

# Medium Speed Urban/Intercity Maglev Development

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## Keywords

Urban Maglev, Linear Synchronous Motor, Electromagnetic suspension, High Capacity, Short Headway.

## Abstract

Shanghai Maglev Transtech Inc. in coordination with Magplane Technology Inc. has purchased the worldwide license for MagneMotion's Urban Maglev system, called *M3*, with the intent to commercialize the technology. In 1999, the Federal Transit Administration (FTA) initiated the Urban Magnetic Levitation (Urban Maglev) Program to develop magnetic levitation technology that offers a cost-effective, reliable, and environmentally-sound transit option for urban mass transportation in the United States [1,2]. In 2001 MagneMotion Inc. was awarded a grant and worked in cooperation with the US Federal Transit Administration (FTA) until 2012. The FTA produced a final report in 2012. The FTA report includes a detailed description of the *M3* design and a comprehensive cost analysis [3]. In Q1 of 2016 The Shanghai Maglev Transtech Ltd. (SMTL) company was formed to purchase the Massachusetts test track and the worldwide license for the *M3* system. The system has been rebranded as medium speed, as it is capable of speeds up to 200 km per hour, or twice the speed of LIM(Linear Induction Motor)-based urban maglev systems. The development program will be carried out by a consortium of private enterprises supported by the China Central Government. The Consortium is largely China-based, under the direction of a strong US-based team including personnel from Magplane Technology Inc and MagneMotion Inc. (MMI). This paper describes the unique features of the *M3* system and discusses the plans for development.

## 1.1 Introduction

The Urban Maglev project was funded by the FTA in stages over 11 years. The first stage resulted in system architecture and a 1/7 scale model with full size magnetics (Figure 1).

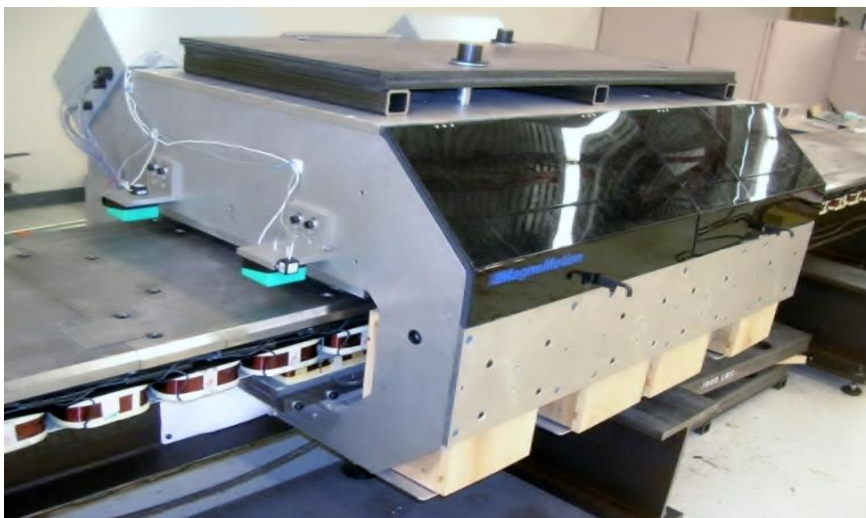


Figure 1. MagneMotion 1/7 scale maglev demonstrator with full size magnetics.

Later project stages resulted in a full scale vehicle, 50 meter indoor working prototype at the MMI Facility in Massachusetts (Figures 2a and 2b).

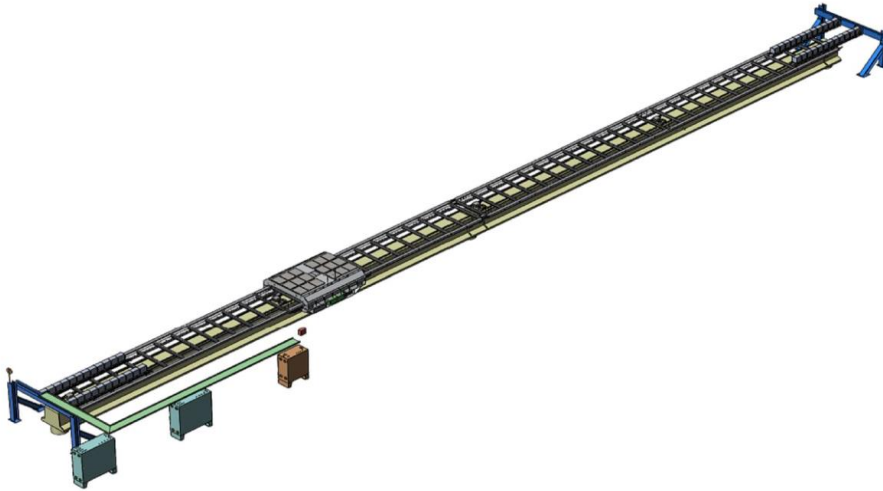


Figure 2a. The *M3* 50 meter test track assembly showing test sled, track, beams, end stops and cabinet layout.



Figure 2b. The *M3* test sled at MMI in Devens, Massachusetts. This test sled is capable of carrying a payload equivalent of a vehicle body and 18 to 20 passengers.

MMI also constructed a 75 meter test track [4] and installed it on an existing outdoor guideway at the campus of Old Dominion University in Virginia (Figures 3a and 3b). The two larger test track systems have been run for over 7000 km with tens of thousands of start/stop and liftoff/touchdown cycles.



Figure 3a. The *M3* system mounted on the guideway at Old Dominion University, Norfolk, Virginia.



Figure 3b. A closeup view of the *M3* system at Old Dominion University, Norfolk, Virginia.

## 1.2 Medium Speed Maglev Characteristics

The *M3* system was developed using a system approach with the goals of major reductions in capital cost, travel time, operating cost, noise, and energy consumption. The concept is that small, van-size vehicles operating automatically with short headways of only 4 to 6 seconds can be operated in platoons to achieve capacities of at least 12,000 passengers per hour per direction. Accurate position sensing is inherent with linear synchronous motor propulsion, and braking does not depend on friction with the guideway. With these capabilities it is possible to operate with close spacing between vehicles. Shorter headway and automated operation make smaller vehicles the preferred choice. Smaller vehicles lead to lighter guideways, lower power requirements for wayside electronics, more effective regenerative braking, shorter wait time for passengers, and reduced station size.

The design uses high-energy permanent magnets on the vehicles, commercially available microprocessor-based power electronics, precise position sensing, lightweight vehicles, and a guideway matched to the vehicles. On each side of the vehicle a single array of permanent magnets provides suspension, guidance and the magnetic field for Linear Synchronous Motor (LSM) propulsion. Feedback-controlled current in control coils wound around the magnets stabilizes the suspension. The LSM motor windings are integrated into suspension rails and excited by inverters along the wayside. The baseline *M3* is designed such that all vehicle position reporting and horizontal movement of the vehicle is on the wayside and there is no onboard propulsion equipment. Operating speeds and accelerations can be increased merely by changing the power system and wayside inverters. Capital cost, travel time and operating cost are predicted to be less than half those of any competing transit system.

The *M3* was designed to exceed all attributes of urban transit systems by using the following objectives and strategies .

- Decrease guideway cost: Use small, light-weight vehicles that operate with short headway on guideways that are matched to the vehicle mass and pier crossing speed;

- Decrease travel time: Allow speeds up to 45 m/s (101 mph), acceleration and braking up to  $2 \text{ m/s}^2$ , short average waiting time and reduced dwell time;
- Decrease operating cost: Use 50% less energy and reduce labor and maintenance;
- Improve on existing maglev designs: Use single permanent magnet structure with a 20 mm gap;
- Improve ride quality: Vehicle and guideway dynamics have been modeled to ensure smooth ride quality;
- Reduce environmental impact: Reduce energy consumption, noise, and guideway size;
- Improve safety: Use a dedicated guideway, totally automated remote operation, vehicles that cannot derail, and redundant linear motor propulsion.

### *I. Operational Characteristics*

Max. operation speed	160 km/h (101 mph), with winding /Inverter chages 200km/h (135mph)
Max. initial acceleration	2 m/sec <sup>2</sup>
Max. deceleration service brake	4.0 km/h/s (2.5 mph/s)
Max. deceleration emergency brake	Not defined
Max. gradient	10%
Min. horizontal curve radius	18 m (60 ft)
Min. vertical curve radius	1000 m
Max. super elevation angle	15° includes vehicle tilting
1-car train passenger capacity – seated	24
1-car train passenger capacity – standing	12
1-car train passenger capacity – total	36

### *II. Vehicle Configuration(Preliminary)*

Vehicle type	Composite body
Train formation	Cars in platoons, no couplers
Car body dimenstions	Length 8.2 m, Width 2.5m, Height 3.6m
Rail gauge	1.5 m
Vehicle weight empty	5 tonnes
Vehicle weight 75% loaded (AW2)	7 tonnes
Car body structure – material	Composites (not defined)

### *III. Levitation System*

Magnet	Permanent magnets and electromagnets
Levitation gap	17 mm mechanical gap, 20 mm magnetic gap

### *IV. Propulsion System*

LSM (Linear Synchronous Motor)	Wavelength 250mm
Power supply	480V AC Rectifier from 600V DC Lin
Inverter type	VVVF

### *V. Suspension System*

Suspension	4 magnet pods
Secondary suspension	None at low speed

### *VI. Brake System*

Service brake	LSM brake (regenerative/reverse phase)
Emergency brake	Skid pad brake
Parking brake	Skids (levitation cut off)

Table1.M3 System Characteristics

### 1.3 MMI M3 concept to commercialization

#### The Move

In May 2016 the M3 test track in Devens Massachusetts was decommissioned after a Factory Acceptance Test for Shanghai Maglev Transtech Ltd. was conducted. The test sled was removed (Figures 4a and 4b) as were the track structure including LSM stators (Figures 5a and 5b), drive cabinets and rectifier. Cabling and tools were packed up for shipment. The entire 50 meter test track was loaded into three shipping containers (Figure 6a) and the test sled into an oversized wooden crate. The contents of the crates were then vacuum sealed to prevent moisture damage during transit. The shipment, weighing 34,000 kg, left New York on May 26, 2016, arrived in Shanghai on June 30<sup>th</sup>, and were unloaded on July 16<sup>th</sup> (Figure 6b).



The 50 meter test track is being reconstructed in a building on the Shanghai EXPO 2010 site.

Figures 4a and 4b. The M3 test sled being removed from the test track.



Figure 5a. Track structure being prepared for removal.



Figure 5b. Track moved outdoors and onto supporting shipping crate.



Figure 6a. Two sections of track and electronics loaded into shipping container at Devens Ma.



Figure 6b. The same unloaded at Shanghai EXPO 2010 Commemoration site.

Concurrent with the packing and shipping in the USA, SMTL's partner, the 23rd division engineering group of China Rail Construction Co.(CRCC) in China, was designing a concrete beam and piers to replicate the beam characteristics that had been present at MagneMotion. Drawings of the Guideway Beams which include critical dimensions and structural specifications were given to CRCC for guidance. Upon the *M3*'s arrival in Shanghai a team of engineers from the US verified the physical attributes of the new demonstration site and directed the reconstruction of the test track. Figure 7a shows the equipment crates on site, and Figure 7b shows the new beams for the 50 meter demonstration site on the EXPO 2010 commemoration exhibition center in Shanghai.



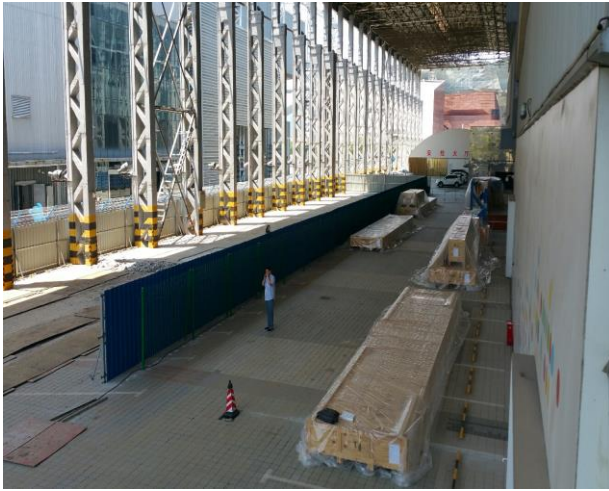


Figure 7a. The M3 equipment in crates on site.

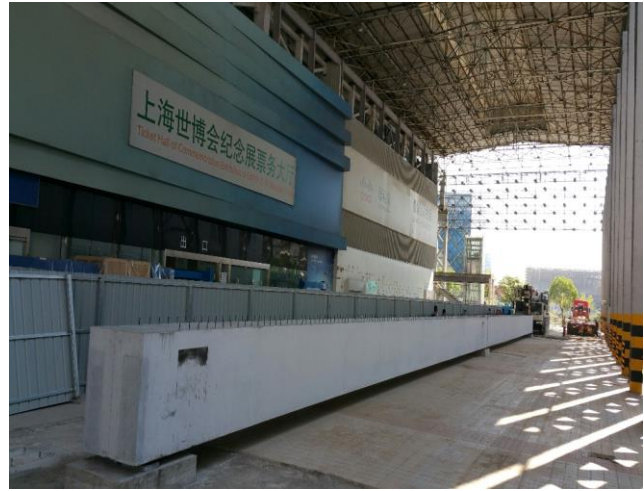


Figure 7b. The new beams on site in Shanghai.

Once the test track was assembled and levelled, the electrical hookup started and the test track underwent a carefully executed set of tests prior to the first full 50 meter demonstrator. A Site Acceptance Test will be performed in Shanghai to verify key performance attributes after which the system will be ready for demonstration to interested parties.

### **Development Plan**

SMTL initiated the *M3* development program prior to the equipment arrival in Shanghai. A comprehensive project plan has been set up and a Statement of Work that outlines the tasks to be performed has been written.

After initial testing on the track in Shanghai, a second test track approximately 5 km in length will be built to accommodate peak velocity, cornering and grade climbing capabilities. The layout is anticipated to be parallel guideways with turnaround loops at each end. One of the parallel tracks will include an inclined element “hill.” The test track will most likely be the beginning of a commercial line in the Shanghai vicinity. The principle focus of the 5 km test track will be commercialization as well as reliability and system testing.

### **Systems Engineering**

In order to achieve an optimal design, 3 key subsystems will be carefully integrated: vehicle, magnetics, and guideway. During the FTA program the basic engineering design and testing was completed. The first step of the development team will be to form a Systems Engineering oversight team that will be tasked with selecting partners for the development of key technologies. The goal is to commercialize the system and improve the manufacturability of the subsystems.

### **Vehicle Constraints**

SMTL will engage a vehicle design team with experience with maglev vehicle design. We will pursue a light-weight vehicle with a look that is sleek and aerodynamically stable. It is critical that the vehicle manufacturing firm has experience in using lightweight materials, modular design and sophisticated construction methodology, with a demonstrated ability to collaborate with other design teams including the bogie design team.

Vehicle weight is very important and there is a cost tradeoff between using a more expensive but lighter vehicle, and requiring heavier guideways with a more powerful linear motor. With careful design and by using composite materials, the empty vehicle weight can be less than 2 times the maximum total passenger

weight. Since transit systems spend much of their energy budget on acceleration, weight savings have an important impact on capital and operating cost.

### **Bogie Design Constraints**

SMTL will partner with institutions that have experience in creating maglev systems. We seek an institutional partner that can design a lightweight articulated bogie to fit on the vehicle. The suspension must be optimized for low to medium speeds with frequent station stops, be capable of making small radius turns in both the horizontal and vertical directions, and be suitable for use with small vehicles.

### **Magnetic Guidance**

The *M3* design uses a single set of magnets to provide all of the functions of suspension, guidance and a field for LSM propulsion. This simplified design was the result of extensive analysis and simulation and is one of the keys to achieving technical success and low cost. If the vehicle tends to move laterally there are very strong restoring forces that keep the magnets aligned with the guideway with up to 0.35 g lateral force. Damping of lateral oscillations is provided by a combination of offset magnets with active control of the suspension control coils and passive damping mechanisms in the secondary suspension.

### **Linear Motor Propulsion**

Maglev developers have universally adopted the linear electric motor for maglev propulsion. There are two types of linear motor that are currently being used for commercial designs: the LIM and the LSM. The *M3* uses a LSM.

The LSM has a number of important advantages: the motor can use the same magnets as the suspension and thereby reduce cost and weight, the magnetic gap can be larger, and the vehicles are lighter so less propulsive power is required. The dramatic reduction in the need for onboard power is a very powerful incentive for using an LSM. Lastly, and perhaps most importantly from a safety standpoint, the propulsion and control equipment is all on the guideway, so communication between central control and propulsion control is more robust than other systems that rely on vehicles reporting their position and velocity data.

### **Guideway constraints**

The *M3* levitator is supported by the vehicle bogie magnets creating attractive forces to the underside of ferromagnetic suspension rails on the guideway. The focus of the design effort was to keep the guideway beams as small and light as possible without jeopardizing ride quality. The resulting design is based on stiffness and resonant frequency considerations, and the strength of the structures is far greater than is necessary so there are no compromises with safety issues.

The production guideway will be designed and built by CRCC, the same group that designed and built the concrete beam used for the Transrapid system that runs from Pudong Airport to Shanghai. Figure 3 shows cross sections of concrete and steel box beam designs that are under consideration. The concrete beam is the least expensive. For longer spans or in areas where it is difficult to handle the heavier concrete beams, it may be preferable to use steel beams in spite of their higher material cost.

### **Higher capacity**

There is a development path possible to expand the capabilities of the *M3* system to 30,000 passengers per hour per direction at higher speeds. It is well recognized that at higher speeds aerodynamic drag becomes dominant which favors larger vehicles. Larger vehicles in turn require bigger guideways, higher power electronics, and fewer windings on the stators. The path and relative cost of increasing capacity and speed have been documented in Thornton R.D. & Wieler J.G.[5].

## **1.4 Summary**

The *M3* system for medium speed urban transit provides multiple advantages over existing systems: lower capital and operating costs, enhanced energy efficiency, smooth operation, and high traffic density. For a more complete description of the system the reader is referred to [2]. The system is being commercialized in China under the guidance and leadership of a US team consisting of both Magplane Technology Inc. and

MagneMotion Inc. (a Rockwell Automation Company). The commercialization project consists of re-assembling a 50 meter demonstration track in Shanghai in 2016, and the construction of a 5 km system test track starting in 2017. It is anticipated that the first commercial line be installed by 2019.

## 1.5 References

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## 1.6 About the Author(s)

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Jim Wieler has more than 30 years of experience in business development, program management, engineering management, and engineering.

As Vice President of Magplane Technologies Mr. Wieler has responsibility for planning and execution of all Magplane projects. For the past 3 years Mr. Wieler acted as the General Manager for the development of the Magtrack LSM ore conveyance system that was build and is being tested in Zhangjiakou, Heibe, China. Prior to Magplane Mr. Wieler was Vice President of Strategic Planning and New Business Development, and Vice president of Engineering at MagneMotion Inc. Where he had responsibility for corporate strategy, planning long term growth, developing partnerships, and pursuing new applications for MagneMotion's M3 Maglev and LSM businesses. In 2003 he led MagneMotion's award winning team in the competition to win the U.S. Navy Advanced Weapons Elevator program. For 16 years, Mr. Wieler served at Raytheon Company in multiple roles, as a systems engineer and program manager. Mr. Wieler began his career as a research scientist at the Air Force Geophysical Laboratory at Hanscom Air Force Base, Bedford, MA. He has authored over 30 technical papers, holds two U.S. Patents and is a senior member of the IEEE. Mr. Wieler holds a B.S from the University of Massachusetts and an M.Sc from the University of Alberta.

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Mr. Binson Du, President Shanghai Maglev TransTech Company Limited, China Operations: Prior to joining SMTL and Magplane Technologies, Mr. Du was active in several China and US industries in management, marketing, and public relations roles. He took important positions in many companies including: Wuhan Rubber Product Factory, Janus Disk Company USA, Junefield Consulting Service Company, Korea Panel Company, Guo Kang Pharmaceutical Development Company, and Well-Star Computer Security & Protection Technology. Throughout his career, Mr. Du was involved in projects including the design and assembly of first computerized system for rubber curing and processing, the design and assembly of a 2000-ton automatic hydro-pressing system, and the establishment of significant market position in China for Janus' disk products. Mr. Du also led the establishment of several joint ventures in China between American and Chinese companies.