Development Status and Global Competition Trends Analysis of Maglev Transportation Technology Based on Patent Data

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Abstract This study investigates magnetic levitation (maglev) transportation technology's development status and global competition trends by mining patent data related to maglev transportation technology from five perspectives. It uses information collected from the Innography patent database: the number of annually registered patents throughout maglev's development history, the key patent-contributing countries and their global distribution, the top 20 innovative organizations in maglev transportation technology, their organization type, and the technology distribution classifications of their patents, core patents, and their holders and registered regions. A comparison and analysis are carried out based on patent data. The study summarizes the development and main trends of maglev technology, the countries with strong competition, the markets with the most potential for maglev technology application, the focuses of technological research and development, and the future research directions of major innovative organizations and their core patents. The study offers suggestions and recommendations from both national/governmental (macro) and organizational (micro) perspectives.

Keywords Maglev transportation · Data mining · Global patent distribution · Core patent · Competitive situation · Innovative organization

1 Introduction

The magnetic levitation (maglev) transportation system is a rail transport method that uses electromagnetic forces generated by a linear motor system to repel and push a train along its track (levitation) as well as to move the train toward its destination. Maglev transportation systems have many advantages over traditional urban rail transit systems such as subways, light rail, monorail, and trams, such as greater safety, stronger environmental adaptability, stronger climbing performance, lower performance–cost ratios, less noise, and lower radiation. Therefore, maglev technology is considered an “eco-friendly” method of travel in the twenty-first century.

Several maglev transportation systems have been constructed and put into operation around the world, such as the Shanghai high-speed Maglev Transit line in China (also known as Transrapid) that runs from Shanghai Pudong International Airport to Longyang station, which is an interchange station, and connects to Shanghai subway line 2 [1, 2]. The other lines are operated at low-to-medium speeds, such as Linimo in Aichi Prefecture, Japan [3, 4], the low-to-medium speed Incheon Airport Maglev that runs from Incheon Airport in South Korea [5], the low-speed Changsha Maglev Line that runs from Changsha Huanghua International Airport in China [6], and the low-speed Beijing S1 maglev transportation line in China [7]. Based on strong market potential, maglev transportation systems have gradually become integrated into urban rail transit systems. The successful construction and operation of maglev transportation lines show that maglev transportation is a promising public transportation system that will play an important role in the future of transport systems [8].

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Maglev technology is a potential solution for future traffic and ecological challenges because the main advantages of maglev technology are obvious: short trip times due to its high speed and/or high acceleration; a high level of safety and comfort due to its magnetic guidance and levitation systems; low operating costs due to the low maintenance effort required (as it is contactless) and high efficiency; flexible alignment due to the high gradients because there is no need for a functional grip between the wheel and the rail; and its eco-friendliness due to its high-efficiency, emission-free system, flexible alignment, low noise, and independence from energy modes [9]. Maglev developers claim that their system can achieve higher speeds and lower energy consumption and life-cycle costs and can take more passengers, while producing less noise and vibration than high-speed rail [10]. Therefore, Maglev transportation has the potential to be more efficient and affordable than alternative technologies for many transportation applications [11].

The research on and application of maglev transportation technology are abundant. Chan and Aldhaban introduce and compare the major determinants of international technology transfer strategies in the high-speed rail industry from the perspectives of both technology import and export [12]. Minakami introduces a new paradigm of the road by using maglev vehicles [13]. Barber discusses the market for maglev technology for urban applications [14]. Hellinger and Mnich compare the different types of linear motors in maglev transportation [9]. Thornton outlines the keys to reducing energy intensity by using light vehicles with low aerodynamic drag. The key to affordability is to use small, light vehicles that can operate on less-expensive guideways and that require less power for propulsion [11]. The academic and engineering research on maglev technologies lends strong support to the benefits of maglev technology's commercial application. Maglev can be both less expensive and more efficient than its alternatives. Maglev has the ability to achieve much higher acceleration and braking rates than steel wheels on steel rails. Designs that take advantage of this fact will maximize efficiency and cost-effectiveness. Maglev's greatly reduced noise, improved ride quality, and reduced energy consumption will make it much easier to sell high-speed ground transportation [11].

This study explores the current maglev transportation development situation and technology trends by mining maglev transportation patent data from a commercial patent database, analyzing the data, and summarizing the maglev transportation development situation and technology trends. Patent data reflect the latest cutting-edge scientific and technological intelligence. Therefore, analyzing patent data may provide useful indicators for the development of corresponding technologies in a nation, region,

and industry, as well as the distribution and development trends of the technologies across nations, regions, and industries. The results of this analysis may help governments and enterprises concentrate essential resources on key technologies, thereby achieving swifter technological catch-up and leapfrog development in the industry.

Based on patent data related to maglev technology from the Innography patent database, the developmental stages and trends of global maglev technologies are analyzed. The main contributing countries with patents, the global distribution of key patents, the focus of the associated technological research and development, the most innovative organizations, and the most valuable patents are also analyzed. The purpose of this research is to provide references that governmental decision-makers can use when formulating supporting policies as well as to help enterprises establish strategies for technological research and development and make appropriate market decisions as maglev transportation systems continue to develop.

2 Maglev Patent Data Sources and Search Results

The data used in this study were obtained from the Innography patent database. Innography is a web-based platform developed by ProQuest Dialog, a member of Cambridge Information Group, that provides online applications and tools related to intellectual property business intelligence. The database has grown to incorporate patent search and analysis tools that enable the mining of core patents and patent quality assessment [15]. The Innography platform includes the patent families, legal statuses, and original descriptions of patents from more than 90 countries and regions, covering approximately 40 years and 60,000 patent litigation entries from the Public Access to Court Electronic Records (PACER) provided by the Federal Judiciary of the USA, as well as financial data on the patentees released by Dun and Bradstreet and the US Securities and Exchange Commission [16].

Based on English terms relevant to the subject of maglev transportation systems and international patent classification codes, the following search parameters were used for the research data queries: @(abstract, claims, title) [(electromagnetic* or magnetic*) and (levitat* or suspen*) or maglev or EML] and (rail* or trans* or train* or vehicle) @* and (ipc_B60 or ipc_E01 or ipc_B61). The search was conducted on November 26, 2017, yielding 12,269 corresponding patents. Patents with classification codes B000 (Performing Operations), E000 (Fixed Constructions), H000 (Electricity), F000 (Mechanical Engineering), G000 (Physics), and A000 (Human Necessities) accounted for 76.68, 12.46, 4.85, 2.68, 1.8, and 0.29% of the total,

respectively. The remaining 1.24% of the patents belonged to other categories.

3 Analysis of Maglev Patent Data Search Results

3.1 Analysis of Global Development Stages and Trends in Maglev Technology

Changes in the number of annual patent applications may provide an overview of the development trends in a given technological field. Maglev-related patent applications from 1998 to 2016 are shown in Fig. 1 based on the patent's priority year. The figure shows that, in general, applications of maglev-related patents have been growing. Based on the number of proposals involving maglev technology and the corresponding scientific discoveries, we extended the timeline to include a review of the development history of and trends in the maglev transportation system. We divided the development of maglev technology into three stages [17, 18].

The first stage is denoted the “stage of scientific discovery (1842–1934).” The concept of magnetic levitation was first proposed by British physicist Samuel Earnshaw in 1842. In 1922, German engineer Hermann Kemper proposed the principle of electromagnetic levitation. He was awarded the world's first patent for maglev technology in August 1934 (Reichs Patent number 643,316). During this first stage, patented maglev technology was developed from scratch, and the development of the technology was slow.

The second stage is denoted the “stage of technological invention (1934–2003).” Starting from the validation of laboratory models, Germany developed eight generations of maglev trains (TR01 to TR08). Japan achieved results from the research and development of conventional maglev trains through the application of superconducting magnets.

Beijing Enterprises Holdings Maglev Technology Development Co. Ltd. (Beijing Maglev) cooperated with the National University of Defense Technology in the development of sample maglev trains, built the first domestically developed maglev line, and put it into trial operation in Changsha, China. During this stage, the number of maglev-related patent applications grew rapidly. In 2003, the world's first commercial high-speed maglev was put into operation in Shanghai, marking the transformation of maglev technology from laboratory samples to valuable prototype products. As a result, applications for maglev-related patents peaked in 2004, at 553.

The third stage is denoted the “stage of engineerization of the technology (2003–2017).” The low-to-medium speed maglev lines in the Aichi Prefecture in Japan and the Incheon Airport in South Korea were successively put into operation. The test of the TR09 was completed in Germany, and the Chinese Ministry of Science and Technology listed maglev technology as one of the major research projects of the 863 Program (also known as State High-Tech Development Plan). In 2011, the Beijing Maglev S1 line, the first developed maglev line in China, began its construction. Applications of maglev-related patents continued to grow in the successive years. In 2016, the number of patent applications reached a total of 721, with a growth rate of 14%. In the same year, the low-to-medium speed maglev train between Changsha Huanghua International Airport and Changsha South Railway Station in China began trial operations. In 2017, the Beijing S1 Line that connects Shimenying of the Mentougou District and Pingguoyuan of the Shijingshan District was put into commercial operation. This achievement symbolized the maturing of maglev technology, as its stability and advancement were deemed fit to serve the public. Thus, the development of maglev technology officially entered the stage of industrialization.

Fig. 1 Annual applications of maglev-related patents from 1998 to 2016. *Data Source:* Innography patent database (extracted on November 26, 2017)

3.2 Key Patent-Contributing Countries and Global Distribution of Patents

3.2.1 Key Patent-Contributing Countries

Patent-contributing countries are the home countries of the patentees. The top 10 patent-contributing countries, sorted based on the number of patents, are shown in Fig. 2. As the figure shows, the five leading countries in maglev technology are China (3360, 27.11%), Japan (3026, 24.66%), Germany (2508, 20.44%), the USA (1312, 10.69%), and South Korea (536, 4.37%). The patent applications from these five countries total 10,714 account for 87.55% of global patent applications. This indicates that patent contributions in this field are highly concentrated and that the core technologies are largely controlled by the five countries listed above.

Although the development of maglev technology in China began relatively late (in the late 1990s), the number of patent applications increased from eight in 1998 to 663 in 2016, a growth of 82.88 times in less than 20 years. As a result, China has become a major contributor of maglev-related patents. Clearly, China's technological innovation and independent research and development capacity have made rapid progress in recent years. Moreover, awareness of intellectual property and rights protection has grown among Chinese patentees.

3.2.2 Analysis of Technology Growth in Patent-Contributing Countries

A technology growth index can reflect the development of a given technology at different stages. The index is calculated by $V = a/A$, where V represents the patent growth

rate of a given year, a represents the number of patent applications in the given year, and A represents the cumulative patent applications in the previous 5 years (excluding those in the given year). An increasing value of V indicates that the corresponding technology of a given country or region is in its infancy or growth stage, whereas a decreasing value of V indicates that the corresponding technology of a given country or region is already at a mature stage [19]. The technology growth index of the top five patent-contributing countries for 2003–2016 (see Fig. 3) shows that the overall development of maglev technology has entered a mature stage. Specifically, maglev technology in Germany, Japan, South Korea, and the USA has entered a mature stage, whereas maglev technology in China is still developing and maturing gradually.

3.2.3 Global Distribution of Patents

The global distribution of patents from contributing countries reflects the patentees' global strategy as well as the countries and regions where the corresponding patented technology may be implemented in the future. Table 1 presents the distribution of patents from the top five contributing countries, extending from the originating country outward to other countries. The Z-axis indicates the country of the patentees, the X-axis indicates the countries where the patented technology is registered, and the Y-axis indicates the number of patents.

Table 1 shows that Germany's patented maglev technologies have the most extensive distribution coverage (33 countries and regions). The number of patented technologies registered domestically in Germany account for 43.46% of all patented technologies; this is followed by the number of patented technologies registered in the USA (13.79%), at the European Patent Organization (EPO) (11.12%), and in China (10.65%). The patented maglev technologies of the USA are registered in 26 countries and regions. The number of patented technologies registered domestically in the USA account for 44.67% of all patented technologies, followed by the patented technologies registered at the EPO (10.73%), in Germany (10.19%), and in China (7.74%). The patented maglev technologies originating from Japan are registered in 17 regions. The number of patented technologies registered domestically in Japan account for 78.62% of all patented technologies, followed by the patented technologies registered in the USA, Germany, at the EPO, and in China, which account for 6.96, 5.15, 3.73, and 2.54% of the total number of patented technologies, respectively. China's patented technologies are registered in 11 countries and regions. Most Chinese patented technologies are registered domestically (97.17%), followed by patented technologies

Fig. 2 Top 10 patent-contributing countries. Data Source: Innography patent database (extracted on November 26, 2017)

Fig. 3 Technology growth in the top five patent-contributing countries. *Data Source:* Innography patent database (extracted on November 26, 2017)

Table 1 Global distribution of patents from the top five patent-contributing countries. *Data Source:* Innography patent database (extracted on November 26, 2017)

Patentee country where patents are registered	China	Germany	USA	Japan	South Korea
China	3232 (97.17%)	268 (10.65%)	101 (7.74%)	77 (2.54%)	20 (3.74%)
Germany	16 (0.48%)	1094 (43.46%)	133 (10.19%)	156 (5.15%)	6 (1.12%)
USA	31 (0.93%)	347 (13.79%)	583 (44.67%)	211 (6.96%)	20 (3.74%)
Japan	3 (0.09%)	161 (6.4%)	96 (7.36%)	2383(78.62%)	4 (0.75%)
South Korea	5 (0.15%)	22 (0.87%)	23 (1.76%)	9 (0.3%)	472 (88.22%)
UK	3 (0.09%)	212 (8.42%)	118 (9.04%)	87 (2.87%)	
France	3 (0.09%)	161 (6.4%)	70 (5.36%)	68 (2.24%)	
Canada		74 (2.94%)	81 (6.21%)	23 (0.76%)	
Australia		42 (1.67%)	34 (2.61%)	17 (0.56%)	
Russia		18 (0.72%)	13 (1%)	5 (0.16%)	1 (0.19%)
Italy	3 (0.09%)	110 (4.37%)	63 (4.83%)	27 (0.89%)	2 (0.37%)
Czech Republic	3 (0.09%)	59 (2.34%)	35 (2.68%)	14 (0.46%)	
WIPO	32 (0.96%)	123 (4.89%)	106 (8.12%)	24 (0.79%)	11 (2.16%)
EPO	4 (0.12%)	280 (11.12%)	140 (10.73%)	113 (3.73%)	2 (0.37%)

registered with the World Intellectual Property Organization (WIPO) (0.96%), the USA (0.93%), and Germany (0.48%). South Korea's patented maglev technologies are registered in nine countries and regions; 88.22% of South Korea's patented technologies are registered domestically, and the patented technologies registered in the USA, China, and with the WIPO account for 3.74, 3.74, and 2.06% of all patented technologies, respectively. These data show that the major patent-contributing countries have focused on the domestic registration of patented technologies, and have then expanded their coverage based on local research and resource development.

3.3 Distribution of Major Research Areas and Focuses

The international patent classification (IPC) is the globally recognized patent classification system. Table 2 presents

IPC classification codes and descriptions of the patents related to maglev technology (Fig. 4).

Analyzing the classification of patent technologies can generate a distribution of patent classifications (see Fig. 5), which reflects the research focus in this field. Figure 5 shows that the research focus for maglev transportation is technologies related to electric propulsion for vehicles (B60L, 22.86%) and vehicle suspension control (B60G, 18.46%), followed by technologies related to railway systems and equipment (B61B, 7.07%) and railway construction (E01B, 8.23%), passenger facilities (B60N, 1.5%) and shock reduction and absorption (F16F, 1.34%), bogies (B61F, 1.07%), and brake control systems (B60T, 1%).

As shown in Table 3, the research focus of the five countries is essentially consistent with the global research focus (B60L, B60G, B61B, and E01B), which further confirms that these sub-classifications of technologies represent the main research focuses and target directions

Table 2 Maglev technology-related IPC classification codes and descriptions

IPC code	Description	IPC code	Description
B000	Performing operations	H000	Electricity
B60B	Increasing wheel adhesion	H01F	Magnets; inductances; transformers; selection of materials for their magnetic properties
B60C	Vehicle tires; tire inflation; tire changing; general connecting valves to inflatable elastic bodies; devices or arrangements related to tires	H02J	Circuit arrangements or systems for supplying or distributing electrical power; systems for storing electrical energy
B60D	Vehicle connections	H02K	Dynamo-electric machines
B60G	Vehicle suspension arrangements	H02N	Electric machines not otherwise provided for
B60H	Heating, cooling, ventilating devices	H02P	Control or regulation of electric motors, electric generators or dynamo-electric converters
B60J	Windows, windcreens, non-fixed roofs	F000	Mechanical engineering
B60K	Arrangement of propulsion units or transmissions in vehicles	F16F	Springs; shock-absorbers; means for damping vibration
B60L	Electric propulsion for monorail vehicles, suspension vehicles or rack railways; magnetic suspension or levitation for vehicles	F16H	Gearing
B60M	Power supply lines, or devices along rails, for electrically propelled vehicles	F16K	Valves; taps; cocks; actuating-floats; devices for venting or aerating
B60N	Arrangements or adaptations of other passenger fittings	F16M	Frames, casings, or beds, for engines or other machines or apparatus
B60P	Vehicles adapted for load transportation; or to transport, carry, or comprise special loads or objects	E000	Fixed construction
B60Q	Arrangement of signaling or lighting devices, the mounting or supports thereof, or circuits therefore, for vehicles in general	E01B	Permanent way; permanent-way tools; machines for making railways of all kinds
B60R	Vehicles, vehicle fittings, or vehicle parts	E01C	Construction or surfacing of roads, sports grounds, or similar; machines or auxiliary tools for construction or repair
B60S	Servicing, maintaining, repairing, or refitting of vehicles	E01D	Methods or apparatus specially adapted for erecting or assembling bridges
B60T	Vehicle brake control systems	E01F	Landing stages for helicopters
B60W	Conjoint control of vehicle sub-units of different types or different functions	E05B	Security systems for windows and doors (locks; keys; window or door fittings; safes)
B61B	Railway systems; equipment	G000	Physics
B61D	Body details or kinds of railway vehicles	G01B	Measuring arrangements characterized by the use of electric or magnetic means
B61F	Rail vehicle suspensions, e.g., underframes, bogies or arrangements of wheel axles	G01D	Component parts of measuring arrangements (not specially adapted for a specific variable)
B61H	Brakes or other retarding apparatus particular to rail vehicles	G01M	Testing of static or dynamic balance of machines or structures
B61J	Shifting or shunting of rail vehicles	G01P	Measuring linear or angular speed, acceleration, deceleration or shock; indicating presence or absence of movement; indicating direction of movement
B61K	Other auxiliary equipment for railways	G01R	Measuring of electric variables; measuring of magnetic variables
B61L	Guiding railway traffic; ensuring the safety of railway traffic	G01S	Radio direction-finding
B62D	Motor vehicles; trailers	G08B	Signaling or calling systems; order telegraphs; alarm systems
B62K	Cycle axle suspensions		
B64D	Equipment for fitting in or to aircraft; flying suits; parachutes; arrangements or mounting of power plants or propulsion transmissions in aircraft		
B64F	Ground or aircraft-carrier-deck installations		
B65G	Transport or storage devices		

Fig. 4 Global distribution of patents from the top five patent-contributing countries. *Data Source:* Innography patent database (extracted on November 26, 2017)

Fig. 5 Distribution of maglev-related patents by IPC classification. *Data Source:* Innography patent database (extracted on November 26, 2017)

for technologies related to maglev transportation systems. However, the countries appear to have differentiated concentrations. Table 3 shows that China is more concerned with the stability of the technologies and considers vehicle suspension systems and bogies (B61F) a main research focus. Germany pays more attention to driving safety, and its main research and development focus is brakes and retarding apparatuses for rail vehicles (B61H). The USA focuses on passenger experience and on improving the comfort of passenger facilities (B60N) as well as the effectiveness of shock reduction and absorption (F16F). Japan and South Korea concentrate on energy saving and efficiency, including environmental protection, with a research focus on magnets, inductance, transformers, and the selection of materials for their magnetic properties

Table 3 Comparison of the top five research perspectives of the top five patent-contributing countries and the world

Rank	Overall	China	Germany	USA	Japan	South Korea
1	B60L	B60L	B60L	B60L	B60G	B60L
2	B60G	B60G	B60G	B60G	B60L	B60G
3	E01B	E01B	E01B	B61B	B61B	E01B
4	B61B	B61B	B61B	B60N	E01B	B61B
5	F16F	B61F	B61H	F16F	H01F	B65G

Please refer to Table 1 for the technology descriptions of the codes

(H01F), as well as transportation and storage devices (B65G).

3.4 Research Status of Innovative Organizations of Maglev Technology

3.4.1 Major Innovative Organizations and Types

Next, we analyze the patentees in the collected samples. Since the English names of some Chinese patentees are not consistent in the collected samples, we referred to the English names used in the patent library of the State Intellectual Property Office of China (SIPO). The top 20 innovative organizations with the most maglev technology patents were then extracted (see Fig. 6).

Among the 20 innovative organizations, eight are from Japan, six are from China, four are from Germany, and the remaining two are from the USA and South Korea. The number of innovative organizations in China is the second highest, exceeded only by that in Japan, which suggests that China has focused intensely on the research and development of technologies related to maglev transportation systems. However, five of the six Chinese patentees are from universities and research institutes; only Beijing Maglev is a private firm. By contrast, the most

Fig. 6 Top 20 innovative organizations with the most maglev-related patents. *Data Source:* Innography patent database (extracted on November 26, 2017)

innovative organizations in other countries are all enterprises. All four innovative organizations in Germany, all the innovative organizations in the USA and South Korea, and seven of the eight innovative organizations in Japan are enterprises. An analysis of the innovative organizations' types shows that the industrialization of the maglev transportation system in China is lagging that in developed countries.

3.4.2 Patent Distribution among Major Innovative Organizations

A further analysis of the patent distribution among the major innovative organizations reveals the patentees' future technology development directions as well as their competitive strategies. In Fig. 7, the X-axis represents the top 20 innovative organizations, the Z-axis represents the countries and regions where the patents are registered, and the Y-axis represents the number of patents registered.

For brevity's sake, this descriptive analysis considers only the most representative institutions with the most patents. The global distribution of patents among the top five major innovative maglev organizations is shown in Table 4.

Table 4 shows that ThyssenKrupp AG in Germany owns the most patents related to maglev transportation systems. Its patented technologies are registered in 17 countries and regions, and most are registered in Germany (31.3%), the USA (17.96%), China (17.78%), at the EPO (16.11%), and at the WIPO (9.07%). Toyota Motor Corporation in Japan registered patents related to maglev transportation technology in 10 countries and regions, including Japan (68.87%), Germany (8.49%), the USA (8.25%), the EPO (8.02%), and China (7.08%). The China Railway Siyuan Survey and Design Group Co., Ltd. (China) registered most of its patents related to maglev transportation technology in China (96.37%) and at the EPO (3.63%). The patented

technologies of the Bose Corporation of the USA are registered in eight countries and regions, including the USA (30.89%), the EPO (22.76%), Germany (21.14%), China (17.07%), and Japan (14.63%). The patented technologies of the Hyundai Motor Company of South Korea are registered in four countries and regions, including South Korea (83.5%), China (9.71%), the USA (3.88%), and Germany (2.91%).

These data show that the innovative organizations in Germany (represented by ThyssenKrupp AG), the USA (represented by Bose Corporation), and Japan (represented by Toyota Motor Corporation) have a relatively balanced geographical distribution of patents, indicating that they have used a "carpet" distribution pattern and patent-fencing strategy [20]. As a result, they have formed a global network of patents and created a clear advantage in the development of the technology as well as in market competition. However, innovative organizations in China (represented by China Railway Siyuan Survey and Design Group Co., Ltd.) and South Korea (represented by Hyundai Motor Company) have mainly targeted their domestic markets, leading to a noticeable disadvantage in terms of international technological development and market competition.

3.4.3 Research Focus Distribution Among Major Innovative Organizations

Figure 8 shows the research focus distribution of the top 20 major innovative organizations. The figure shows that the research focus of these organizations mainly covers technologies related to electric propulsion for vehicles (B60L), vehicle suspension control (B60G), railway systems and equipment (B61B), and railway construction (E01B).

Detailed data on the patented technology classification of the top 20 innovative maglev organizations are provided in Table 5.

Fig. 7 Distribution of patents among the top 20 major innovative organizations. *Data Source:* Innography patent database (extracted on November 26, 2017)

Table 4 Global patent distribution among the top 5 major innovative maglev organizations

Organization global distribution	ThyssenKrupp AG	Toyota Motor Corporation	China Railway Siyuan Survey and Design Group Co., Ltd	Bose Corporation	Hyundai Motor Company
China	96 (17.78%)	30 (7.08%)	239 (96.37%)	21 (17.07%)	10 (9.71%)
Germany	169 (31.3%)	36 (8.49%)		26 (21.14%)	3 (2.91%)
USA	97 (17.96%)	35 (8.25%)		38 (30.89%)	4 (3.88%)
Japan	29 (5.37%)	292 (68.87%)		18 (14.63%)	
South Korea	3 (0.56%)	5 (1.18%)		2 (1.63%)	86 (83.5%)
UK	33 (6.11%)	22 (5.19%)		12 (9.76%)	
France	33 (6.11%)	24 (5.66%)		12 (9.76%)	
Canada	27 (5%)				
Australia	12 (2.22%)	2 (0.47%)			
Russia	6 (1.11%)	4 (0.94%)			
Italy	27 (5%)	7 (1.65%)		7 (5.69%)	
Czech Republic	22 (4.07%)	7 (1.65%)			
WIPO	49 (9.07%)	12 (2.83%)	9 (3.63%)	8 (6.5%)	
EPO	87 (16.11%)	34 (8.02%)		28 (22.76%)	

The table shows that most of the patents (84.64%) of ThyssenKrupp AG are in the classifications of B60L (electric propulsion for monorail vehicles, suspension vehicles or rack railways, magnetic suspension or levitation for vehicles; 41.67%), E01B (permanent way; permanent-way tools; machines for making railways of all kinds; 27.04%), and B61B (15.93%). Most of the patents (62.05%) of Hitachi, Ltd are in B60L, B60G, and B61B, accounting for 31.51, 19.94, and 10.6% respectively. Most of the patents (64.66%) of Mitsubishi Electric Corporation are in B60L (33.83%), B61B (16.54%), and E01B (14.29%). More than two-thirds of the patents (67.82%) of

Beijing Maglev are in B60L (30.43%), G01P (20%), and B60M (17.39%). Most of the patents (59.69%) of Southwest Jiaotong University are in B60L (46.6%), B61B (6.81%), and B61F (6.28%). Most of the patents (58.99%) of the National University of Defense Technology are in B60L, B61F, and B61L, accounting for 41.73, 10.07, and 7.19% of its patents, respectively. Most of the patents (63.2%) of Tongji University are in B60L, E01B, and B61D, accounting for 36.79, 15.09, and 11.32% of its patents, respectively. Most of the patents (62.65%) of the Railway Technical Research Institute are in B60L (47.3%) and B61B (15.35%). More than four-fifths of the patents

Fig. 8 Distribution of research focus of the top 20 innovative organizations. *Data Source:* Innography patent database (extracted on November 26, 2017)

Table 5 Top 8 innovative maglev technology organizations and their patent distribution focuses

Organization name	Majority patents registered area	2nd majority patents registered area	3rd majority patents registered area	Total (%)
ThyssenKrupp AG	B60L (41.67%)	E01B (27.04%)	B61B (15.93%)	84.64
Hitachi, Ltd	B60L (31.51%)	B60G (19.94%)	B61B (10.6%)	62.05
Mitsubishi Electric Corporation	B60L (33.83%)	B61B (16.54%)	E01B (14.29%)	64.66
Beijing Maglev	B60L (30.43%)	G01P (20%)	B60M (17.39%)	67.82
Southwest Jiaotong University	B60L (46.6%)	B61B (6.81%)	B61F (6.28%)	59.69
National University of Defense Technology	B60L (41.73%)	B61F (10.07%)	B61L (7.19%)	58.99
Tongji University	B60L (63.2%)	E01B (15.09%)	B61D (11.32%)	63.2
Railway Technical Research Institute	B60L (47.3%)	B61B (15.35%)	H01F (9.54%)	72.19
Bose Corporation	B60G (46.34%)	B60N (34.96%)	F16F (8.13%)	89.43
Central Japan Railway Company	B60L (45.19%)	B61B (33.65%)	H01F (4.81%)	83.65
Hyundai Motor Company	B60G (37.86%)	B60L (29.13%)	F16F (5.83%)	72.82
Toyota Motor Corporation	B60G (83.96%)	F16F (3.77%)	B60K (2.12%)	89.85
Jiangsu University	B60G (79.09%)	F16F (5.45%)	B60K (4.55%)	89.09
Nissan Motor Company Ltd.	B60G (75.26%)	B60K (6.19%)	B60R (4.12%)	85.57
ZF Friedrichshafen AG	B60G (62.28%)	G01B (7.89%)	B62D (6.14%)	76.29
Sumitomo Electric Industries	B60L (69.47%)	E01B (7.38%)	B61B (7.37%)	84.22
Siemens AG	B60L (63.3%)	B61B (4.38%)	B61L (3.37%)	71.05
Toshiba Corporation	B60L (61.6%)	B61B (9.7%)	E01B (6.75%)	78.05
China Railway Siyuan Survey and Design Group Co., Ltd	E01B (80.65%)	E01D (8.87%)	B60M (2.02%)	91.54
Max Bögl Group	E01B (62.41%)	B60L (29.08%)	B61B (4.96%)	96.45

Please refer to Table 1 for technology descriptions of the codes

(81.3%) of Bose Corporation are in B60G and B60N, accounting for 46.34% and 34.96% of its patents, respectively. More than three-quarters of the patents (78.84%) of the Central Japan Railway Company are in B60L (45.19%) and B61B (33.65%), and approximately two-thirds of the patents (66.99%) of the Hyundai Motor Company are in

B60G (37.86%) and B60L (29.13%). These findings show that these innovative organizations are able to fully utilize their resource endowments to seek breakthroughs in the chain of maglev technologies and ultimately expand the comprehensive value chain through a concentric diversification strategy.

The patents of Toyota Motor Corporation, Jiangsu University, Nissan Motor Company Ltd., and ZF Friedrichshafen AG are concentrated in B60G, accounting for 83.96, 79.09, 75.26, and 62.28% of their maglev technology-related patents, respectively. The patents of Sumitomo Electric Industries, Siemens AG, and Toshiba Corporation are mainly in B60L, accounting for 69.47, 63.3, and 61.6% of their maglev technology-related patents, respectively. The patents of China Railway Siyuan Survey and Design Group Co., Ltd. and the Max Bögl Group are concentrated in E01B, accounting for 80.65% and 62.41% of their maglev technology-related patents, respectively.

The data in Table 5 suggest that the top 20 innovative organizations generally focus their resources on a single technology area in order to become global technological leaders through a specialization strategy.

3.5 Identifying Core Patents Related to Maglev Technology

3.5.1 Patent Strength

Core patents are the patents needed to manufacture a given product; they generally cannot be bypassed [21]. The Innography platform contains a powerful core patent mining capability. Using the results of research on patent value determination conducted by the University of California, Berkeley, George Mason University, Stanford University, and the University of Texas, Innography divides the strength of patents into three levels: A patent with a strength indicator value equal to or greater than 80% is considered a core patent; a patent with an indicator between 30 and 80% is considered an important patent; and a patent with an indicator less than 30% is considered a general patent [22].

An analysis of patent strength shows that 229 of the investigated patents are core patents (1.87%), 2557 are important patents (20.84%), and 9483 are general patents (77.29%). The relative scarcity of core patents highlights their value in the field of technology.

3.5.2 Core Patents

An in-depth analysis of the 229 core patents provides high-value scientific and technological intelligence about the field and reveals the research directions and trends in maglev technology.

Concerning the origins of core patent holders, approximately half (114, 49.78%) are from the USA, accounting for 8.69% of the nation's total patents. More than one-fifth (52, 22.71%) of the core patents are held by German organizations, accounting for 2.07% of the country's total patents. Japan has 27 (11.79%) core patents, accounting for

0.89% of its total patents. Only three of the core patents (1.31%) are from China, much less than for the UK and South Korea. Core patents accounted for only 0.09% of China's patents. Thus, although Chinese organizations have the highest number of patent applications, few of these patents are core patents, indicating that the quality of the patents held by China is generally not high.

The classification of core patents is presented in Table 6. Most of the core patents belong to the following five main classifications: performing operations (B000, 181; 78.7%), which includes vehicle suspension arrangements, electric propulsion for vehicles, railway systems and equipment; electricity (H000, 15; 6.5%); mechanical engineering (F000, 14; 6.1%); fixed construction (E000, 12; 5.2%); and physics (G000, 8; 3.4%). Thus, the core technologies of maglev transportation systems are concentrated in the domains of suspension control, propulsion technology, and railway systems.

The main contributors of core patents—the USA, Germany, and Japan—have core patents distributed across all five classifications. However, China has only three core patents in B000, including two patents related to vehicle suspension arrangements (B60G) and one patent related to railway systems and equipment (B61B).

4 Conclusions and Suggestions

4.1 Conclusions

This study explored and analyzed the global development trend in maglev technology, the distribution of patent-contributing countries, their associated research focuses, and their core patents. The following conclusions can be drawn.

- (1) The total number of patent applications related to maglev technology continues to grow. After a long period of scientific discovery and technological innovation, as well as a difficult stage of engineering demonstration and implementation, the maglev transportation system, as a new rail transit mode, has entered the industrialization stage, characterized by standardized technologies, a scaled market size, and popularized consumption.
- (2) China, Japan, Germany, the USA, and South Korea have contributed 87.3% of the world's patented maglev technologies. The maglev technologies in Western countries are the most mature, and the patents of Western organizations have been registered in 20–30 countries and regions.
- (3) Most of the patents are related to the electric propulsion of vehicles, vehicle suspension control,

Table 6 IPC classifications of the core patents

IPC code	Core patent (number)	IPC code	Core patent (number)	IPC code	Core patent (number)
B000	181	B61L	2	F16M	2
B60G	67	B61J	1	F16K	1
B60L	55	B61K	1	F16H	1
B60T	7	B61H	1	E000	12
B60K	6	B62D	2	E01B	8
B60N	5	B62K	1	E01F	1
B60R	4	B64F	1	E01C	1
B60Q	3	B64D	1	E05B	2
B60C	2	H000	15	G000	
B60B	2	H02K	8	G01M	2
B60D	2	H02J	2	G01P	2
B60P	2	H02P	2	G01D	1
B60W	1	H02N	1	G01B	1
B60S	1	H01F	2	G01S	1
B60H	1	F000	14	G08B	1
B60J	1	F16F	7		
B61B	12	F16D	3		

Please refer to Table 1 for the technology descriptions of the codes

and railway system and construction tools. These represent the core technologies and research focuses in the development of maglev transportation systems.

- (4) China is second only to Japan in the number of productive innovative organizations. However, most of the innovative organizations in developed countries are private firms, while most of the innovative organizations in China are universities and research institutions. This indicates that the industrialization of maglev technology in China is lagging that in the other main patent-contributing countries.
- (5) An in-depth analysis of the core patents reveals that developed countries have a higher ratio of core patents to total patents. In addition to reaching commanding heights of technology, developed countries have also achieved a more sophisticated distribution of patented technologies from the perspectives of both geography and the industrial chain.

4.2 Suggestions

Based on the research results about the global competition in maglev technology, the following suggestions and recommendations are proposed from both a national/governmental (macro) and organizational (micro) level.

- (1) It is necessary to strengthen technological foresight and forecasting capabilities and focus more on breakthroughs in core technologies and improving patent quality for both national governments and innovative organizations. Accordingly, technological foresight should be developed at both the national and industrial levels to identify priority areas for technological development through the overall screening of maglev transportation systems. The identified areas should be then included in national science and technology programs to fill the research gaps in this area. In addition, technological forecasting should be conducted at the enterprise level to identify the technological frontier and trends as well as research focuses and gaps, thereby gaining a mastery of the core technologies and enhancing patent quality.
- (2) It is important to train and nurture leading technological talents, strengthen university–industry cooperation, and promote enterprise-oriented industry technological alliances. On the national level, maglev technology should be considered a “first class” initiative, and more high-quality scientific researchers in the field must be trained. In addition, governments should conduct extensive searches for technological elites around the world. At the organizational level, enterprise-oriented university–industry cooperation among enterprises, universities, and research institutions should be established so that they may compensate one another’s shortcomings, share benefits and risks, and jointly develop core technologies, thereby breaking through the

development bottlenecks in maglev transportation systems.

- (3) It is important to set up various international cooperatives and exchanges, introduce patented technologies, and re-innovate new technologies. Governments, enterprises, and research institutions should create conditions for international exchange and cooperation with countries that have advanced maglev technologies and introduce patented technologies through patent transfer, licensing, and cross-licensing. The aim is to master core technologies through reverse engineering and development, break through the technological bottlenecks, and gradually form a global network of registered patents in order to establish a competitive advantage in the global market.

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