

Study on Flux-Pinned Load Characteristics of High Temperature Superconducting Maglev Vehicle

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Abstract: With the special pinned effect, the high temperature superconducting magnetic levitation vehicle is characterized by its high-performance self-stability, strong anti-interference ability and non-contact, which would start a new chapter about the transportation. In this paper, the high temperature superconducting maglev test platform in Southwest Jiaotong University was utilized to study the flux-pinned force, including the calibration of vertical and lateral load characteristic curve under quasi-static conditions. In addition, the variation law of flux-pinned force under straight and curved tracks at different running speeds of maglev vehicle was attained.

Key words: HTS maglev vehicle, pinning effect, quasi-static conditions, calibration

1 INTRODUCTION

Currently, the traditional vehicles based on wheel-rail system are gradually approaching the limitation of the maximum speed. As a new type of transportation that mainly relies on the force between the high-temperature superconductor and the permanent magnet track to suspend the vehicle in the air and self-stable, achieving non-mechanical contact between the train and the ground track, using the interaction between the induction plate and the stator coil to drive the train, the high temperature superconducting maglev might no limitation in theory^[1].

The flux pinned theory is one of the most essential part of the studies about high temperature superconducting magnetic levitation, which attracts a substantial number of scientists to study in. The magnitude of levitation force is the significant element in the levitation system^[2]. During the process of studying levitation force, the performance of apparatus would determine the accuracy and credibility of the data. Moon and Change et al. were the first to conduct the test about repulsion force between magnet and super-conductor and got the hysteresis large loop about repulsion force versus the superconductor-magnet distance, which enclosed the high hysteresis in the superconductor-magnetic distance and levitation force^[3]. Johansen et al. devised a pendulum feedback system to measure the lateral force on a magnet placed above a high-T_c superconductor^[4]. Wang.J.S. et al. developed SCML-01 HTS maglev measurement system to investigate the levitation properties^[5]. Valiente-Blanco et al. presented the results of an experimental study of the levitation mechanical properties of a journal superconducting suspension in a high vacuum and temperatures from 90 to 12 K, demonstrating that the temperature influence on superconducting levitation systems is significant^[6]. Surdacki, Pawel studied the features of high current low- and high-temperature superconducting devices, elucidated the influence of the superconductor characteristics on the stability issues^[7]. DN Diev et al. discussed the design of an HTS rotary separator prototype with the horizontally oriented rotor axis together with the magnetic fields and forces calculations that define prototype working parameters^[8].

Based on the model of High Temperature Superconducting Maglev-Evacuated Tube Transport System of Southwest Jiaotong University, the calibration of lateral and vertical flux-pinned force characteristic curve of its running gear is carried out, the calibration curve and polynomial fitting under the corresponding loads are given. What is more, the time history of the flux-pinned force is given by recording the vertical displacement and lateral displacement of the maglev carriage running on the test track. And the variation law of flux-pinned force under straight and curved tracks at different running speeds of maglev vehicle is studied.

2 APPARATUS OF FLUX-PINNED FORCE TEST

2.1 Mechanism of High-Temperature Superconducting Maglev

Magnetic levitation is a device that realizes suspension by an interaction force between an induced magnetic field and a fixed magnetic field according to the law of electromagnetic induction^[9]. According to the different suspension principle, there are electromagnetic suspension (EMS), electrodynamic suspension (EDS) and high temperature superconducting magnetic levitation^[10]. Flux-pinned effect is a specific phenomenon belonging to the Type-2 superconductors^[11]. The Type 2 superconducting material

used in this experiment is Yttrium barium copper oxide (YBCO). When the temperature reaches 30-35K, the superconducting state would be triggered. In this state, the exterior magnetic flux would penetrate into the superconductor in quantized packet surrounded by a superconducting current vortex. However, the magnetic flux line cannot enter the material due to the resistant force caused by vortex, which is known as Pinned force [12]. Flux pinned state is a mixing state of superconductor, where some parts of the interior superconductor are in normal state and some of them are in superconducting state whereas all of them are in flux pinned state. If the exterior magnetic field is triggered by permanent magnetic track, the pinned effect is represented by the pinned interaction between superconductor and permanent magnet [13].

2.2 Test Track and Vehicle

In 2013, a high temperature superconducting magnetic ring test line for vacuum pipeline has been developed by Zigang Deng and his group, which is the first to verify the feasibility of magnetic suspension transportation in evacuated Tube. The test vehicle on the track is shown in Fig.1. It is 45 meters in length and consists of two 3.5-meter straight line and a curved track with a radius of 6 m. Where the induction motor is located on one side of the linear track, which is 3 meters long, and the maglev vehicle can be accelerated in the area of the induction motor.



Fig. 1 Test vehicle on track

3 CALIBRATION METHOD OF FLUX-PINNED FORCE

3.1 Calibration of Vertical Flux-Pinned Force

The longitudinal degree of freedom was constrained through the front/rear stop before the calibration, then the vertical load was calibrated by applying the load in the middle of the bogie, with a laser displacement sensor arranging at each of the four ends of the frame to measure the vertical displacement under the homologous load state. The distribution of the sensor and the position of the load application were shown in Fig.2. The laser displacement sensor used in the test has a range of 0-300mm, which can meet the test requirements. Furthermore, the load was realized by standard weight, linearly increasing from 0N to 3000N. Thus, the vertical flux-pinned force characteristic curve under quasi-static conditions can be obtained by measuring the displacement of each sensor under the corresponding load condition.

3.2 Calibration of Lateral Flux-Pinned Force

When calibrating the lateral load characteristic curve, the longitudinal degree of freedom of the vehicle was constrained. At the same time, the lateral load was applied to the middle of the frame through the jack, ensuring that the maglev vehicle was evenly stressed without yawing and rolling motion, where the lateral displacement sensor installation position was in the left side of the bogie frame, as shown in Fig.3. The lateral flux-pinned force was sequentially loaded from 0N to 2500N, displayed through the standard force sensor and acquired the corresponding data at intervals of 250N. As a consequence, the lateral flux-pinned force characteristic curve under quasi-static conditions was attained through the displacements of lateral sensors.

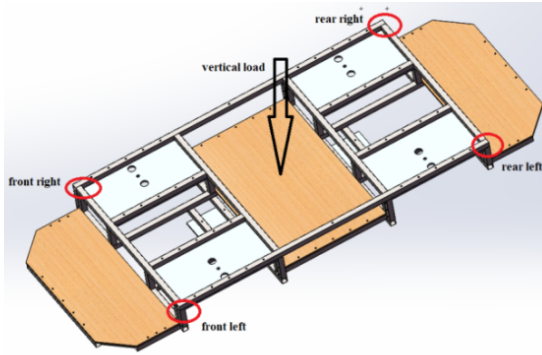


Fig. 2 Diagram of vertical flux-pinned force calibration

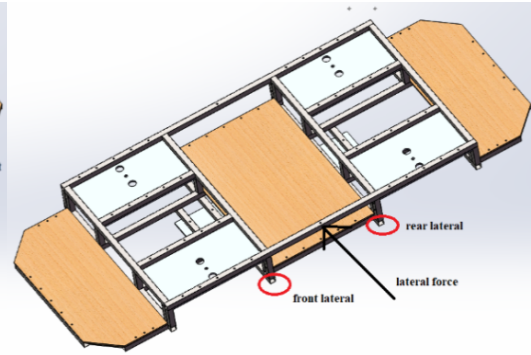


Fig. 3 Diagram of lateral flux-pinned force calibration

4 CALIBRATION RESULTS

4.1 Vertical Calibration Results

The displacement curve of the sensor under quasi-static vertical flux-pinned force loading and unloading conditions was shown in Fig.4 and Fig.5. It can be seen from the figure that in the process of increasing the vertical load from 0N to 3000N, the displacement of sensor at the end of the frame is increasing, with the amplitude ranging from 5 to 7mm. While during the unloading process, the signal of the displacement sensor reduces with the decrease of the load, but the vertical displacement cannot return to the initial displacement after the load is completely removed. Therefore, in the process of vertical load calibration, the relationship between flux-pinned force and displacement can be regarded as nonlinear.

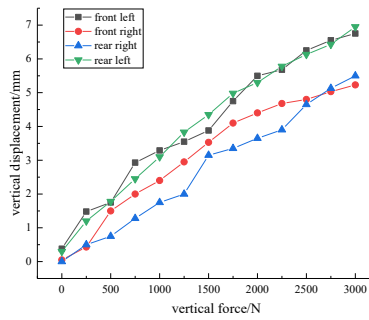


Fig.4 Vertical loading condition

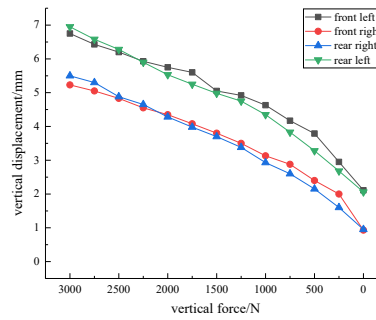


Fig.5 Vertical unloading condition

Considering that there may be eccentric load during the application of vertical flux-pinned force, the average value of the displacement signals of each sensor was used, and the force-displacement curve under loading and unloading conditions was obtained by polynomial fitting, which was illustrated in Fig.6. Accordingly, the vertical flux-pinned force of the vehicle can be derived from the value of the vertical displacement.

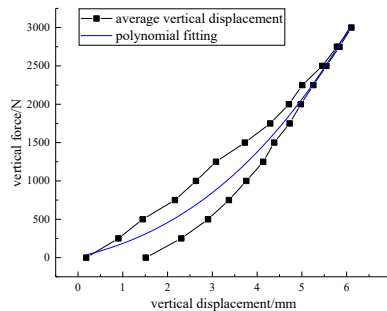


Fig.6 Polynomial fitting in vertical flux-pinned force condition

4.2 Lateral Calibration Results

The displacement curve of the sensor under quasi-static lateral flux-pinned force loading and unloading conditions was shown in Fig.7 and Fig.8. Obviously, the lateral displacement increases during the process of increasing the lateral load from 0N to 2500N, presenting a approximately linear growth with a range of 30-40mm. However, in the process of decreasing of lateral loads, although the displacement also shows a decreasing trend, the lateral displacement cannot be restored to 0 after unloading. Overall, the lateral force-displacement relationship of the experimental maglev vehicle is also nonlinear. Compared with the vertical flux-pinned force characteristic curve, the lateral load characteristic curve is more uniform during the loading condition, and the lateral stiffness of the maglev vehicle is smaller than the vertical stiffness.

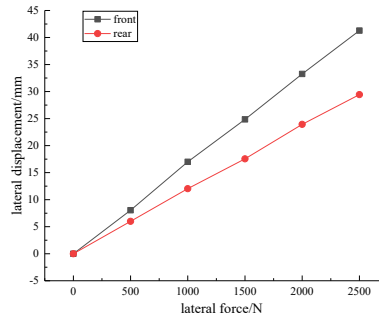


Fig.7 Lateral loading condition

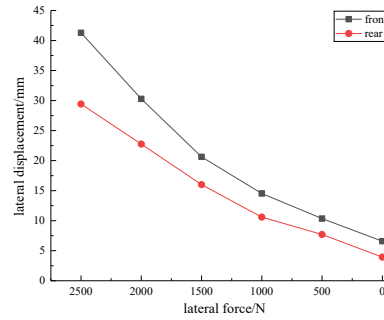


Fig.8 Lateral unloading condition

Referring to the fitting method of the vertical flux-pinned force characteristic curve, the average value of the displacement signal of the lateral sensor was taken, and the force-displacement curve under the loading and unloading conditions was got by polynomial fitting, as shown in Fig.9. Similarly, the lateral flux-pinned force can be derived from the average value of the lateral displacement.

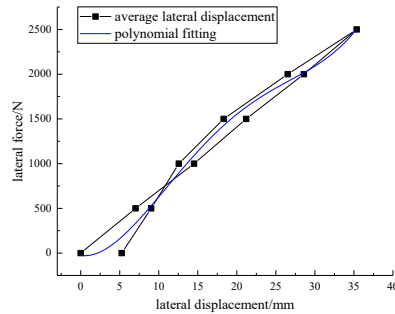


Fig.9 Polynomial fitting in lateral load condition

5 TEST RESULTS OF MAGLEV VEHICLE RUNNING ON TRACK

On the test track described in 2.2, the maglev vehicle was operated at speeds of 10km/h and 15km/h respectively, with the force between the vehicle and the track at different speeds was acquired, as demonstrated in Fig.10.



Fig.10 Maglev vehicle running on the track

During the test, the vehicle was empty, and the displacements were measured through the corresponding sensors whose positions are identical to the calibration method, running from the end of the induction motor. The displacement test results of the whole track are shown in Fig.11- Fig.14.

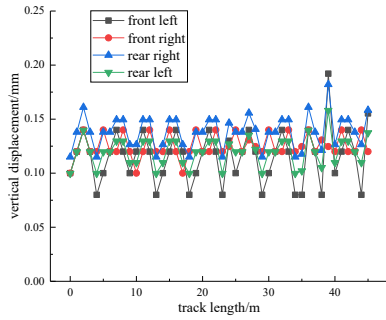


Fig.11 Vertical displacement at 10km/h

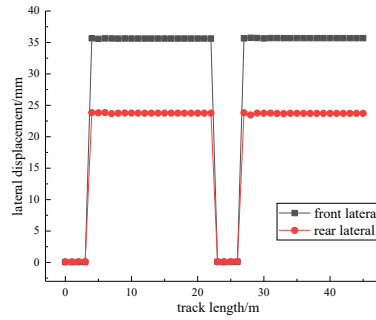


Fig.12 Lateral displacement at 10km/h

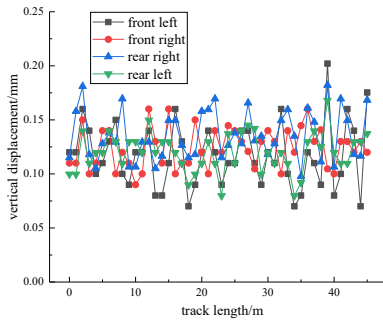


Fig.13 Vertical displacement at 15km/h

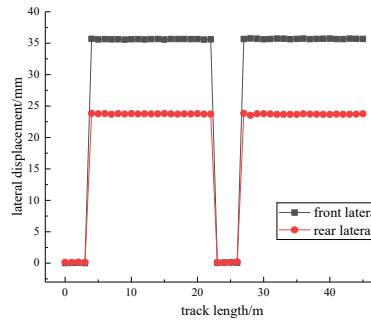


Fig.14 Lateral displacement at 15km/h

The figures demonstrate that the vertical displacement remains stable when the test vehicle was running under a test track consisting of a straight and curved track, while the lateral displacements were respectively mutated at 3.6 m and 22.5 m in the test track, and then kept stable, resulting from the transition between curved and straight track at 3.6 m and 22.5 m respectively, so the lateral displacement changes significantly in the curved track area. At the same time, we can find that the displacement signal has no obvious change at the speed of 10km/h and 15km/h, that is, the speed level has no definite influences on the flux-pinned force of the test maglev vehicle.

Based on the previous vertical and lateral flux-pinned force calibration formulas, the vertical and lateral displacements of the vehicle at 10km/h and 15km/h are converted into corresponding loads, as shown in Fig.15-16.

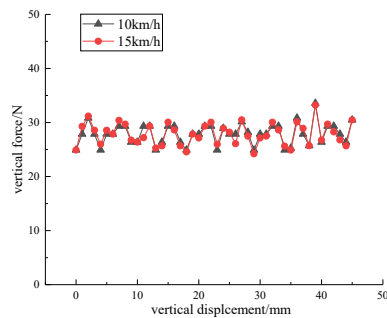


Fig.15 Vertical force

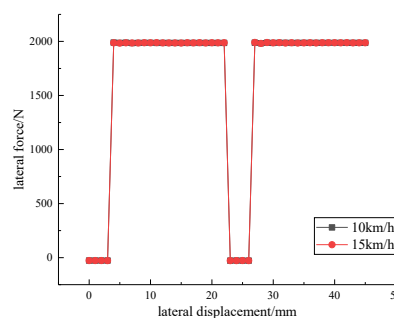


Fig.16 Lateral force

Apparently, the vertical flux-pinned force is basically maintained at 10% above and below the 28N in the test track area, which

may result from the irregularity of the track. The gap of vertical loads between different speeds is quite small, and the trend is consistent with the displacement. While the lateral flux-pinned force has a mutation at the boundary between the corresponding curved and straight track, with the mean value 2000N.

6 CONCLUSION

Based on the high-temperature superconducting magnetic levitation model, the vertical load and lateral load characteristic curves are calibrated. The effects of different speed grades and lines on the test vehicle load are studied through the test track, which can be concluded as follows.

(1) In the process of quasi-static test vehicle load calibration, the vertical stiffness is greater than the lateral stiffness.

(2) The vertical and lateral pinned force characteristic curves of the test vehicle are nonlinear in the loading and unloading process, which means that the vertical and lateral displacements cannot be restored to the initial position after unloading.

(3) The straight or curved track has no predominant influence on the vertical displacement of the vehicle, while the lateral displacement can be greatly affected by the junction between curved and straight track.

(4) The running speed has no obvious effect on the lateral and vertical loads of the maglev vehicle during 10-15km/h.

Due to the limitations of the experimental platform, the impact of different load conditions on the pinned force of the maglev vehicle failed to realize, which is recommended to be carried out in the further study.

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