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Technological Development of a High-Speed Maglev System Based on a Low-Vacuum Pipeline

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Abstract: Wheel-rail-type transit systems are the main type of current technology systems in rail transit. However, these systems face limitations of air resistance, wheel-rail adhesion, and operating noise, and therefore, it is difficult to achieve a significant increase in the economic operational speed of rail vehicles at the current technological level. To meet the demand for higher economic operational speeds, the use of magnetic levitation technique to reduce wheel-rail friction and vibration and the creation of a low vacuum operating environment to reduce air resistance and noise are important development directions for higher speed rail transit technology in the future. This paper presents the significance of developing a high-speed maglev system based on a low-vacuum pipeline, evaluates its technical characteristics and the current situation, analyzes the scientific problems and key technologies of this system, and proposes relevant policy suggestions, including project-setting research at the national level, building of test lines, and the construction of national laboratories.

Keywords: rail transit; low vacuum pipelines; high speed maglev system; system technology

1 Introduction

The 19th National Congress of the Communist Party of China explicitly proposed to build a “transportation powerhouse” and to measure the development level of the transportation industry and its technological innovation ability. Speed is one of the most important indicators of transportation development. Increase in transportation speed has played an important role in accelerating the development of human civilization. A majority of existing rail technology systems is the wheel-rail type system. The maximum test speed of a wheel-rail test train is 574.8 km/h (French AGV test train V150) [1]. The maximum test speed of an operational train is 486.1 km/h (high-speed train CRH380AL in China). The current maximum operating speed in China is 350 km/h.

Owing to the limitations of air resistance, wheel-rail adhesion, hunting instability, operating noise, and pantograph-catenary current collection, it is difficult to economically increase the operating speed of wheel-rail transit. Meanwhile, energy consumption and mechanical friction increase significantly with the increase in speed. The latest test results show that the energy consumption of electric motor train unit (EMU) at 400 km/h is about 30% higher than that at 350 km/h.

In the 1920s, the concept of magnetically levitated (maglev) trains originated in Germany [2]. Maglev

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technology was applied to solve the problems of wheel-rail adhesion, friction, vibration, and high-speed flow in wheel-rail transit. High-speed maglev technology has gradually matured. On December 31, 2002, China opened the first commercial maglev line in the world, the Shanghai maglev line, with a speed of 430 km/h. Japan started its construction of a high-speed maglev line from Tokyo to Nagoya in 2014, with a designed maximum operating speed of 505 km/h. It is scheduled to open in 2027. China is developing a high-speed maglev system with a speed of 600 km/h.

In both wheel-rail and maglev systems, when the vehicle is running in an open space environment, it will face huge problems from air resistance (proportional to the square of the speed) and noise (proportional to six to eight times the square of the speed). When the speed exceeds 400 km/h, air resistance accounts for more than 80% of the total resistance during train operation. Therefore, high-speed travel brings economic and environmental challenges to business operations.

To achieve higher operational speeds economically, for using maglev technology to reduce wheel-rail friction and vibration, the construction of a low-vacuum operating environment to reduce air resistance and noise is an important direction for the future technological development of higher speed rail.

2 Significance

The low-vacuum pipeline high-speed maglev system is a disruptive technology oriented to the future of track transit, which is not only a massive-system engineering task but also a large complex system. The characteristics of a low-vacuum pipeline are huge investment, large engineering scale, enormous technical difficulty, complex levels, interface relationships, and great social and economic benefits.

2.1 The development of the low-vacuum pipeline high-speed maglev system is an important measure to trigger the reform of transportation modes.

A low-vacuum pipeline is located in an airtight environment that is less affected by severe weather, such as storms, rain, and snow. The train has high reliability and low noise inside and outside. The low-vacuum pipeline high-speed maglev system has greater carrying capacity, less energy consumption, and less environmental pollution when compared to aircraft. It also has a higher speed and occupies less land than current high-speed railways. By connecting the major regional centers in a country or even the world through low-vacuum pipelines, the high-speed delivery of passengers and goods can be realized, meeting public demand for higher quality and faster transportation services. This can greatly improve the current situation, where passengers and goods travel much slower than information, and can thus trigger a reform of transportation modes.

2.2 The development of a low-vacuum pipeline high-speed maglev system is an important impetus to the construction of “super urban agglomeration,” the rapid growth of economy, and industrial development.

In the past ten years, Chinese high-speed rail has played an important role in improving the conditions of transportation infrastructure along routes and promoting regional economic growth and coordination. The advent of the low-vacuum pipeline in a high-speed maglev transportation system will promote the optimal allocation of resources in the “super city cluster,” reduce the restrictions of spatial distance on the free circulation of people and products, and form a “one-hour economic life circle” covering the whole country with a radius of 600–1 000 km. The original regional industrial and economic layout of “central city + satellite city” will gradually evolve to the national economic layout represented by a “super city cluster.” The resource elements of original cities will be integrated rationally to accelerate the aggregation of capital, talent, and technology, thus realizing the huge economic benefits of aggregation to accelerate the economic transformation and upgrade China’s national economy.

2.3 The development of a low-vacuum pipeline high-speed maglev system resembles the implementation of a new development concept and is an essential embodiment of an innovative country.

The remarkable advantages of the low-vacuum pipeline high-speed maglev system are high speed, low energy consumption, and low pollution. This is important given the significance of current prominent environmental problems, the promotion of regional green development, and the requirement for new modes of clean, low-carbon, safe, efficient, and green transportation. As a typical representative of frontier technology, the low-vacuum pipeline high-speed maglev system plays a leading role in the technological innovation of related fields in China.

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2.4 Developing a low-vacuum pipeline high-speed maglev system is a powerful tool to consolidate the leading edge of China's high-speed railway, and it implements the strategy of transportation power.

China's high-speed railway technology is developing rapidly and taking a leading position in the global railway industry. At the same time, countries including Russia, the United States, France, Germany, Japan, and South Korea are actively planning and developing various modes of transportation technology. Russia is designing and building a high-speed rail line with a top speed of 400 km/h from Moscow to Kazan. Japan carried out research on superconducting high-speed maglev technology and set a world record of 603 km/h for manned travel in 2015. The United States has carried out research on Magplane, Hyperloop, and other technical solutions. The international union of railways (UIC) has established the pipeline high-speed rail technology group to carry out preliminary research. China is in urgent need of deepening its research in the field of higher speed rail transit and making good strategic technical reserve decisions. The development of the low-vacuum pipeline high-speed maglev system is a powerful tool to practice the national "innovation-driven" strategy, seize the technological commanding point in the future, and support the development of national higher speed rail transit.

3 Technical characteristics and research actuality

3.1 Technical characteristics

A maglev railway is propelled by an electromagnetic attraction or repulsion force to suspend the vehicle on a guide rail by using the principle of the linear motor. According to the speed of the rails, maglev railways can be divided into high-speed maglev and medium/low-speed maglev, which are different in driving, guiding, and control modes. The operating speed of medium/low-speed maglev railways is less than 120 km/h.

According to the different types of maglev, there are two kinds of high-speed maglev trains: electromagnetic suspension (EMS) and electrodynamics suspension (EDS). The EMS type, also known as the magnetic attraction type, generally adopts a "T" type guide rail with the vehicle running around the guide rail. The magnetic field is generated through electrifying and exciting the vehicle-mounted suspension electromagnet under the guide rail. The magnet attracts the ferromagnetic elements on the track, lifting the train upward and suspending it on the track. The suspension gap between the magnet and ferromagnetic track is generally about 10 mm. The train ensures a stable suspension gap by controlling the excitation current of the suspension magnet. The EDS type, also known as the magnetic repulsion type, uses the relative motion between the vehicle magnet and ground coil to generate two induced magnetic fields. These two magnetic fields interact to produce an electromagnetic force. When the vehicle reaches a certain speed, the electromagnetic force is strong enough to float the vehicle. The suspension height of the electric suspension vehicle is over 100 mm. A typical representative of EMS type is the Transrapid TR08 train in Germany, which can reach a maximum speed of 400–500 km/h. A typical example of EDS type is the magnetically levitated (ML) MLX01 in the Japanese superconducting maglev system, which has a maximum velocity of 500–600 km/h. The electromagnet of a high-speed maglev system is of two types: normal conductive and superconducting. The superconducting electromagnet is cooled to a very low temperature with superconducting materials, putting it in a superconducting state. In this situation, the resistance is close to zero, and thus, the power loss is small, the current can be large, and the electromagnet can be very powerful. As the superconducting temperature of different materials is different, high-speed maglev systems can be divided into low-temperature superconducting (liquid helium cooling, working temperature: −269 °C) and high-temperature superconducting (liquid nitrogen cooling, working temperature: −196 °C).

The low-vacuum pipeline high-speed maglev system is a means of transportation for high-speed maglev trains (aluminum, carbon fiber, or other high-strength–lightweight materials made into closed carriages) in a closed steel pipeline. Steel-reinforced concrete columns are used to erect steel structures at a certain height above ground level or underground. When the pipe is pumped to a low vacuum, the air pressure inside is about a few hundredths or even a thousandth of the atmospheric pressure at sea level. The low-vacuum pipeline high-speed maglev system combines vacuum pipeline technology and maglev train technology. Thus, there are no problems with wheel-rail dynamics, pantograph dynamics, or air resistance experienced in conventional high-speed maglev railways. Therefore, the low-vacuum pipeline high-speed maglev system can realize operational speeds of ground transportation greater than 600 km/h relatively economically.

The disadvantages of the low-vacuum pipeline high-speed maglev system mainly include the following two aspects. First, as a high-speed transportation system with different technologies from the wheel-rail high-speed railway, it cannot be connected with the railway network of more than 100,000 km that has been built in China.

Second, due to the restrictions of high-speed maglev turnout and its related technologies, the train tracking interval is long, which affects the train operating efficiency. The above deficiencies are mainly proposed based on competition with the conventional wheel-rail high-speed railway. With the low-vacuum pipeline high-speed maglev system operating at a significantly higher speed than that of the wheel-rail high-speed railway, its supplement to existing transportation modes will greatly strengthen the function of the existing transportation system.

3.2 Research actuality

3.2.1 Maglev railways

In the 1960s, Germany, Japan, and the United States began to develop maglev trains. In the 1970s, the United Kingdom, Canada, and the former Soviet Union also joined the research on maglev railway. However, as time went by, the United States, the former Soviet union, Canada, and the United Kingdom successively abandoned their research on maglev railway. After the 1980s, South Korea and China also joined the research on maglev railways [3].

Germany is the birthplace of the maglev railway concept. A German scholar named Kemper proposed the theory of maglev as early as the 1920s, and he obtained the invention patent for a maglev train in 1934. Research into maglev trains began in Germany in 1968. In 1969, TR01, the first model vehicle of a maglev train in the world, was developed. In the following years, TR02, TR03, TR04, and other models of maglev trains were developed. These maglev trains adopted the principle of a short-stator linear motor and operated mainly at medium and low speeds. In 1979, TR05 was designed under the principle of a long stator synchronous linear motor for the first time. The trains after TR05 were driven by a synchronous linear motor. From 2007 to 2017, TR09 was the latest model. To carry out high-speed maglev train tests, Germany completed the 31.5 km test line (TVE) at Emsland in 1988.

In 1962, Japan National Railway began to study the routine conductive maglev train. In 1972, it began to study the superconducting electric maglev train with low-temperature superconducting magnets. In the same year, it developed the world’s first single-section test vehicle, ML100. Later, the models of ML500, MLU001, MLU002, MLU001N, MLX01, etc., were developed. To better serve the development of their maglev systems, Japan built the 7 km Miyazaki maglev test line in the 1970s, and set a maximum test speed of 517 km/h without carrying a human in 1979. In 1997, a new 42.8 km test line was built between Chuancun and Qiushan village in Yamanashi County. The first test line (18.4 km) was completed in 1999, and the whole project was completed in 2013. As early as 2003, a high-speed maglev train in Japan set a world record of 581 km/h on the test line for manned travel. On October 26, 2010, Japan issued technical requirements for the first generation of L0-series maglev trains for business lines. In November 2012, the newly developed L0-series maglev trains entered the Yamanashi test line. The L0-series of vehicles travel on rubber wheels at low speeds. When the speed is greater than 150 km/h, the electromagnetic force is sufficient to convert the vehicle body to the maglev moving line, with a suspension height of about 100 mm. On April 21, 2015, the L0 system set a world record of 603 km/h on the manned Yamanashi test line.

China began to conduct research on maglev railway technology in the 1980s. In the beginning, the research institutions included the China Academy of Railway Sciences (CARS), Southwest Jiaotong University, National University of Defense Technology, the Institute of Electricians, and the Chinese Academy of Sciences. In 1989, the National University of Defense Technology developed their first small maglev test vehicle. In 1994, Southwest Jiaotong University developed a double-bogie 4 t maglev vehicle. In 1998, CARS developed a 6 t single-drive maglev to stabilize the suspension. In 2000, Southwest Jiaotong University successfully developed the world’s first manned high-temperature superconducting maglev experimental vehicle. Since the beginning of the 21st century, China has built a maglev test line at the National University of Defense Technology, a maglev train project test line at Qingcheng Mountain, and a high-speed maglev test line at Tongji University. On October 21, 2016, the Ministry of Science and Technology of the People’s Republic of China commissioned a key special project of “research on the key technologies of high-speed maglev transportation system” to the China Railway Rolling Stock Corporation, marking the beginning of research into high-speed maglev trains with a speed of 600 km/h in China. This project aims at developing the core technologies of suspension, traction, and control of high-speed maglev transportation systems, forming a new generation of core technology systems and standard specification systems for high-speed maglev transportation systems with independent intellectual property rights and international adaptability, and enabling China to have complete autonomy and industrialization capability for high-speed maglev transportation systems.

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3.2.2 The low-vacuum pipeline high-speed maglev system

American scholar Robert David put forward the idea of “vacuum pipeline transportation” as early as 1904. In the 1970s, Switzerland proposed an underground low-vacuum high-speed maglev subway system with tunnels as pipelines, namely the Swiss metro system. The system pumps the underground tunnels into a 10^{-1} atm vacuum, using linear push technology and maglev and guidance technology to realize a design speed of 500 km/h [4]. In the 1990s, Oster, an American engineer, registered a trademark and invention patent for the vacuum piping transportation system (ETT), which is a small, decentralized pipe “vehicle” model with a low vacuum inside and a cylindrical maglev cabin that can seat six people and reach a speed of 6,500 km/h. In 2004, Shen Zhiyun, an academician, proposed a technical scheme for the development of the low-vacuum high-temperature superconductor maglev high-speed system [5].

Although the concept of low-vacuum pipeline high-speed maglev systems has been proposed for decades, it has not been applied in engineering in many countries due to technical and economic reasons. In 2013, Elon Musk, the CEO of Tesla electric motor corporation, launched an initial program for Hyperloop and participated in a project for high-speed rail in California, and this again raised interest in vacuum tube technology around the world. According to Musk’s design, Hyperloop consists of four main parts: capsules, tubes, propulsion systems, and energy-storage components. The capsules can carry 28 passengers and travel up to 1,220 km/h. The pipes are made of steel, and the pressure in the pipes is expected to be 1/1000 of the pressure on the surface of the Earth. Since Musk proposed the concept of “Hyperloop,” a number of American firms have been working on Hyperloop technology, including Hyperloop One Company and Hyperloop Transportation Technologies (HTT).

In December 2015, Hyperloop One started testing at a test site with an approximately 1-km-long track in northern Las Vegas. In May 2016, Hyperloop One’s Hyperloop propulsion system was successfully tested outdoors for the first time. The test vehicle weighs about 680 kg and accelerates at a rate 2.5 times the speed of gravity. It only takes 1.1 s to go from 0 to 97 km/h. The maximum test speed reached was 186 km/h. Three more phases were tested in 2017.

(1) First full system test of maglev vehicle under a low-vacuum environment.

On May 12, 2017, Hyperloop One performed the first system-wide test of Hyperloop in a vacuum-filled pipeline in Nevada. In the test, Hyperloop One used maglev technology to travel for 5.3 s through a low-vacuum tube, accelerating at nearly 2 g and traveling at 113 km/h.

(2) Full-size passenger cabin test.

On July 29, 2017, Hyperloop One started to operate its full-size passenger cabin XP-1, which is 8.7 m long, 2.4 m wide, 2.7 m high, and made of aluminum and carbon fiber. The test vehicle completed the course with a top speed of 310 km/h. After the test, Hyperloop One said that the engine, electronics, vacuum pump, and maglev mechanism all worked well during the test. The XP-1 passenger cabin slides along the track in a maglev mode. The drive power of the propulsion system is 3.5 times that of the first stage. The lower pipe pressure was reduced to the pressure equivalent at an altitude of 2×10^5 ft (1 ft = 0.3048 m), which minimized the running resistance.

(3) Higher speed test.

In mid-December of 2017, Hyperloop One completed a test with a top speed of 387 km/h. In addition to the speed test, the company also conducted a series of tests on the new airlock system (which allows the train to operate in 500 m long vacuum tubes and at normal air pressure), electric motors, control and power electronics equipment, maglev equipment, etc.

HTT companies started to construct a test track of approximately 8 km in the central part of California in 2015. The first full-size carriage, the Hyperloop™, also entered the manufacturing phase on March 22, 2017. HTT plans its “Hyperloop” to transport goods by 2019 and passengers by 2021.

South Korea also once planned to develop its own subsonic capsule train, which is planned to be used on the ultra-high speed railway between Seoul and Busan. On October 21, 2016, Korea Institute of Railway Technology, Korea Institute of Construction Technology, and Ulsan National Institute of Science and Technology jointly established a research association on magnetic levitation based on vacuum pipeline. In early 2017, the Korean government and related academic institutions announced plans to build a Hyperloop code-named “HTX.”

In China, Southwest Jiaotong University; China Aerospace Science and Industry Group Co., Ltd.; China Academy of Railway Sciences; and other units are committed to the research of low-vacuum pipeline high-speed maglev systems. These units have established related test platforms. Southwest Jiaotong University developed a superconducting maglev system with low profile, low vacuum, and high temperature in 2011. A prototype of a low-vacuum pipeline for high-speed maglev trains was built in 2014.

4 Technological problems and key technologies

4.1 Science and technology problems

In theory, the use of low-vacuum pipeline technology to put the train in a vacuum environment without air resistance will greatly improve the speed of the maglev train, but to truly achieve an “engineered” solution, there are still many problems and controversies related to the technology, economy, safety, and other aspects that must be considered. In this paper, the possible scientific, technical, and engineering problems of a low-vacuum pipeline high-speed maglev system are summarized from four aspects, including the top-level design of the giant system, the low-vacuum pipeline and the environment, the high-speed maglev system, and commercial operation.

4.1.1 Top-level design of the giant system

The top-level design of the giant system mainly includes the high-speed maglev line selection and flat profile design; degree of vacuum; vehicle-pipe section selection; arrangement of station; line conversion and transition of passenger riding and landing environment; the reliability, availability, maintainability, and safety (RAMS) system of the whole life cycle of subsystems and components; building and guarantee; system internal and external interface relationships and management; and flow–solid–magnetic–thermal physical field coupling mechanism and analysis.

4.1.2 Low-vacuum pipeline and environment

The low-vacuum pipeline and environment mainly include the low-vacuum pipe material and structural design of the pipeline support structure, laying precision, temperature and settlement deformation modes and deformation coordination, pipeline connection, pipe auxiliary system arrangement, pipeline connection mode, management of long and large sections of low-vacuum environment, efficient build and control of the pipeline, vehicle body seal and the maintenance of the vehicle environment, body and electrical components under conditions of low-vacuum heat dissipation, the characteristics of low-vacuum electrical equipment and electromagnetic dynamic distortion, low vacuum noise propagation mechanisms and interior noise control, wireless communication in ultra-high speed vehicles under a low vacuum airtight environment, emergency evacuation and rescue in a low-vacuum environment, and maintenance and repair of the pipeline.

4.1.3 High-speed maglev system

The high-speed maglev system mainly includes the suspension guide technology scheme selection, track beam geometric accuracy and matching, high speed running under suspension stability control conditions, driving and braking schemes under high-speed operation and control conditions, braking and suspension guide magnetic field coupling drive mechanism and analysis method for high-speed operation, high-speed operation low-pressure vacuum tube wave effect and its influence on train operation safety, stability, high speed runtime smooth optimization, magneto resistance effect and magnetic field under the high-speed operations for long distances, multipart synchronous coordination control of traction power supply, aerodynamic thermal radiation, heat conduction, and heat dissipation caused by a high-speed moving boundary.

4.1.4 Commercial operation

Commercial operation mainly includes the construction of relevant technical standard systems, scheduling command and security protection, transportation organization and passenger service, operation and maintenance, as well as connections with the existing transportation system and other issues.

4.2 Key technologies

In terms of system functions, a low-vacuum pipeline high-speed maglev system could be divided into the overall system, low-vacuum and track systems, vehicle system, suspension guidance system, driving and braking systems, communication and operation control systems, and safety protection, disaster prevention, and rescue systems, etc. 22 key technologies for these subsystems are preliminarily proposed.

4.2.1 Overall system

There is no successful design experience for reference on the overall level of the low-vacuum pipeline high-speed maglev system, and the key technologies to be mastered include integrated design technology, complex multi-physical field system coupling analysis technology, system safety and reliability technologies, system simulation optimization and test verification technologies, etc.

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4.2.2 Low-vacuum and track systems

These systems have a large vacuum space, so it is difficult to dissipate heat in a timely manner through convection. At the same time, high-speed line smoothness, reliability, structural characteristics, and other parameters present higher requirements. The key technologies to be mastered include the construction and control of a large-size pipeline in a low-vacuum environment; design and manufacturing technologies for a high-precision track, line bridge, and tunnel; high-speed maglev turnout technology [6]; and instantaneous large-area high-heat dissipation technology for the track.

4.2.3 Vehicle system

Under high-speed operation, vehicles are coupled by loads of force, heat, vibration, and noise, which present new requirements for the train body and running mechanism. The key technologies to be mastered are low resistance/noise/heat body shape integration design technology, lightweight, high-bearing body structure design technology, high natural frequency walking mechanism design technology, etc.

4.2.4 Suspension guidance system

Stability, loss suppression, and structural strength of the suspension system are required at high speed. The key technologies to be mastered are large and heavy load stable magnetic levitation design technology, fluctuation suppression technology for the high-speed dynamic suspension force, new development technology for a high-performance superconductor, etc.

4.2.5 Driving and braking systems

When the train is running at high speeds, there are higher requirements for the working efficiency of the driving system under the conditions of high frequency, high voltage, and large current, as well as the braking force density and speed range of the eddy current brake at different speeds. The key technologies to be mastered include high-thrust high-speed motor development technology, high-power high-speed drive converter control technology, high-density and reliable energy storage and power supply technologies, and wide-area high-density eddy current braking technology.

4.2.6 Communication and operation control systems

The low-vacuum pipeline high-speed maglev system has strong coupling, complex control, and high reliability requirements. The key technologies to be mastered are high-speed and high-reliability operation control technology and low-vacuum airtight environment high-speed and high-reliability vehicle-ground wireless communication technology.

4.2.7 Safety protection, disaster prevention, and rescue systems

Safety protection, disaster prevention, and rescue systems mainly include state and disaster monitoring, assessment technology, and emergency response and rescue technologies.

5 Suggestions

5.1 Project approval at the national level

Although China’s Ministry of Science and Technology has set up a key project of “key technologies of maglev transportation system,” the technical complexity of the system has been greatly increased owing to the low-vacuum environment characteristics being combined with the high-speed maglev system. The proposal shall be approved at the national level on the basis of previous studies and a study on low-vacuum pipelines with a speed of over 600 km/h for a high-speed maglev system, including research on the overall system architecture and system technology, infrastructure design and construction technologies, key equipment and manufacturing technologies, and operation maintenance and security assurance strategies.

5.2 The construction of a low-vacuum test pipeline for a high-speed maglev system

As a complex giant system engineering technology, engineering verification experiments need to be conducted repeatedly. The Southwest Jiaotong University is building a low-vacuum high-temperature superconducting maglev straight test line, with a total length of 140 m. The test line is used for the testing with speeds under 400 km/h, and it cannot achieve the purposes of the engineering verification tests. It is suggested to set up a research project to build a test line of about 5 km in length, promote the engineering application breakthrough of a low-vacuum pipeline high-speed maglev system, and expedite the engineering and industrialization process for scientific and technological achievements.

5.3 A national laboratory for a low-vacuum pipeline high-speed maglev system

The laboratory should be jointly built by the Ministry of Science and Technology, the Ministry of Transport, and China Railway Corporation. The laboratory mainly relies on joint construction by CARS, Southwest Jiaotong University, China Railway Rolling Stock Corporation, Aerospace Science and Industry Group, China Railway Corporation, China Railway Construction Corporation, and China Petroleum Pipeline Corporation. Aimed at the demand of developing a “transportation power,” the laboratory will carry out continuous scientific and technological innovation through resource sharing among scientific research institutes, universities, and large enterprise groups in the field of rail transit. Finally, the laboratory will be the research and development base, academic exchange center, and talent training base for the low-vacuum pipeline high-speed maglev system in China. The laboratory will form the technological innovation system for the low-vacuum pipeline high-speed maglev system.

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