Current status and reflection on the development of high-speed maglev transportation

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Abstract

Purpose – High-speed maglev technology can address the issues of adhesion, friction, vibration and high-speed current collection in traditional wheel-rail systems, making it an important direction for the future development of high-speed rail technology.

Design/methodology/approach – This paper elaborates on the demand and significance of developing high-speed maglev technology worldwide and examines the current status and technological maturity of several major high-speed maglev systems globally.

Findings – This paper summarizes the challenges in the development of high-speed maglev railways in China. Based on this analysis, it puts forward considerations for future research on high-speed maglev railways.

Originality/value – This paper describes the development status and technical maturity of several major high-speed maglev systems in the world for the first time, summarizes the existing problems in the development of China's high-speed maglev railway and on this basis, puts forward the thinking of the next research of China's high-speed maglev railway.

Keywords High-speed maglev, Necessity, Current development status, Problems in development, Reflections

Paper type Research paper

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1. The necessity of developing high-speed maglev railway

1.1 The demand for societal and economic advancement

Currently, the world economic growth pattern, international industrial division, global investment and trade rules, geopolitical environment, etc. are undergoing profound changes. China's economic development has entered a new normal in response to the trends of the times. The new economic development model and regional development pattern put forward faster and more comfortable high-quality demand for transportation. At the same time, as China continues the process of building a socialist modernized strong country comprehensively, there is an increasing demand for rapid, secure and convenient transportation. The pursuit of speed by people will never remain at the existing level, and the progress of human civilization and socio-economic development will continuously demand new requirements for transportation speed.

(1) The demand for more efficient business rapid mobility.

As economic development evolves towards a more advanced stage with optimized division of labor and a more rational structure, new forms of industrialization, informatization and urbanization are deepening. New growth drivers and emerging growth areas continue to grow and expand, leading to an increase in the proportion of final consumption and the service sector. This enhances economic vitality and accelerates factor flows, thereby generating a higher demand for efficient business and rapid flow.

(2) The demand for rapid connectivity between urban agglomerations and metropolises.

The State Council has put forward the initiative to promote regional coordinated development, led by the construction of the Belt and Road, coordinated development in the Beijing-Tianjin-Hebei region and the development of the Yangtze River Economic Belt (Zhang, Yang, Jiao, Liu, & Wu, 2020; Kluehspies, 2017). This initiative aims to facilitate extensive horizontal and vertical connections between the eastern, central and western regions of China, forming new economic growth poles, growth belts and urban clusters. The implementation of these three strategies necessitates prioritizing the construction of fundamental transportation infrastructure. The balanced development of the eastern and western regions also requires the planning and construction of high-speed transportation corridors in key hub cities between the eastern and central-western regions.

The development of new urbanization is accelerating. It is expected that China's urbanization rate will rise to over 80% by 2040 (Yan, 2006). Urban agglomerations will become the main form driving China's economic development. The development of urbanization will present three trends: Firstly, the strategic position of central cities will become more prominent, and the development trend of urban agglomerations (circles, belts) will be further strengthened; The second is that the main transportation channel will become the primary area of urbanization, with significantly enhanced aggregation effects along the main channel and faster development speed than other regions; Thirdly, the number of newly built small towns will rapidly increase, and the interactivity of large cities will further strengthen. The demand for rapid interconnectivity between urban agglomerations and megacities has experienced a dramatic surge.

(3) The demand for higher travel quality.

With the development of the economy and the improvement of people's living standards, the average number of trips per person has significantly increased. There is an urgent demand for faster and more comfortable high-quality travel, as well as diverse transportation options. The structure of passenger transportation has undergone significant changes, with the demand for high-speed rail, civil aviation, and small car travel constantly increasing. The demand for high-quality, multi-level, diversified, and personalized travel is rapidly growing (Han, Yim, Lee, Hur, & Kim, 2009; Chen, Sun, Zhu, & Zhai, 2021). The demand for international passenger travel, as well as travel between major urban agglomerations and within urban agglomerations, has become more intense, shifting from a development focus on “accessibility” and “connectivity” to “quality mobility” and “efficient transportation”.

1.2 The demand for rapid growth in passenger flows

In 2008, the passenger volume of high-speed rail in China was only 7.34mn. After more than a decade of explosive growth, the passenger volume of high-speed rail reached 2.29bn in 2019. From 2008 to 2018, the share of high-speed rail passenger traffic in the total passenger transportation market increased from less than 1% to 11.5%, while the share in the railway transportation market increased from 0.5% to 60.9% in 2018. The public’s demand for high-speed rail has shown a significant increase compared to other transportation modes. In order to meet the continuously growing demand for high-speed passenger flow, maintain the market competitiveness of railway transportation, and further expand market share, it is necessary to further improve the transportation speed of rail transit systems.

From the current situation of the Beijing-Shanghai channel, the channel consists of the Beijing-Shanghai high-speed rail, air transportation provided by major city airports along the Beijing-Tianjin-Jinan-Nanjing-Shanghai route, and the Beijing-Shanghai Expressway (G2), Shenhai Expressway (G15), Changshen Expressway (G25) and other highways within the channel.

From the perspective of the Beijing-Shanghai high-speed rail, in 2017, a total of 43,932 train services were operated, carrying 56.386mn passengers with a daily average occupancy rate of as high as 80.2%. From the opening of the high-speed rail on June 30, 2011, until June 30, 2019, a total of 1.03bn passengers were transported within eight years, with an average annual growth rate of 20.4%. Among them, 192mn passengers were transported in 2018, accounting for 9.6% of the total high-speed rail traffic. The carrying capacity of some sections of the Beijing Shanghai high-speed railway is nearly saturated, and the capacity utilization rate during peak hours even exceeds 100%. It is urgent to take effective measures to solve the bottleneck of transportation capacity.

From the analysis of regional transportation volume, long-distance passenger transportation in the region is mainly by railway, supplemented by air, and short distance passenger transportation is mainly by road. In 2017, the total passenger volume of the whole society was 4.34bn people, accounting for 22.3% of the national total, with roads accounting for 82.1%; The completed passenger turnover volume is 577.8bn person kilometers, with railways accounting for 56.9%. Since the “10th Five-Year Plan” period, the passenger volume of regional rail has maintained rapid growth, with an average annual growth rate exceeding 7% from 2000 to 2018, which is higher than the national average growth rate of 6.5% during the same period. The current regional railway passenger volume stands at 870mn people, accounting for 34.6% of the national total.

With the rapid development of the economy and society, the public’s demand for more convenient high-speed transportation is becoming increasingly strong. For medium and long distance passenger transportation, high-speed rail transit has obvious comprehensive advantages in terms of price, travel time and other aspects. At the same time, based on the current operation of high-speed railway lines, some sections of the Beijing Shanghai high-speed railway in China, as well as developed areas such as Guangzhou, Shenzhen, Shanghai, Hangzhou, Shanghai and Nanjing, are basically in a saturated state. It is urgent to take faster and more convenient measures to solve the bottleneck of future transportation capacity.

2. The significance of high-speed maglev technology development

The high-speed maglev speed can reach 600km/h, which is an important development direction of higher speed rail transit in the future (Wu, Xiao, An, Wu, & Shen, 2022; Lee, Kim, & Lee, 2006). As a disruptive technology, high-speed maglev railway will have the main characteristics of disruptive technology, which will bring certain challenges to the development of traditional transportation modes, form a new market pattern, improve the economic benefits of the railway itself and have an important impact on economic and social development.

The high-speed maglev transportation engineering project effectively promotes regional coordinated development and optimizes and adjusts the comprehensive transportation system. The high-speed maglev railway will reach a speed of over 600 kilometers per hour, which can greatly shorten passenger travel time, significantly increase the traffic speed between major cities such as Beijing, Shanghai and Guangzhou, promote regional agglomeration effect, significantly improve the accessibility, efficiency and high-quality transportation services between urban clusters, achieve coordinated regional development on a national scale and enrich the existing comprehensive transportation system, Helping to form a new pattern of market sharing among different modes of transportation.

3. Current development status of high-speed maglev technology

3.1 Foreign development status

Since the 1960s, developed countries such as Japan, the United States and Germany have all regarded high-speed maglev railways as the future development direction in the transportation field and have carried out long-term technological research and development reserve competition and industrial layout at the national level (Xiong & Deng, 2021; Ma, Luo, Zhang, & Sheng, 2021).

Japan has constructed a 42.8-km-long high-speed maglev test line, achieving a manned test speed of 603 km/h. They are currently in the process of building the Chuo Shinkansen, a high-speed maglev railway line spanning 286 kilometers from Tokyo to Nagoya. It is planned to be operational for commercial use in 2027, with a maximum operating speed of 505 km/h.

The United States has been studying high-speed maglev technology for military testing. In 2016, they achieved a test speed of 1,018 km/h and have plans to use this technology for a "Super High-Speed Rail" with a speed of 1,000 km/h. In 2020, they completed manned tests at a speed of 172 km/h, and the U.S. Department of Transportation officially confirmed the federal financing qualification for the "Super High-Speed Rail."

Germany built a 31.5-km-long high-speed maglev engineering test line in 1986, with a maximum speed of 450km/h for manned testing in 1990. In 1991, Germany announced the maturity of its high-speed maglev transportation technology with a design speed of 500km/h.

3.2 Domestic development status

(1) Conventional electromagnetic maglev

Since 2000, China has carried out systematic research on the high-speed maglev transportation system of the conventional electromagnetic system. Taking the introduction of German technology to build the Shanghai high-speed maglev demonstration operation line as an opportunity, Chinese railway workers will organize national efforts to digest and absorb German high-speed maglev transportation technology through engineering construction links such as technical negotiations, factory supervision, installation and commissioning and operation training.

At the same time, through the National 863 Major Special Project and the Science and Technology Support Plan and using the time of the four five-year plans, we carried out prototype research and development, engineering product manufacturing, research on substitute imported parts, technical standard research, engineering application project planning and design for the conventional high-speed maglev transportation system and comprehensively mastered the technical system of conventional high-speed maglev transportation.

Additionally, through 18 years of trial operation and commercial operation of the Shanghai Maglev Demonstration Line, Chinese railway workers have accumulated rich maintenance and management experience and technology, becoming the only country in the world with technology in the construction, product manufacturing and commercial operation management of high-speed maglev projects. China Railway Rolling Stock Corporation (CRRC) Qingdao Sifang designed a high-speed maglev transportation system with a speed of 600km/h, which will be launched on July 20, 2021. It has successfully developed a complete set of engineering equipment for vehicle and traction operation control communication and built a commissioning line. The sample vehicle has completed a low-speed full system joint commissioning test on the commissioning line, marking that the domestic conventional electromagnetic maglev has basically met the conditions for engineering test demonstration.

(2) Superconducting electromagnetic maglev

In China, since 2017, China Aerospace Science and Industry Corporation Limited (CASIC), CRRC and other units have successively organized teams to specialize in tackling the superconducting electromagnetic Maglev. Since the “13th Five Year Plan”, CASIC has independently developed a prototype superconducting magnet with a magnetic field strength of more than 3T through self-financing projects. The construction of the scaled test line was completed in 2018, and it is expected to complete the construction of a 2-km full-size test line in December 2023, to achieve full scale functional verification of the whole system; In May 2022, the first low-temperature superconducting Maglev prototype vehicle was completed, and the inaugural test run was conducted on the full-scale test line, achieving a test speed of 50 km/h.

CRRC Changchun Railway Vehicles fully launched research and engineering verification of superconducting electromagnetic maglev technology in early 2018. In terms of technology research and development, CRRC Changchun Railway Vehicles has made breakthroughs in core technologies such as nonmagnetic track, ground coil, superconducting magnet, speed measurement and positioning, traction converter, lightweight car body, contactless power supply, system dynamics, aerodynamics, electromagnetic shielding, etc., and has basically mastered the design and manufacturing technology of key components, built a high-speed electromagnetic maglev full system hardware in the loop simulation platform, Electric maglev ground static levitation test bench, 600 kilometers per hour long stator high-speed maglev traction test bench. In addition, CRRC Changchun Railway Vehicles has also built a 200 m all element superconducting electromagnetic maglev test line. In 2022, the first High-temperature superconductivity electromagnetic maglev project prototype vehicle was produced. The type test of the prototype vehicle was completed by the end of 2022, and the inaugural test run was completed in April 2023.

(3) Superconducting pinning maglev

In 2000, Southwest Jiaotong University verified the original superconducting pinned high-speed maglev principle in China. In February 2013, it successfully developed China’s first manned superconducting pinned maglev vehicle ring test line and completed the verification of the superconducting pinned maglev vehicle system with bogie, braking, wireless communication and other functions for practical applications. On this basis, in June 2014, the first international vacuum pipeline superconducting pinning maglev vehicle test system “Super Maglev” was successfully constructed and debugged. In terms of high-speed test, relying on the ejection high-speed test bench, the high-speed test of the High-temperature superconductivity maglev model car with a speed of 400 kilometers per hour has been completed, and the suspension characteristics and stability of motion characteristics during high-speed operation have been verified. In July 2021, the High-temperature superconductivity maglev high-speed rotating test bench with the highest linear speed of 700km/h was developed to carry out the long-term reliability experiment of the suspension guidance system. In recent years, with the support of the National Development and Reform Commission, Sichuan Provincial Development and Reform Commission and other departments, Southwest Jiaotong University is planning to build a "polymorphic coupling rail transit dynamic simulation test platform" (Deng *et al.*, 2016). The platform is a 1620m long pipeline with continuously adjustable air pressure ranging from 0.005 to 1.0atm, used to simulate the operating environment of trains. The type and scale ratio of the model can be varied from 1:10 to 1:1 according to the test needs, for different types and scales of model tests, with a maximum test speed of 1500km/h. At present, the project has been tendered in September 2021 and plans to conduct experiments in 2023.

4. Problems in the development of high-speed maglev

Throughout countries such as the United States, Japan and Germany that have advanced high-speed maglev technology, they are all driven by national macro planning and deployment and develop high-speed maglev technology to support commercial operations through the construction of tens of kilometers of engineering test lines. In the past 20 years of development, China's high-speed maglev industry has achieved significant results, but there are also some problems.

(1) The environmental impact of high-speed maglev railways needs to be thoroughly evaluated, and there are obstacles to their promotion and application. It is urgent to eliminate public misunderstandings.

At present, the noise impact of high-speed maglev trains is significant. According to the results of Shanghai maglev testing, the maximum sound pressure level at a distance of 25 m from the track centerline reaches 98dB (A) when the operating speed is 430km/h (Han *et al.*, 2022). In addition, the electromagnetic environmental effects of high-speed maglev railways are comparable to those of high-speed railways, and further objective evaluation and promotion are needed. The impact of construction and operation periods on the environment urgently needs to be rigorously evaluated from various aspects such as acoustic environment, vibration environment, electromagnetic radiation, social environment, ecological environment, etc (Mitropoulos, Kortsari, Koliatos, & Ayfantopoulou, 2021). Corresponding technical plans should be formulated for the adverse effects. In May 2019, the construction of the South Alps Tunnel on the Central Shinkansen in Japan caused water gushing, resulting in a decrease in surface river flow (Oei River). As of October 2019, Shizuoka Prefecture had not received an environmental impact assessment approval, and although the Ministry of Land, Infrastructure, Transport, and Tourism was eager to start construction, there was no way to do so. This dispute may affect the opening of the Central Shinkansen in 2027; The Shanghai Hangzhou maglev project, which received national approval in 2010, has not yet started construction due to significant controversies over radiation, safety and economic issues. Therefore, China should do a good job in environmental assessment in advance, eliminate public misunderstandings and avoid any impact on project implementation.

(2) The lack of a 600km/h high-speed magnetic levitation test line makes it impossible for the offline sample vehicles to conduct further testing and verification.

In terms of high-speed maglev trains, Japan and Germany have conducted many technical feasibility verifications, among which the most critical issues are safety issues, including high-speed braking and durability. Only after completing the feasibility verification test can the practicality be evaluated. At present, Japan's high-speed maglev train has undergone 22 years of safety and reliability verification on the Yamanashi Test Line (completed in 1997 with a length of 18.4 kilometers and extended to 42.8 kilometers in 2013) and the first maglev line, the Central Shinkansen, is also scheduled to open in 2027. Under the leadership of the Ministry of Science and Technology, CRRC Corporation of China has carried out a key special research project on "Key Technologies of Magnetic levitation Transportation System", which has conquered the core technologies of high-speed magnetic levitation transportation system suspension, traction and control. The high-speed magnetic levitation test prototype with a speed of 600 kilometers per hour was officially launched on May 24, 2019. However, there is currently no corresponding test line to verify the functionality, reliability, safety and other aspects of the test prototype.

(3) The economic benefits of the line are not yet clear, and there are certain investment risks.

The magnetic levitation railway requires a large investment and has a long payback period, which will to some extent affect investor confidence and restrict the development of the magnetic levitation railway. The Shanghai Airport Maglev Line in China is the world's first commercially operated high-speed maglev line. The total annual passenger volume is basically over 4mn, but the operating income cannot cover the operation and maintenance expenses.

This paper assumes the Beijing Shanghai Line as the usage scenario for maglev railways and estimates the construction costs, financial benefits, operating subsidy levels and national economic benefits of three types of high-speed maglev railways. Overall, although the national economic benefits of the three types of maglev railways are relatively good, their financial benefits are not ideal, and their investment payback periods are all over 30 years.

(4) There are a large number of research and development enterprise in China with high investment, but there is a lack of overall coordination.

CRRC and Tongji University are actively conducting research on the conventional maglev railway, while Southwest Jiaotong University and Aerospace Science and Engineering are conducting research on high-speed maglev railways and have established or are promoting the establishment of relevant experimental platforms. Each company has invested heavily in funds, platforms, personnel, and other aspects, aiming to form a new generation of high-speed maglev transportation system core technology system with independent intellectual property rights in China. The high-speed maglev railway is a complex system engineering that involves a wide range of disciplines and majors. We need close communication and coordination among multiple units with expertise in China to jointly tackle key issues. However, at present, the sources of research funding vary among different units, and there is a lack of unified coordination among the leading units, which is not conducive to forming a joint force, fully utilizing funds and talent resources and improving research and development efficiency.

5. Prospect of the future research direction

(1) Currently, the bottleneck problem facing the development of 600km/h atmospheric pressure and constant conductivity high-speed maglev in China is the construction of engineering test lines and the planning of application lines. There are no major technical obstacles that need to be addressed in the long term for the high-speed maglev under atmospheric pressure, but it is necessary to solve the high-speed test verification of key technologies. The superconductivity maglev is likely to achieve higher operating speed. On the basis of the mature development of the above technologies, researchers will further

break through the operational speed limit by introducing a low vacuum environment. However, there are many unresolved and undiscovered scientific and technical problems in the low vacuum tube (tunnel) high-speed maglev railway, and there is currently no corresponding experimental or commercial operation line experience to learn from. Many data rely on theoretical analysis, simulation calculations and laboratory verification, and its technical feasibility still needs to be further demonstrated (Luo, Li, & Shi, 2020).

Therefore, in the next step, priority should be given to promoting the construction and application line planning of 600km/h atmospheric pressure and constant conductivity high-speed maglev railway test line, and at the same time, accelerating the research on basic theories and key technologies of high-temperature superconductivity permanent magnet, superconducting electric suspension and low vacuum tube (tunnel) high-speed maglev railway and driving the enthusiasm of property, science, research and use (local government) (Deng *et al.*, 2017; He, Sun, & Lu, 2020).

(2) Deeply evaluate the environmental impact of high-speed maglev railways and improve their environmental adaptability. The impact of high-speed maglev railway construction and operation on the environment urgently needs to be rigorously evaluated from various aspects such as acoustic environment, vibration environment, electromagnetic radiation, social environment, ecological environment, etc. Corresponding technical plans should be formulated for the adverse effects. Therefore, China should do a good job in environmental assessment in advance, eliminate public misunderstandings and avoid any impact on project implementation.

In order to improve the environmental impact of high-speed maglev railways such as noise and electromagnetism and enhance their environmental adaptability, the next step is to jointly organize domestic experts in the field of rail transit noise, electromagnetism and other fields and technical personnel of high-speed maglev train development units as soon as possible, form a professional team for environmental impact assessment of high-speed maglev railway, set up special research projects, assess the noise and electromagnetic environmental impact of high-speed maglev railway, study relevant technical measures and remove developmental disorder.

(3) Deeply demonstrate the economic feasibility of the high-speed maglev railway project and propose practical and feasible measures from a professional perspective to enhance financial and national economic evaluation. The high-speed maglev railway project requires a large investment and a long investment payback period, which will to some extent affect investor confidence and restrict the development of the maglev railway. The next step is to conduct analysis based on basic information such as investment, freight rates and costs, study the financial evaluation of the project and clarify the investment income situation of the high-speed maglev railway. On this basis, comprehensive environmental benefits, modal shift benefit, induced demand benefit and other related calculations will be conducted, and economic evaluation and comprehensive analysis will be carried out. Suggestions for the operation and management of high-speed maglev railway will be proposed from the perspectives of financial support and risk prevention and control.

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