating on two types of PMG, which are the normal PMG with iron flux concentration and Halbach-type PMG, were investigated by experiments. The dynamic signals for different field-cooling heights (FCHs) and loading/unloading processes were acquired and analyzed by a vibration analyzer and laser displacement sensors. The resonant frequency, stiffness and levitation height of the model were discussed. It was found that the maglev model on the Halbach-type PMG has higher resonant frequency and higher vertical stiffness compared with the normal PMG. However, the low lateral stiffness of the model on the Halbach-type PMG indicates poor lateral stability. Besides, the Halbach-type PMG has better loading capacity than the normal PMG. These results are helpful to design a suitable PMG for the HTS system in practical applications.

1. Introduction

Due to the unique flux-pinning property, high temperature superconductors (HTSCs) can confirmedly levitate above permanent magnets without extra control system [1]. This feature suggests that HTSCs have widely applications such as flywheel, launch propulsion system and maglev transportation [2–4]. High temperature superconducting (HTS) maglev transportation, with the advantages of low maintenance and energy consumption, high-speed and no noise, has attracted many attentions of the researchers from China, Germany, Brazil, and so on [4–6].

For the possibility of getting better performance of HTS maglev system, much work has been done including configuration optimization of permanent magnet guideway (PMG), material processing and numerical analysis [7–9] etc. PMG is an important component of the HTS maglev system, and the magnetic field provided by the PMG largely determines the performance of the HTS maglev including its electromagnetic force and dynamic stability. Moreover, the main cost of a maglev system is the PMG due to its large size in kilometers. In present HTS maglev system, two main types of PMG, which are the normal PMG with central iron flux concentration and the Halbach-type PMG, are widely applied [10]. Meanwhile, the dynamic issue should be considered for the safe operation of the HTS maglev vehicle. The characteristics of dynamic response for HTS maglev system under the conditions of free vibration, low speed and unbalanced load have been reported elsewhere [11–13].

In our study, the dynamic characteristics of a cryostat regarded as a maglev model levitating above the two permanent magnet arrays were experimentally investigated. Different field-cooling heights (FCHs) were applied as well. The dynamic parameters such as acceleration, resonance frequency (RF), stiffness and levitation height (LH) were studied in the conditions of loading and unloading weight to the central location of the model. The work done in this paper can provide evidences to design a suitable PMG for the HTS maglev in practical application.

2. Experimental setup and procedure

The experimental setup is mainly composed of three parts: a maglev model, two PMGs and an acquisition system. The photograph of the experimental scene is presented in Fig. 1. The maglev model is a cryostat, one of the four cryostats applied in a 45-m long HTS maglev loop [14] as presented in Fig. 2. The cryostat is made by ATZ GmbH, Germany [15], which contains two lines with 24 bulk HTSCs. Each HTSC has three domains and with the dimension of $64\times32\times13$ mm^3. The total weight of the cryostat filled with liquid nitrogen is about

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* Corresponding authors. Tel.: +86 2887634067.
E-mail addresses: jzheng@swjtu.cn (J. Zheng), deng@swjtu.cn (Z.G. Deng).

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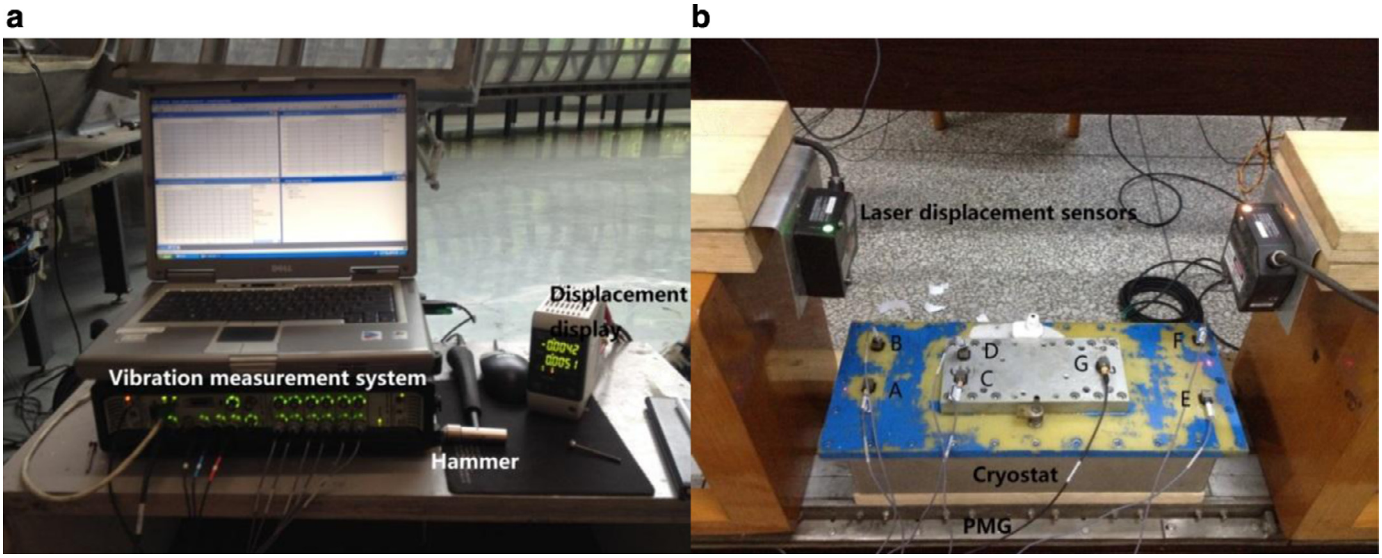

Fig. 1. Pictures of the experimental scene. (a) The vibration analyzer, the hammer for excitation and displacement display; (b) the cryostat, PMG1 and the laser displacement sensors, marked A–G accelerations.

Fig. 2. The vehicle composed of four cryostats is levitating and running on a 45-m-long HTS maglev loop with a passenger.

18 kg. Two different types of PMG, one of which is a Halbach-type bimodal PMG and the other one is a normal PMG with central iron flux concentration, were applied in the experiments. The schematic diagrams of the two PMGs and bulk HTSCs are shown in Fig. 3(a). Here, the Halbach-type PMG was denoted as PMG1, and the normal one as PMG2. The cross section of the two PMGs is 120 × 25 mm^2 and 130 × 30 mm^2, respectively. Fig. 3(b) shows the vertical component of magnetic flux density above the surface of the two PMGs along the horizontal direction at different heights. The zero-point is the center of the PMGs in horizontal direction. From Fig. 3(b), the magnetic flux density for PMG1 has two obvious peak values and the peaks are symmetrical to the center line of the PMG. On the contrary, PMG2 has three peaks and the largest one is in the center of the PMG, and the peak value is almost the same as PMG1. The acquisition system, including a B&K vibration analyzer and two laser displacement sensors, was to acquire and analyze the dynamic signals. Seven accelerometers marked A–G were fixed on the top of the model, as shown in Fig. 1(b). The two laser displacements sensors from LK-G Series of KEYENCE Company were to measure the vertical displacements of the cryostat. The detailed procedure of the experiments is as follows:

The maglev model was placed above the center of the PMG with a specific FCH as shown in Fig. 1(b) and cooled by liquid nitrogen for 60 min to ensure the HTSCs to enter the superconducting state. Then it was released from the cooling position to the equilibrium position until the levitation force generated by the HTSCs was equal to its gravity. Subsequently, an impulse force by a hammer was applied to the vertical/lateral direction of the model. At the same time, the

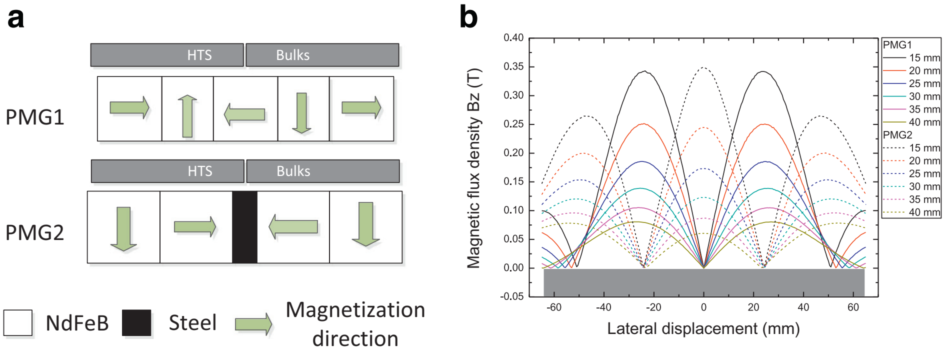

Fig. 3. (a) Schematic diagram of the two PMGs and the HTS bulks above them, PMG1 is the Halbach-type PMG and PMG2 is the normal PMG. (b) The vertical component of magnetic flux density (the absolute value) of the PMGs along transverse direction, the solid lines are for PMG1 and the dash lines for PMG2. The gray region represents the two line HTS bulks in horizontal direction.