Preliminary Design of The Magplane MagTrain System

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Abstract

Magplane "MagTrain", a novel medium to high speed train system powered by linear synchronous motors, is under development with the purpose to fill a niche in the intercity transportation market. The system is designed to carry a capacity of 12,000 passengers per hour per direction. The system can be installed on new transit lines or provide a seamless retrofit on existing track. A linear motor is attached to the sleepers between the tracks. A set of permanent magnet arrays are secured to the bottom of each vehicle bogie. The magnet arrays interact with the linear motor to provide propulsion. Motor drive cabinets distributed along the track provide required output voltage and frequency to control the speed. There is no third rail or unsightly catenary system as the system does not require on board power for propulsion. The MagTrain system will significantly reduce vehicle weight and energy consumption. This paper briefly describes the MagTrain design, motor drives, and global control.

1. Introduction

Global warming is becoming one of most alarming environmental issues that we must face and act responsibly. Passenger and freight transportation has been determined to be a major contributor to the warming of the environment. According to the United States Environmental Protection Agency (US EPA) reports, the use of trains has doubled in the last 35 years, and by 2030, trains will be responsible for about one-third of all particulate pollution in the air from the transportation sector, unless more protective solutions are found and standards are put in place [1].

Linear motor propulsion systems can completely resolve the pollution issue with the least disruption to the environment and lowest installed costs. These systems operate on magnetic fields and therefore are noiseless, pollution free and have no moving parts to wear out. There are basically two types of linear motors: the short primary linear induction motor (LIM) and the long primary linear synchronous motor (LSM) [2]. The LIM utilizes a very simple reaction rail track, third-rail power pickup on the vehicle, and passive guideway rails which simplifies the track switches. Vehicles with different design and performance parameters are easily adaptable without changes to the guideway.

The LIM was developed to be used for the Chubu HSST (Maglev) and Linear Metro for urban transport in Japan. It is also used by Bombardier Transportation in the driverless Advanced Rapid Transit (ART) system to access New York's JFK International Airport. Similar systems are operating in Kuala Lumpur Transit Malaysia, and on the Vancouver SkyTrain Millennium Line, Toronto Scarborough Light Rail in Canada [3].

A significant advantage of the LIM drive is that the on-board power conditioning system and construction is very similar to that used in conventional urban and high speed electric railway vehicles. Many of the power conditioning equipment system sections and components are common, and there exists a significant database of practical experience and design with manufacturers and line operators. The basic technology has been well established, and the technical step to move from rotary induction motor drives for steel-wheel vehicles to LIM propulsion is not large. The incentive for this transition to LIM propulsion is the all-weather capability to negotiate tight curves and steep grades, and meet precise stopping requirements with high deceleration that is not possible with power-driven steel-wheels. The transition provides improvement in service and ride quality, and meets the expectations of safety and reliability for transit systems.

However, the energy efficiency of the LIM is lower than the rotary induction motor with much smaller air gap between the stator winding and the rotor. The on-board LIM primary winding provides all the power that generates the gap field and the induced currents in the reaction rail, and the on-board powering equipment weight limits the operational speed capability of the LIM-driven system to 160km/h with a practical speed at 120km/h.

In comparison, the LSM using the passive permanent magnets for the field winding should be more efficient than the LIM, and there is no need for electrified third rails nor unsightly overhead catenary wires as the system does not require on board power for propulsion. The system is fully compatible and can operate concurrently with existing rail operations. Like hybrid automobiles the systems actually produce electricity for operations from regenerative braking while reducing the wear and tear on the wheels and rails because the propulsive force is magnetic not friction. The LSM driven transport systems could also be used in Maglev systems including Shanghai Maglev Line, pipelines like 1km MagTrack built in Zhangjiakou [4], and electric locomotives for railroad switchyard systems.

There is an intercity transportation market blank between high-speed trains and urban light rails or sub-ways. A novel medium to high speed train system using permanent-magnet linear synchronous motors, called “MagTrain”, is under development in Magplane Technology, Inc. with the purpose to fill a niche in the intercity transportation market up to 200km/h. The system is designed to carry a capacity of 12,000 passengers per hour per direction.

2. Preliminary MagTrain Design

According to the requirements for speed and transportation capacity for the transport market, a single 20m-long vehicle with two light bogies carrying permanent magnet arrays is designed to run at 200km/h to carry 100 passengers with the headway time of 30 seconds.

Vehicle

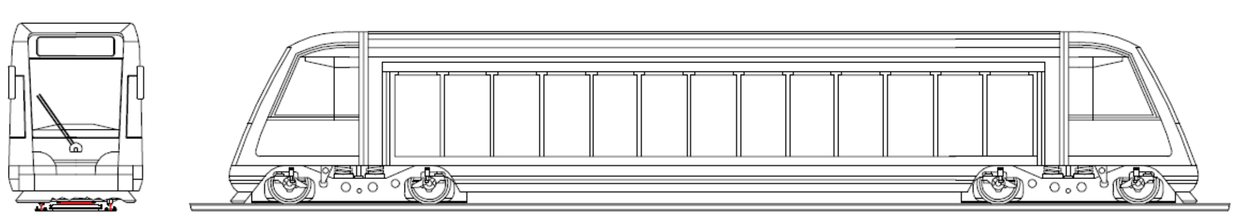

Fig. 1. A single 20m-long MagTrain vehicle with 2 magnet arrays attached on bogies

One Vehicle	
Design Speed	200km/h
Length	20m
Height	3.0m
Width	3.2m
Weight	Total 29,000kg
Empty	21,000kg
Passenger	8,000kg (100 passengers)
Transport Capacity	12,000 phpd
Headway	30s

Table 1. Vehicle Size, Weight and Headway

Figure 1 shows the front and side views of a single 20m-long Magtrain car with 2 wheel bogies. Seen from the front view, the vehicle is similar to the low-floor electric streetcar supported by the conventional wheels-rail system, but driven by the permanent magnet arrays underneath each bogie interacting with the linear motor windings sitting between the rails along the track to provide propulsion. The main design parameters of vehicle are listed in Table 1. The vehicle is 20m long, 3.2m wide and 3.0m high. The vehicle design utilizes a four-across first-class seating arrangement with average passenger density of 2 passengers/m^2, so one vehicle has 100 seats to carry 100 passengers without standing. The intercity medium to high speed MagTrain vehicles are designed as single vehicles rather than as coupled sets. At 30 second headway, the vehicles will carry 12,000 passengers per hour in each direction.

The typical bogie itself weight for high speed trains above 200km/h ranges from 6.5t to 11t [5-6]. According to Bombardier reports, their 4.6t FLEXX Eco bogie has already been successfully applied on the 200 km/h Voyager and Meridian trains in the UK and is currently be manufactured NSB in Norway and for the new UK TURBOSTAR trains [7]. The FLEXX Eco bogie is about 30% reduction in bogie mass in comparison with conventional bogie. Based on this light bogie, we expect that the empty weight of MagTrain vehicle will be 29t, plus the 8t weight of 100 passengers, so the total weight of one 20m-long vehicle will be 29t.

Together with light bogie design, the passive on-board permanent magnet linear motor will further reduce the total weight of vehicle, so the new vehicle design with high efficient LSM can simplify the structure with reduced cost, optimize energy use to minimize CO2 emissions, make less noise without third rail or catenary system, and improve overall operation efficiency and total train performance.

Linear Motor Coils and Magnets

The motor windings are mounted between the rails with the top surface aligned with the rail head surface so as to keep the magnet arrays attached on the bottom of vehicle bogies above the rail head surface to avoid the collision with the rail when crossing the switches. The motor windings will consist of one-layer three phase coils mounted with the teeth of non-metallic holding structures. As shown in Figure 2, there are 18 slots in one wavelength, and each phase of the 3-phase winding is wound from a single wire in three passes within three different adjacent slots and therefore all three turns are in series. The wire will be made of aluminum stranded or foil materials in order to be manipulated in a tight radius. One wire could be wound three turns for one wavelength and then continuously for five wavelengths to make a standard 2.4m-long motor module in order to make less joints. The windings are inserted between the rails continuously along the track except the switching and crossing sections, in order to achieve the better ride comfort quality.

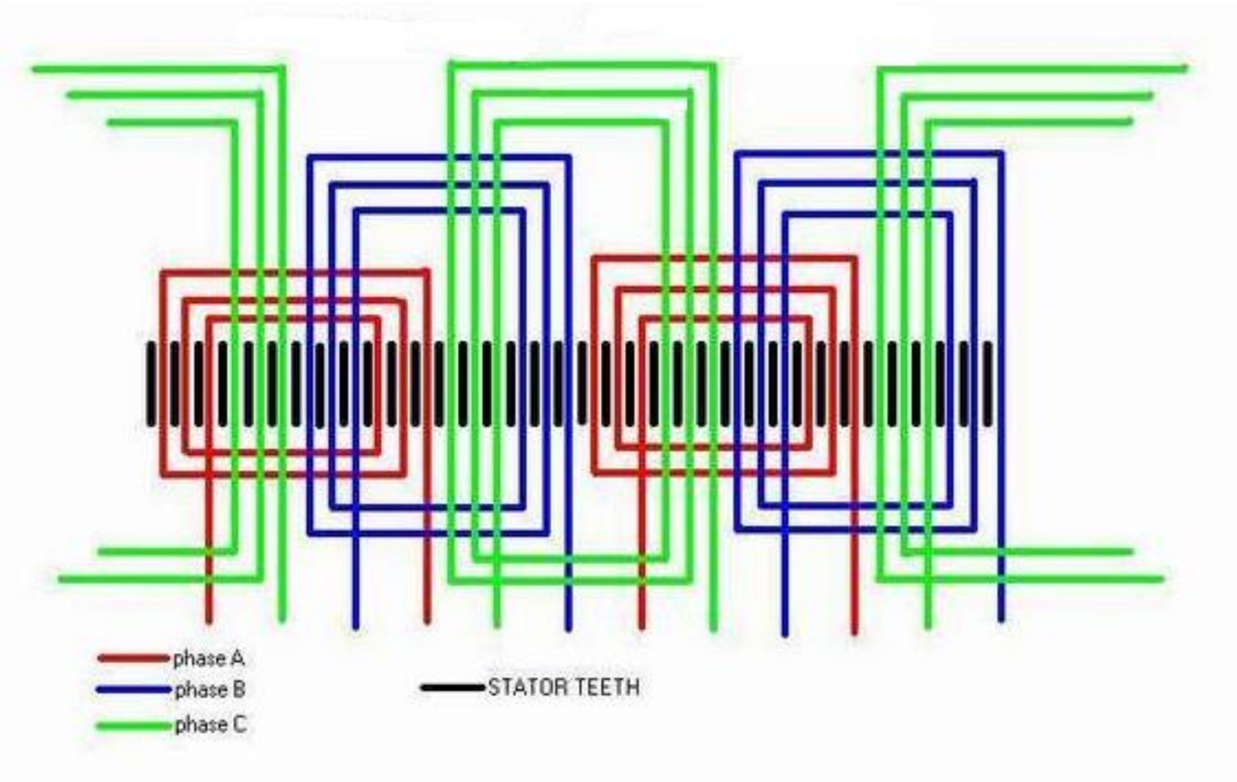

Fig 2. Three-phase, four-pitch windings scheme of MagTrain LSM

Linear Motor Coil	One-layer three-phase
Length	48m
Height	0.14m with holding structure
Width	1m
Magnet Arrays	
Length	10m
Width	0.8m
Thickness	2.5cm
Grade	N42H
Motor Performance	
Acceleration	0.1g
Max Slope Grade	10%

Table 2. Linear Motor Coils and Magnets

Table 2 lists some design parameters of linear motor coils and magnets. The motor winding is 1m wide with typical assembly length of 48m, which is composed of 100 wavelengths of windings. The standard stator module could be 2.4m long with 5 wavelengths of windings, so one typical motor winding is connecting 20 standard motor modules together in series. One vehicle carrying 10m-long magnet arrays can provide the 30,000N thrust which can accelerate one 29t vehicle at 0.1g on a straight flat line or let vehicle climb the slope at a grade of 10%.

Magnet Arrays Assembly

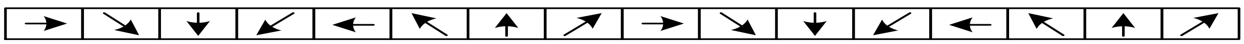

Fig. 3. Two wavelengths of Halbach-array permanent magnets

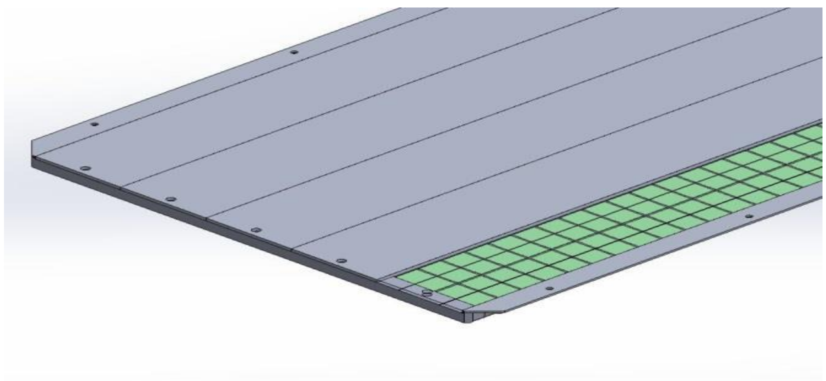

Fig. 4. Typical assembly of Halbach-array permanent magnets

Magnet grade	N42H (NdFeB)
Basic magnet block	0.06×0.025×0.05 m
Block number for one Halbach array	128
Block number for one vehicle	2,560
Halbach array wavelength	0.48 m

Table 3. Parameters of permanent magnets

As shown in Figure 3, one wavelength of Halbach array has eight blocks of magnets with rotated magnetization degrees. Figure 4 shows the typical assembly of Halbach-array permanent magnets. Some parameters of permanent magnets are listed in Table 3. The basic magnet block size is 6 cm long, 2.5 cm high, and 5cm wide. Eight basic magnet blocks form a 0.48m long Halbach array with the magnetization rotated 45 degrees from the previous magnet. There are 10 wavelengths of Halbach arrays on the bottom of each bogie, and each vehicle has 2,560 blocks of magnets on the bottom with the total weight of 1.46t magnets (25% at 0 degree magnetization angle, 25% at 90 degree angle and 50% at 45 degree angle).

During assembly contact cement is used to hold the blocks in place. When mounted on the bottom of bogie the magnet array is covered with a stainless steel sheet which secures the blocks in place and protects the surface.

Light Bogie Design and Magnet Mounting

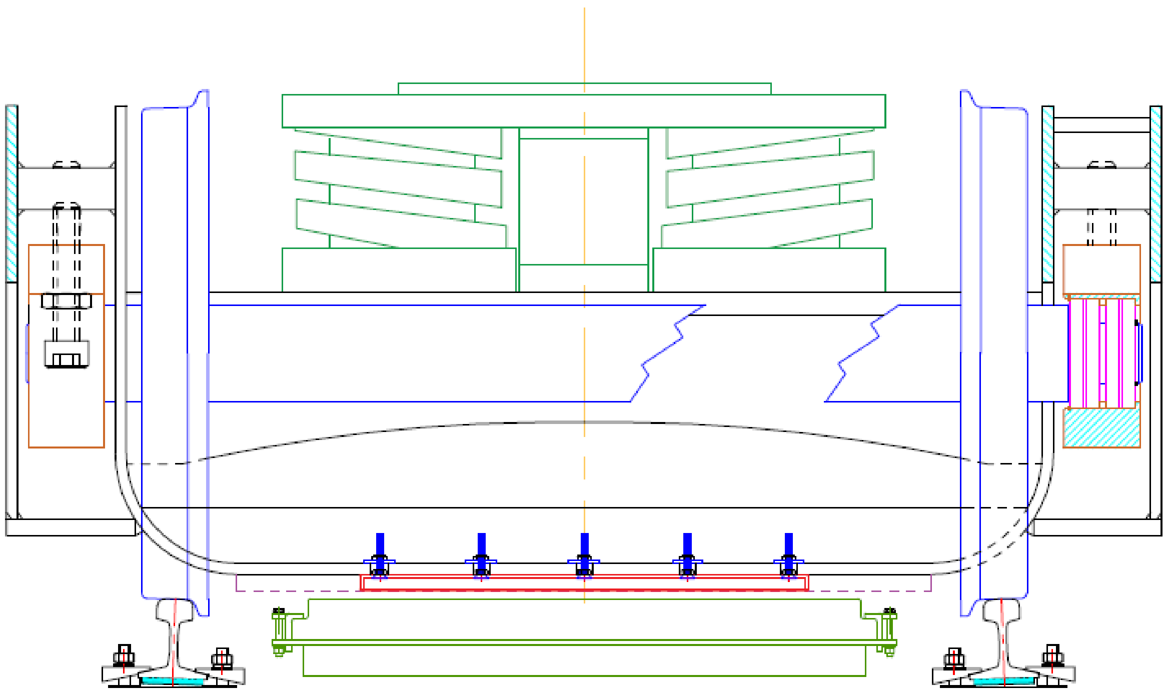

Fig. 5. The front view of light bogie with mounting Halbach-array permanent magnets

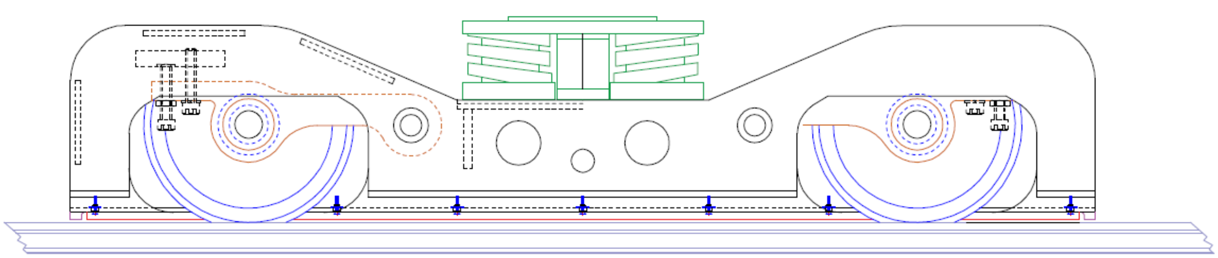

Fig. 6. The side view of light bogie with mounting Halbach-array permanent magnets

Figures 5 and 6 show the front and side view of a single light bogie with Halbach-array permanent magnets (red) mounted on the bottom. The bogie frame (black) is a double layer weldment or casting with a transverse plate across the bottom to make a light bogie. As shown in Figure 5, the dual wall bogie side frame shows the swing arm details with axle bearings shown on the right side, and the jacking gap height adjustment screw detail shown on the left side. The cross plate has an array of holes that the magnet assembly studs line up with and then washers and lock nuts are torqued down. The working gap between the permanent magnet arrays and the linear motor windings is 1.5 cm, and it will become smaller as the wheel and rail wear off along the way. The wheel axles (blue) are mounted on swing arms to allow adjustments of the air gap between magnets and track.

3. Motor Drives and Rectifiers with Regeneration

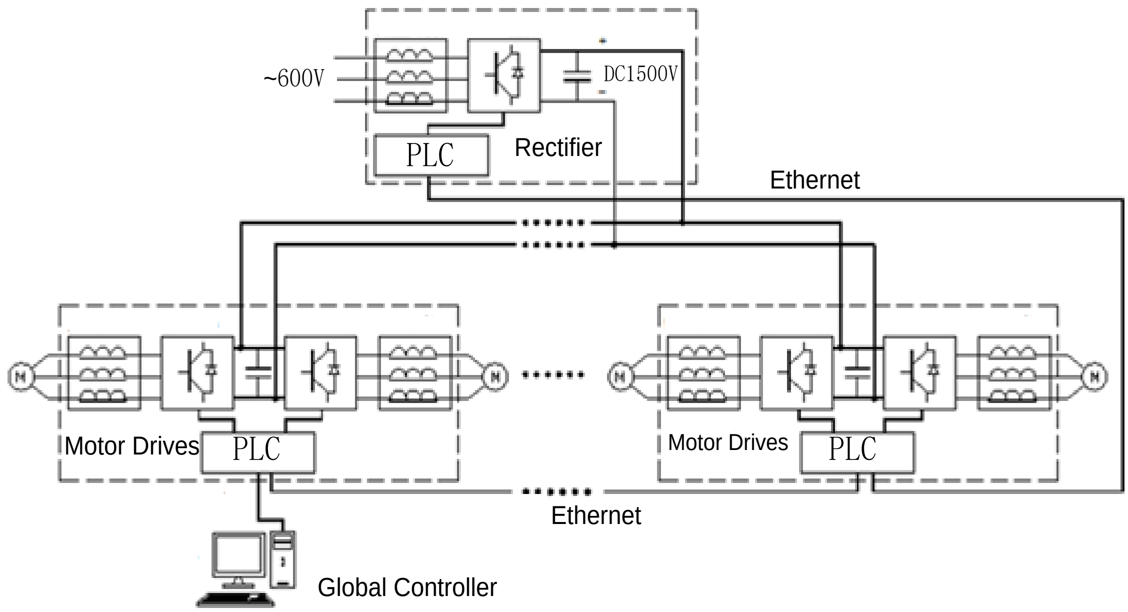

Fig. 7. Scheme of common DC Bus power for motor drives

Motor Drives	
Power	850kW
Power Supply	DC 1500V
Rectifiers with Regeneration	Per dual-line km
Power	3,400kW

Table 4. Parameters of Motor Drives and Rectifiers

As shown in Figure 7, the three-phase public utility power can be rectified by an active rectifier with braking regeneration into a common DC bus to power the motor drive cabinets along the track. The motor drive cabinets distributed along the track can verify the output voltage frequency to control the speed. One motor drive cabinet has two sets of motor drives to control two 48m-long linear motor windings. Therefore, typically one rectifier can power 21 motor drive cabinets per dual-line km or four motor drive cabinets using the leap-frog switching method. The max power of one motor drive is 850kW, so the rectifier station power will be 3,400kW per dual-line km as shown in Table 4. The common active four-quadrant rectifier can regenerate the braking power back to the grid in order to reduce the power consumption and operation cost.

4. Global Control System

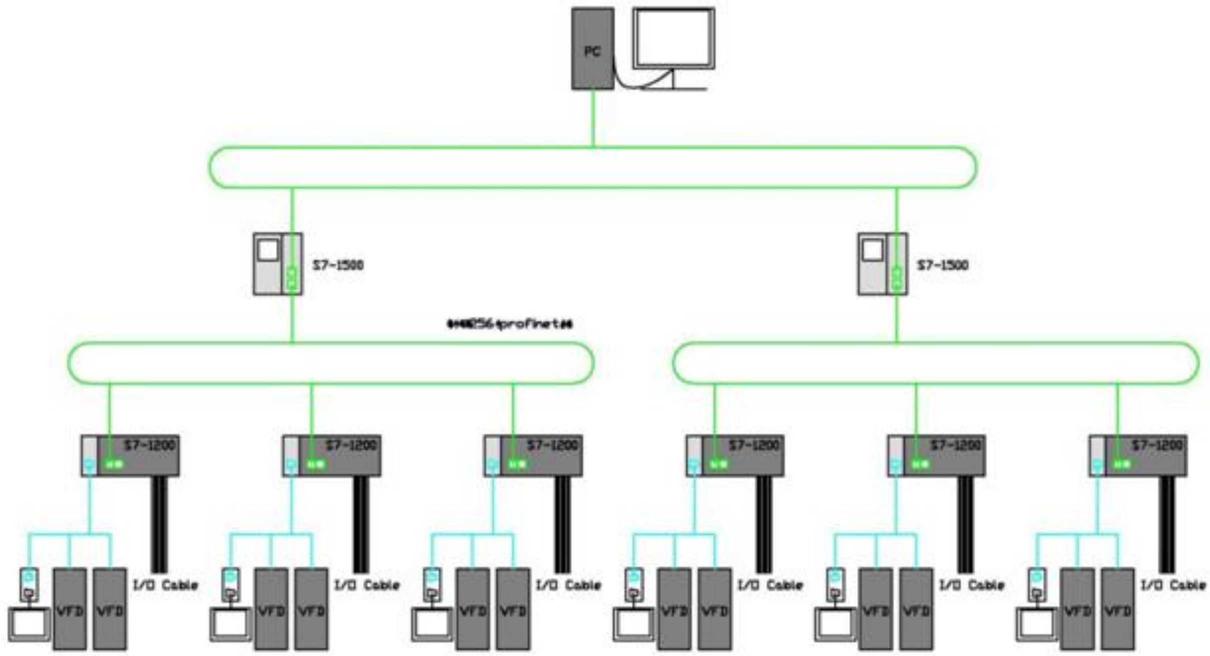

Fig.8. Scheme of the global control system

As shown in Figure 8, the global control has been divided into three levels: on-site motor drive control, middle-level zone coordinator, and top-level central controller. The low-level motor drives can position the vehicle along the track and report the running status to the middle-level zone controller for the moving permission. The top-level central controller can instruct the middle-level control zones to avoid the collision. The functions of the global controller also include starting up the system from a stopped condition, shutting the system down in a controlled manner, collecting configuration and operation data for analysis, and dealing with system faults in a safe manner. Local vehicle speeds within the control zones are based on instructions from the global system control. The global control system also can regulate acceleration and deceleration and send instructions to the stations, switches, and maintenance bypass operations.

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Jiarong Fang, Vice President for Engineering and Deputy Chief Technical Officer, Magplane Technology, Inc., received the Ph.D. degree from the Institute of Electrical Engineering, Chinese Academy of Sciences, China, in 2001. During the past two years, he was a project group director to lead all the three joint-venture partners for the whole project to make the successive running of 1km-long MagTrack Demoline in Zhangjiakou, China, in cooperation with China Coal and Rongxin Power Electric. Prior to joining Magplane Technology, Inc., in 2007, Dr. Fang was a Postdoctoral Fellow with the Francis Bitter Magnet Laboratory, Massachusetts Institute of Technology (MIT) in 2002 and then a Visiting Scientist with the MIT Plasma Science and Fusion Center. His main research contributions during the past 26 years have included maglev trains, linear drives, pipeline transportation, magnetic bearings, and superconducting magnets. Dr. Fang was an Administration Officer with the Maglev Office, Ministry of Science and Technology of China, in 1999-2001. He was a national maglev expert and a Review Committee Member for the maglev project of the National 863 High-Tech Plan.

Dr. D. Bruce Montgomery, Chairman of the Board and Chief Technical Officer MagPlane technologies. Dr. Montgomery is a recognized expert in the generation of magnetic fields for applications including magnetic levitation and propulsion, Magnetic Resonance Imaging, and nuclear fusion confinement devices. His book on Solenoid Magnet Design, first published in 1969 remains a standard reference in the field. He is the author of more than 100 papers on magnet design, superconductivity, and a wide range of magnetic field applications. Prior to retirement from Massachusetts Institute of Technology (MIT) in 1996, he was the Associate Director of the Plasma Science and Fusion Center - the largest interdisciplinary on-campus research center at MIT. Early in his carrier he worked for Arthur D. Little and Raytheon. He is currently an emeritus Senior Lecturer at MIT. He was elected to the National Academy of Engineering in 1998. Dr. Montgomery led the US magnet design team working on ITER prior to leaving the Massachusetts Institute of Technology in 1996 to join the private sector.

Stephen J. Kochan has more than 25 years' experience in research as well as new product development. For the last 3 years Mr. Kochan has been the On-Site Technical Manager and New Product Development Innovator for Magplane Technology, spending substantial periods of time living in Zhangjiakou, Hebei, China. While in China he has been the value added direct contact for Magplane's Joint Venture partners at ZMM, monitoring the building of the 1 kilometer LSM Magtrack Demo Line there. He developed designs and methods for complex magnet array manufacture and assembly, as well as motor coil process tooling. Mr. Kochan was part of an earlier Magplane design team on a project in Baotou, China. Prior to his time at Magplane, Mr. Kochan worked in various industries, including heavy commercial, and theater machinery markets. Before that, for 10 years Mr. Kochan worked at the Massachusetts Institute of Technology (M.I.T.) Plasma Science and Fusion Center, as R & D Engineer as well as Sponsored Research Staff First Wall Engineer for Ultra-High Vacuum environments. During his stay at M.I.T. he led the 4 year design and manufacture of the pure molybdenum first wall armor of the C-Mod Fusion Reactor vacuum vessel, and was published in the IEEE review of that design. Mr. Kochan is named as primary inventor on 5 patents in the overhead lifting industry, and holds additional patents in the area of gearing and power transmission. He was educated on a full tuition scholarship to Wentworth Institute of Technology where he received a BSc in Technical Management and Mechanical Design Engineering. Mr. Kochan received an MSc in Innovation and Change Leadership from Buffalo State College in 2007.