Postprint of the Wayside Traction System for Medium-Speed Maglev Train Test Line

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Abstract

The new medium-speed maglev train employs a traction system based on a long-stator permanent magnet linear synchronous motor with Halbach magnets, offering advantages such as low energy consumption, strong climbing capability, and small turning radius. It holds broad application prospects in transportation systems operating at speeds of 150–250 km/h. This paper primarily introduces the development and testing of the traction system for the medium-speed maglev train test line, encompassing the structural characteristics of the medium-speed maglev train, the principle and composition of the ground traction system, and test line results.

Full Text

Applied Research on the Ground Traction System for Medium-Speed Magnetically Levitated Trains

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Abstract

The new medium-speed magnetically levitated train employs a traction system based on a long-stator permanent magnet linear synchronous motor (PMLSM) with Halbach arrays. This system offers advantages including low power consumption, strong climbing capability, and small turning radius, making it highly promising for transportation applications in the 150–250 km/h speed range. This paper primarily introduces the development and testing of the traction system for a medium-speed maglev train test line, covering the structural characteristics of the train, the principles and composition of the ground traction system, and the test line results.

Keywords: Medium-speed magnetically levitated train; ground traction system; Halbach array; long-stator permanent magnet linear synchronous motor

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1 Introduction

Maglev trains represent a non-contact ground rail transportation system that has attracted increasing attention due to their safety, comfort, and environmental benefits. Unlike conventional wheel-rail vehicles, maglev trains derive their support and guidance forces from electromagnetic attraction or repulsion between the vehicle and guideway, while propulsion is generated by linear motors. This paper focuses on the development and testing of the traction system for a medium-speed maglev train test line, addressing the train' s structural features, ground traction system principles and composition, and test line results.

2 Principles and Structural Characteristics of the Medium-Speed Maglev Train System

Based on suspension principles, maglev train systems can be classified into electromagnetic suspension (EMS) and electrodynamic suspension (EDS). According to motor type, traction systems can be categorized as long-stator linear synchronous motors or short-stator linear induction motors. The former is primarily used for high-speed maglev trains, while the latter suffers from end effects that result in low motor efficiency and severe traction force degradation with increasing speed, limiting its application to low-speed systems below 100 km/h.

Currently, operational maglev systems worldwide include the Shanghai high-speed maglev demonstration line and three low-speed maglev test lines in Aichi (Japan), Incheon (Korea), and Changsha Huanghua Airport (China). All four systems employ normal-conducting electromagnetic suspension. The Shanghai high-speed maglev train uses additional guidance electromagnets with active lateral control to ensure vehicle stability, though this results in complex structure and greater vehicle weight. Low-speed maglev trains adopt integrated U-shaped electromagnets for both suspension and guidance, offering simpler structure and lower noise.

The new medium-speed maglev train combines electromagnetic suspension technology with a long-stator PMLSM using Halbach arrays. This approach retains the advantages of low-speed maglev systems—such as simple structure, low noise, small turning radius, and strong climbing ability—while addressing the limitations of low traction efficiency and high energy consumption. The system shows broad application prospects for transportation in the 150–250 km/h speed range.

As shown in [Figure 1: see original paper], the medium-speed maglev train suspension system employs a normal-conducting electromagnetic attraction EMS system similar to low-speed maglev systems. Suspension and lateral guidance are achieved through electromagnetic attraction between U-shaped suspension magnets and the two wings of the F-shaped guideway, which helps reduce weight, complexity, and improve reliability.

Like low-speed systems, the vehicle is propelled by a long-stator PMLSM with Halbach arrays. The motor mover (secondary), composed of multiple Halbach magnets with different magnetization directions, is installed at the center of the vehicle bogie. The stator armature windings are laid along the center of the guideway.

For maglev train traction motors, normal force is a critical performance metric. As shown in [Figure 2: see original paper], to minimize the impact of motor normal force on the suspension system, the ground stator adopts a coreless, single-layer chain structure. Force analysis indicates that achieving an ideal sinusoidal air-gap flux density significantly reduces motor ripple. Conventional magnet configurations cannot produce an ideal sinusoidal air-gap flux density distribution. Applying Halbach arrays to permanent magnet motors not only sinusoidalizes the air-gap flux density but also increases air-gap flux, resulting in greater electromagnetic traction force. As shown in [Figure 3: see original paper], the magnetization angle difference between adjacent Halbach permanent magnet blocks is 45°, with eight magnet blocks forming one mover pole pair.

3 Ground Traction System for Medium-Speed Maglev Train

To validate the new medium-speed maglev train system, a single-bogie test vehicle was developed, and a 204-meter test line was constructed. Photographs of the test line and vehicle are shown in [Figure 4: see original paper].

The ground traction system employs DC750V power supply and consists of a high-voltage electrical cabinet, traction inverter, braking resistor, feeder cable, trackside switch cabinet, and long-stator linear synchronous motor. Based on the motor design parameters, under rated phase current effective value of 1,200A, the traction and normal force characteristics of a single motor are shown in [Figure 3: see original paper]. The results demonstrate that the traction and normal force characteristic angles differ by 90°. At a 90° power angle, traction force reaches its maximum while normal force is nearly zero, minimizing the impact on the suspension system.

The traction converter main circuit operating principle is shown in [Figure 5: see original paper]. DC power from the substation passes through the high-voltage cabinet to the traction inverter, which converts it into variable-voltage variable-frequency (VVVF) three-phase AC power for the long-stator linear synchronous motor primary windings, generating propulsion or electric braking force.

Traction Converter Electrical Parameters:

- **High-Voltage Cabinet:** Rated input voltage DC550–900V; rated input current 900A; protection class IP20.

- **Inverter Cabinet:** Rated input voltage DC550–900V; output voltage AC0–660V; rated input current 900A; rated output current 1,200A; instantaneous peak output current 1,400A; output frequency 0–50Hz; switching frequency 500–1,000Hz; protection class IP20.
- **Braking Resistor Cabinet:** Rated braking power 250kW/2.5Ω; overload capacity 6 times; braking activation voltage DC841V; braking deactivation voltage DC799V; automatic triggering; instantaneous braking power 1,500kW; protection class IP20.

For longer guideways, the traction power supply system adopts a multi-section power supply mode, with trackside switch stations completing power switching between different sections. For the 204-meter long-stator PMLSM converter system, the trackside switch cabinet comprises two switch systems: one for remote switching operations by the traction control system, and another for short-circuiting the stator three-phase windings during emergency braking to enable eddy current braking. The trackside switch cabinet also provides safety protection during inspection and maintenance of the long-stator cable.

The traction inverter includes protection against overvoltage, undervoltage, overcurrent, overload, short circuit, ground fault, phase loss, three-phase current imbalance, and overheating. When overvoltage, undervoltage, short circuit, ground fault, or phase loss occurs, the inverter is blocked and the high-speed switch disconnects. For overcurrent, overload, or overheating, power is first reduced; if the fault persists, the inverter is blocked and the high-speed switch disconnects.

The high-voltage cabinet' s primary function is to deliver external DC input voltage to the inverter cabinet through a charging circuit. Additionally, when faults occur on the inverter side or DC input side, the high-voltage cabinet' s high-speed switch disconnects to provide fault isolation and protection. The cabinet components are shown in [Figure 3: see original paper], with two current sensors CS1 and CS2 forming a ground fault detection sensor, VS1 detecting DC input voltage, CCK and RC constituting the charging circuit, SCK as the main contactor, and FU1 as a fuse.

The inverter cabinet is the core component of the long-stator PMLSM traction converter system. Its main function is to convert DC bus voltage into variable-voltage variable-frequency three-phase AC voltage based on external commands, enabling real-time closed-loop control of motor traction, vehicle speed, and position. As shown in [Figure 2: see original paper], the inverter main circuit adopts a two-level voltage-source DC-AC inverter circuit, with VS2 detecting capacitor voltage, FC as the DC support capacitor, and CS3-CS5 detecting inverter output three-phase currents. The inverter unit integrates seven 1,700V/2,400A IGBT elements as the three-phase bridge arms and braking phase bridge arm. The module also includes a heat sink, fan, temperature sensor, and low-inductance busbar.

Signal transmission between the traction control unit and drive unit is implemented via fiber optics, which easily resolves high-voltage isolation and improves anti-interference performance. The allowable dissipation power and on-state current of IGBTs are inversely proportional to junction temperature. Junction temperature is typically controlled below 125°C with case temperature below 100°C. Considering safety margins, junction temperature is controlled below 110°C with temperature protection implemented.

Unlike linear induction motors, permanent magnet linear synchronous motors generate back-EMF from permanent magnets during faults or power loss that can damage devices. Therefore, the braking resistor cabinet not only dissipates regenerative braking energy but also provides safety protection for the converter.

For long-stator linear synchronous motor-driven maglev train systems, field-oriented control achieves real-time closed-loop control of traction force, speed, and position. From the dynamic equations, adopting an Id = 0 field-oriented control strategy enables maximum traction output per unit current while simultaneously minimizing normal force impact on the suspension system, as shown in [Figure 3: see original paper].

4 Test Line Results

The developed ground traction system was installed on the 204-meter medium-speed maglev train test line, driving the single-bogie test vehicle to complete full-line operation tests at a maximum speed of 20 km/h. Partial results are shown in [Figure 6: see original paper].

[Figure 6: see original paper] presents the complete traction and braking process test waveforms at a maximum speed of 20 km/h. In the figure, *s* represents the vehicle position curve, *Ia* is the A-phase current, and *vref* and *vfed* are the speed command and feedback values, respectively. *Idref*, *Idfed*, *Iqref*, and *Iqfed* represent the d-axis and q-axis current commands and feedback values. The results show that throughout the operation, motor speed and dq-axis current feedback accurately track command values with stable traction-to-braking transition.

During operation, due to the lightweight test vehicle, the converter' s maximum output peak current was 1,000A under constant acceleration conditions, which did not reach the design maximum. The motor d-axis current remained near zero, indicating minimal impact of the traction system on the suspension system.

5 Conclusion

The medium-speed maglev train combines electromagnetic suspension technology with a long-stator PMLSM using Halbach arrays, retaining the advantages of low-speed maglev systems—simple structure, low noise, small turning radius, and strong climbing ability—while addressing limitations of low traction efficiency and high energy consumption. The system demonstrates broad application prospects for transportation in the 150–250 km/h speed range.

This paper has introduced the development and testing of the current medium-speed maglev train test line traction system. Future work will focus on developing a multi-section medium-speed maglev train traction system for 200 km/h operation, laying the foundation for broader application of the new medium-speed maglev train technology.

References

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Note: Figure translations are in progress. See original paper for figures.