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Turnout Scheme for HTS Maglev Vehicle’s Permanent Magnet Guideway

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ABSTRACT: Nowadays, the high temperature superconducting (HTS) Maglev is one of the most popular types of high-speed maglev trains. The turnout is one important and irreplaceable device involved in Maglev systems. Even though, a little improvement researches have been done about it, this issue has not been resolved sufficiently yet. This paper introduces the present schemes for the permanent magnet guideway (PMG) turnouts of HTS Maglev systems. Permanent magnet guideway (PMG) involved in HTS Maglev system is straight or circle. The turnout in the HTS Maglev system is indispensable but few works have done about it.

KEYWORDS: Maglev, HTS, turnouts, permanent, guideway, scheme, indispensable, device

I. INTRODUCTION

High-temperature superconducting (HTS) magnetic levitation vehicles are one of the next-generation high-level magnetic levitation (Maglev) transportation systems. With the development of high-temperature superconducting materials technology, in the future HTS Maglev train will be vigorously developed. The non-contact wheel–rail system causes many difficulties for the turnout system. In this paper, a novel mechanical permanent magnetic guideway (PMG) turnout system is proposed utilizing a single inclination permanent magnet (PM) for PMG turnout. To assemble the PMG turnout with the proposed single inclination PMs, the wedge-shape air gap between two fixed PMs is used to adjust the PMG body bending in the horizontal plane for Maglev vehicle guideway switching purposes. The relationship of the geometric dimensions of the single inclination PM and its inclination angle and the negative turning radius of the PMG turnout is successfully derived. The magnetic field uniformity of the PMG turnout under the condition of the minimum turning radius of 4 meters, which responds to angle 1.1459° of the single inclination PMs, has been simulated by the finite element method. The calculation results show that the influences of the wedge air gap on the magnetic field uniformity along the PMG longitude direction are small despite the turnout PMG being in a straight state or in a switching state. There are only minor differences in the magnetic fields on both sides of the PMG between the normal PMG and the turnout PMG in straight state and in switching state and so may not influence the HTS Maglev vehicles running stability during the PMG switching operation.[1,2]

The guideway unit is simulated as a series of simple beams with identical span and the maglev vehicle as a rigid car body supported by levitation forces. To carry out the interaction dynamics of maglev vehicle/guideway system, this study adopts an onboard PID (proportional-integral-derivative) controller based on Ziegler-Nicholas (Z-N) method to control the levitation forces. Interaction of wind with high-speed train is a complicated situation arising from unsteady airflow around the train. In this study, the oncoming wind loads acting on the running maglev vehicle are generated in temporal/spatial domain using digital simulation techniques that can account for the moving effect of vehicle's speed and the spatial correlation of stochastic airflow velocity field. Considering the motion-dependent nature of levitation forces and the non-conservative characteristics of turbulent airflows, an iterative approach is used to compute the interaction response of the maglev vehicle/guideway coupling system under wind actions. For the purpose of numerical simulation, this paper employs Galerkin's method to convert the governing equations containing a maglev vehicle into a set of differential equations in generalized systems, and then solve the two sets of differential equations using an iterative approach with the Newmark method. From the present investigation, the aerodynamic forces may result in a significant amplification on acceleration amplitude of the running maglev vehicle at higher speeds. For this problem, a PID+LQR (linear quadratic regulator) controller is proposed to reduce the vehicle's acceleration response for the ride comfort of passengers.

II. DISCUSSION

High-speed transportation patents were granted to various inventors throughout the world.[9] The first relevant patent, U.S. Patent 714,851 (2 December 1902), issued to Albert C. Albertson, used magnetic levitation to take part of the weight off of the wheels while using conventional propulsion.[3,4]

Early United States patents for a linear motor propelled train were awarded to German inventor Alfred Zehden. The inventor was awarded U.S. Patent 782,312 (14 February 1905) and U.S. Patent RE12700 (21 August 1907). In 1907, another early electromagnetic transportation system was developed by F. S. Smith. In 1908, Cleveland mayor Tom L. Johnson filed a patent for a wheel-less "high-speed railway" levitated by an induced magnetic field.Jokingly known as "Greased Lightning," the suspended car operated on a 90-foot test track in Johnson's basement "absolutely noiseless[ly] and without the least vibration." A series of German patents for magnetic levitation trains propelled by linear motors were awarded to Hermann Kemper between 1937 and 1941. An early maglev train was described in U.S. Patent 3,158,765, "Magnetic system of transportation", by G. R. Polgreen (25 August 1959). The first use of "maglev" in a United States patent was in "Magnetic levitation guidance system" by Canadian Patents and Development Limited. Japan operates two independently developed maglev trains. One is HSST (and its descendant, the Linimo line) by Japan Airlines and the other, which is more well known, is SCMaglev by the Central Japan Railway Company.

The development of the latter started in 1969. Maglev trains on the Miyazaki test track regularly hit 517 km/h (321 mph) by 1979. After an accident which destroyed the train, a new design was selected. In Okazaki, Japan (1987), the SCMaglev was used for test rides at the Okazaki exhibition. Tests in Miyazaki continued throughout the 1980s, before transferring to a far longer test track, 20 km (12 mi) long, in Yamanashi in 1997. The track has since been extended to almost 43 km (27 mi). The current 603 km/h (375 mph) world speed record for manned trains was set there in 2015.

Development of HSST started in 1974. In Tsukuba, Japan (1985), the HSST-03 (Linimo) became popular at the Tsukuba World Exposition, in spite of its low 30 km/h (19 mph) top speed. In Saitama, Japan (1988), the HSST-04-1 was revealed at the Saitama exhibition in Kumagaya. Its fastest recorded speed was 300 km/h (190 mph).Construction of a new high-speed maglev line, the Chuo Shinkansen, started in 2014. It is being built by extending the SCMaglev test track in Yamanashi in both directions. The completion date is currently unknown, with the most recent estimate of 2027 no longer possible following a local governmental rejection of a construction permit.[5,6]

There are currently two competing efforts into high-speed maglev systems, i.e., 300–620 km/h (190–390 mph).The first is based on the Transrapid technology used in the Shanghai maglev train and is developed by the CRRC under license from Thyssen-Krupp.In 2006 the 500 km/h (310 mph) CM1 Dolphin prototype was unveiled[54] and began testing on a new 1.5-kilometre (0.93 mi) test track at Tongji University, northwest of Shanghai.A prototype vehicle of the 600 km/h (370 mph) CRRC 600 was developed in 2019 and tested from June 2020. In the public imagination, "maglev" often evokes the concept of an elevated monorail track with a linear motor. Maglev systems may be monorail or dual rail—the SCMaglev MLX01 for instance uses a trench-like track—and not all monorail trains are maglevs. Some railway transport systems incorporate linear motors but use electromagnetism only for propulsion, without levitating the vehicle. Such trains have wheels and are not maglevs.Maglev tracks, monorail or not, can also be constructed at grade or underground in tunnels. Conversely, non-maglev tracks, monorail or not, can be elevated or underground too. Some maglev trains do incorporate wheels and function like linear motor-propelled wheeled vehicles at slower speeds but levitate at higher speeds. This is typically the case with electrodynamic suspension maglev trains. Aerodynamic factors may also play a role in the levitation of such trains.

III. RESULTS

Each implementation of the magnetic levitation principle for train-type travel involves advantages and disadvantages.

Technology	*Pros*	*Cons*
EMS (electromagnetic suspension)	Magnetic fields inside and outside the vehicle are less than EDS; proven, commercially available technology; high speeds (500 km/h or 310 mph); no wheels or secondary propulsion system needed.	The separation between the vehicle and the guideway must be constantly monitored and corrected due to the unstable nature of electromagnetic attraction; the system's inherent instability and the required constant corrections by outside systems may induce

		vibration.
EDS (electrodynamic suspension)	Onboard magnets and large margin between rail and train enable highest-recorded speeds (603 km/h or 375 mph) and heavy load capacity; demonstrated successful operations using high-temperature superconductors in its onboard magnets, cooled with inexpensive liquid nitrogen.	Strong magnetic fields on the train would make the train unsafe for passengers with pacemakers or magnetic data storage media such as hard drives and credit cards, necessitating the use of magnetic shielding; limitations on guideway inductivity limit maximum speed; vehicle must be wheeled for travel at low speeds.
Inductrack system (permanent magnet passive suspension)	Failsafe suspension—no power required to activate magnets; Magnetic field is localized below the car; can generate enough force at low speeds (around 5 km/h or 3.1 mph) for levitation; given power failure cars stop safely; Halbach arrays of permanent magnets may prove more cost-effective than electromagnets.	Requires either wheels or track segments that move for when the vehicle is stopped. Under development as of 2008; no commercial version or full-scale prototype.

Neither Inductrack nor the Superconducting EDS are able to levitate vehicles at a standstill, although Inductrack provides levitation at much lower speed; wheels are required for these systems. EMS systems are wheel-free.

The German Transrapid, Japanese HSST (Linimo), and Korean Rotem EMS maglevs levitate at a standstill, with electricity extracted from guideway using power rails for the latter two, and wirelessly for Transrapid. If guideway power is lost on the move, the Transrapid is still able to generate levitation down to 10 km/h (6.2 mph) speed, using the power from onboard batteries. This is not the case with the HSST and Rotem systems.

Energy for maglev trains is used to accelerate the train. Energy may be regained when the train slows down via regenerative braking. It also levitates and stabilises the train's movement. Most of the energy is needed to overcome air drag. Some energy is used for air conditioning, heating, lighting and other miscellany.At low speeds the percentage of power used for levitation can be significant, consuming up to 15% more power than a subway or light rail service. For short distances the energy used for acceleration might be considerable.The force used to overcome air drag increases with the square of the velocity and hence dominates at high speed. The energy needed per unit distance increases by the square of the velocity and the time decreases linearly. However power increases by the cube of the velocity. For example, 2.37 times as much power is needed to travel at 400 km/h (250 mph) than 300 km/h (190 mph), while drag increases by 1.77 times the original force.Aircraft take advantage of lower air pressure and lower temperatures by cruising at altitude to reduce energy consumption but unlike trains need to carry fuel on board. This has led to the suggestion of conveying maglev vehicles through partially evacuated tubes.

The Shanghai maglev demonstration line cost US$1.2 billion to build in 2004. This total includes capital costs such as right-of-way clearing, extensive pile driving, on-site guideway manufacturing, in-situ pier construction at 25 m (82 ft) intervals, a maintenance facility and vehicle yard, several switches, two stations, operations and control systems, power feed system, cables and inverters, and operational training. Ridership is not a primary focus of this demonstration line, since the Longyang Road station is on the eastern outskirts of Shanghai. Once the line is extended to South Shanghai Train station and Hongqiao Airport station, which may not happen because of economic reasons, ridership was expected to cover operation and maintenance costs and generate significant net revenue.The South Shanghai extension was expected to cost approximately US$18 million per kilometre. In 2006, the German government invested $125 million in guideway cost reduction development that produced an all-concrete modular design that is faster to build and is 30% less costly. Other new construction techniques were also developed that put maglev at or below price parity with new high-speed rail construction.The United States Federal Railroad Administration, in a 2005 report to Congress, estimated cost per mile of between US$50 million and US$100 million.The Maryland Transit Administration (MTA) Environmental Impact Statement estimated a pricetag at US$4.9 billion for construction, and $53 million a year for operations of its project.The proposed Chuo Shinkansen maglev in Japan was estimated to cost approximately US$82 billion to build, with a route requiring long tunnels. A Tokaido maglev route replacing the current Shinkansen would cost 1/10 the cost, as no new tunnel would be needed, but noise pollution issues made this infeasible.[7]

IV. CONCLUSIONS

Samuel Earnshaw was the one to discover in 1839 that “a charged body placed in an electrostatic field cannot levitate at stable equilibrium under the influence of electric forces alone”. Likewise, due to limitations on permittivity, stable suspension or levitation cannot be achieved in a static magnetic field with a system of permanent magnets or fixed current electromagnets. Braunbeck’s extension (1939) states that a system of permanent magnets must also contain diamagnetic material or a superconductor in order to obtain stable, static magnetic levitation or suspension.Emile Bachelet applied Earnshaw's theorem and the Braunbeck extension and stabilized magnetic force by controlling current intensity and turning on and off power to the electromagnets at desired frequencies. He was awarded a patent in March 1912 for his “levitating transmitting apparatus” (patent no. 1,020,942). His invention was first intended to be applied to smaller mail carrying systems but the potential application to larger train-like vehicles is certainly apparent.In 1934 Hermann Kemper applied Bachelet’s concept to the large scale, calling it “monorail vehicle with no wheels attached.” He obtained Reich Patent number 643316 for his invention and is also considered by many to be the inventor of maglev.In 1979 the Transrapid electromagnetically suspended train carried passengers for a few months as a demonstration on a 908 m track in Hamburg for the first International Transportation Exhibition (IVA 79).The first commercial Maglev train for routine service was opened in Birmingham, England in 1984, using electromagnetic suspension, and a linear induction motor for propulsion.[8]

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