Title: **Maglev Goes High Rise? The Potential of Horizontal Maglev Technology for Vertical High-Rise Elevators**

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Maglev goes high rise?

The Potential of horizontal Maglev technology for vertical high-rise elevators

Within the past ten years magnetic levitation (maglev) technology has gained substantial interest and significant development internationally. Most notably is the application of maglev technology to trains. In Asia and Europe maglev trains ride on air and reach speeds up to 250 mph. This technology also has great potential in other applications, such as elevator systems – not only for greater energy efficiency, but also in offering the potential for non-vertical routing. Steps have recently been taken to develop the first maglev elevators. The elevator moves via the same means as maglev trains creating a smooth and quiet ride, but rather along a vertical path. This development has opened up a number of opportunities with regard to elevator system design, elevator travel, and ultimately, high-rise building design.

Principles of Magnetic Levitation

Magnetic forces occur due to the movement of electrically charged particles. Magnetic fields are formed and exert attractive or repulsive forces on other materials. This phenomenon can occur naturally in materials due to the orbital motion of their electrons, forming "permanent magnets," or it can occur as a result of inducing an electrical current, know as electromagnetism. An electrical current occurs as electrons move from negative to positive poles and a magnetic field forms around it. The direction of the magnetic field is dependent on the current so that it can be inverted by inverting the direction of the current. Also, the strength of the magnetic field is in direct relationship with that of the current; the more current, the stronger the magnetic field and, similarly, if the electrical current were switched off, the magnetic field would reduce to zero. It is this ability to easily manipulate a magnetic field by controlling the electrical current that gives electromagnets an advantage over permanent magnets.

Magnetic levitation (maglev or magnetic suspension) occurs when the force of a magnetic field overcomes forces due to gravity. This can occur with an attractive or repulsive force as a material can be attracted from above or repelled from below (Fig. 1). It is on these principles that a maglev train hovers above it track for a frictionless ride.

fig 1. Magnetic Levitation forces in the metal rod repelled by opposite forces below. Source: Levitating bar. [Online Image] Available www.flyingmagnet.com/usindex2.html.

fig 2. Typical Maglev Train, Shanghai. Source: Transrapid Shanghai maglev train. [Online Image] Available http://en.wikipedia.org/wiki/Maglev_train

Maglev Trains

Throughout the world, maglev trains are being used as an alternative to traditional combustion engine trains. Maglev trains use electromagnetic forces to suspend, propel and brake their cars creating a smooth, quiet, frictionless ride. The most notable commercial application of a high-speed maglev line is in Shanghai, China (Fig. 2). The train transports passengers 18.6 miles (30 km) to and from the airport in under 8 minutes at an operating speed of 268 mph (430 km/h). Other applications are running in Japan and Germany, while systems under construction and in proposal can be found throughout Asia, Europe, India and the United States.

The maglev line in Shanghai was developed by Transrapid International and provides a good example of applied magnetic levitation and propulsion. Transrapid describes the levitation technology (see Fig. 3):

> *Electronically controlled support magnets located on both sides along the entire length of the vehicle pull the vehicle up to the ferromagnetic stator packs mounted to the underside of the guideway. Guidance magnets located on both sides along the entire length of the vehicle keep the vehicle laterally on the track. Electronic systems guarantee that the clearance remains constant (nominally 10 mm). To hover, the Transrapid train requires less power than its air conditioning equipment. The levitation system is supplied from on-board batteries and thus independent of the propulsion system. The vehicle is capable of hovering up to one hour without external energy. While traveling, the on-board batteries are recharged by linear generators integrated into the support magnets.*

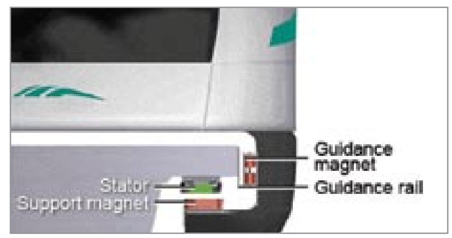

fig 3. Maglev train – detail of side contact point. Source: Maglev train section. [Online Image] Available http://www.transrapid.de/cgi-tdb/en/basics.prg?session=d82f8833463f50c9&a_no=41

While the car is suspended off the track, it is propelled and braked with a linear synchronous motor.

Linear Synchronous Motor (LSM)

A linear synchronous motor works due to the interaction of two concentrated magnetic fields; one permanent and one of changing strength and direction. The permanent magnets on the train car are aligned so that the resulting magnetic field is concentrated to one surface of the alignment while the resulting force on the opposite surface is near zero. This alignment is known as an Halbach Array.

Discovered by J. C. Mallinson in 1973, the pattern of left, up, right, down can be continued endlessly with a resulting 'one-sided flux' (Mallinson, 1973). This concentration of magnetic field is directed away from the train and towards the high-thrust stator located on the track. The stator produces a directional magnetic field through the manipulation of an alternating electrical current. Figure 4 shows a portion of a high-thrust stator that would be located on the track. Electrical current is supplied through the wrapping coil to create a directional magnetic field. The magnetic field travels over the high-thrust stator and interacts with the Halbach array on the train car. The car is then propelled or braked depending on the direction (an attractive or repulsive force) and strength of the stator's magnetic field. Dimensions of the stator and the distance between coil sections (e.g. 2mm) influence the efficiency and performance of moving the car. Also, digitally encoded location flags on the guideway provide for precise starting and stopping. Ronald Kaye of Sandia National Laboratories and Professor Eisuke Masada of the Science University of Tokyo further describe the control and power systems:

> *In order to reduce operational losses and for stability of the power supply system, the long stator of the LSM is separated into a number of sections controlled by the section switches.*

> *The minimum length between two section switches depends on the required acceleration and length of a train. The operating frequency of the section switches becomes high if a large number of trains are operated on the track each day.*

> *The currents in the stator coils must be synchronized with the train's position and velocity. Proper control of the train can only be accomplished by sending information to the converter stations through the use of sensing equipment and signal transmission systems. Because synchronization is essential to the LSM, the sensing and signal transmission system must have high precision and reliability.*

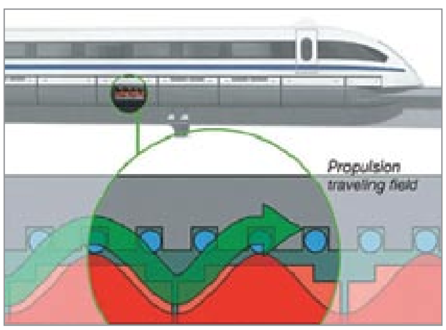

fig 4. Section showing propulsion system for typical mag lev train. Source: Maglev train elevation. [Online Image] Available: http://www.transrapid.de/cgi-tdb/en/basics.prg?session=d82f8833463f50c9&a_no=41,

fig 5. Magnemotion's mag lev elevator platform. Source: Advanced weapons elevator demonstration. [Image Clip from Online Video] Video Available http://www.magnemotion.com/products/elevators/main.shtml

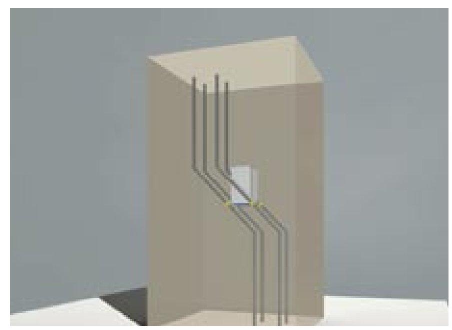

fig 6. Diagram of mag lev elevator potential in non-vertical routing (image pending).

Moving Into the Vertical plane

MagneMotion, a company located outside of Boston, MA, is a self-titled "Force in Electromagnetic Systems." Their work involves the development of maglev systems that use linear synchronous motor technology to transport goods and people. Successful applications include the design-build of assembly lines and elevators. Most thoroughly developed are their assembly line systems. The MagneMotion QuickStick LSM is an advanced modular unit used in assembly automation and material handling. MagneMotion's website (www.magenmotion.com) showcases a video library displaying QuickStick's numerous system capabilities.

Multiple QuickStick motors on the same path communicate with each other preventing collisions; precision positioning is achieved within a five-hundredth of a millimeter, turning corners or switching paths is achieved with turntables; grooved platforms provide for a second axis of movement; double-bogie vehicles provide the capability to navigate turns; and, most notably, diagonal and vertical transport paths are achieved with efficient loading capacities. It is here, in the vertical potential of the technology, that MagneMotion developed its maglev elevator prototype (see Fig. 5)

Maglev Elevators

On October 20, 2005 Northrop Grumman Corp. announced that the Federal Equipment Company and their technology partner, MagneMotion, were chosen to develop a full-scale prototype maglev elevator for the new US Navy aircraft carrier, CVN 21. Prototyping is to be completed by late 2007 and shipboard installation in mid-2010. As of May 2007, MagneMotion has completed a corner of a full scale prototype (Fig. 5); one of four posts that lifts, lowers, brakes and holds a transport platform using a linear synchronous motor system similar to that of the QuickStick and maglev trains. The main difference between the vertical and horizontal applications is that, in the vertical, a constant flow of electricity is required as the car must consistently overcome the force of gravity by using the linear synchronous motor rather than permanent magnets. MagneMotion's prototype is equipped with a mechanical emergency braking system in case of a power failure. The corner prototype has a lifting capacity of 12,000 lbs giving the complete system a lifting capacity of 48,000 lbs. It can reach a top speed of 150 ft/min, a dismal comparison to traditional cable elevators (currently, the fastest elevator is located in Taipei 101 in Taiwan achieving a top speed of 3,314 ft/min). Dr. Richard Thorton, chairman and CEO of MagneMotion, further describes the company's achievements:

> *They [MagneMotion] also take advantage of a careful integration of electrical, electronic and thermal design with major concern for manufacturing economies and reliable operation. For elevator applications, an important property of the LSM is that the individual stator segments operate with low-duty cycle, so it is possible to get a much*

higher thrust than one might infer by scaling the force capabilities of rotary motors. The ability to overload a LSM without affecting its reliability is probably the single most important fact that makes these motors practical for elevators, (Thorton, 2006).

Advantages of Mag lev elevators

Despite relative low speeds, the linear synchronous motor maglev elevator has substantial technological advantages and design potential. First, compared to traditional elevator systems, the maglev elevator lacks a cable system or counterweight. The most apparent advantage of this is the capacity for multiple high-speed, independently controlled cars, or double-deck cars, to operate along a single path. This could dramatically increase the efficiency by which passengers travel through the building. Computer software and algorithms could be written so that multiple elevators in one shaft would travel in the most efficient manner to facilitate the current needs within the building.

The sharing of hoistways also reduces the footprint dedicated to elevators within a building, therefore offering the economic benefits of allocating more usable square footage per rentable square footage due to the consolidation of elevator cars to fewer shafts.

Furthermore, the lack of cables, gears and wheels provides for a smoother and quieter ride. This would be beneficial for those riding in the car and those within the building. Noise pollution at the core of the building due to elevator travel would reduce to nearly zero.

Perhaps the more significant benefits are the sustainable advantages inherent in the maglev elevator. The system would require much less electricity to operate than conventional elevators. There is also the potential for energy generation within the system:

Energy generated by a descending elevator can be used by an ascending elevator, stored in a battery or returned to the mains. When there is more than one hoistway with a central controller, one can schedule movement to enhance the probability that regenerated power from a descending cab can be used to power an ascending cab, thereby mitigating much of the penalty of not using counterweights. Modern batteries developed for hybrid automobiles offer the possibility of even greater smoothing of power requirements while simultaneously providing backup power in case of a utility power loss. (Thorton, 2004).

Other developments

MagneMotion is not the only company to develop this technology. On January 17, 2006 the Toshiba Elevator and Building Systems Corp. (TELC) announced "it has developed the world's first elevator guiding system in which "non-contact magnetic suspensions" has been used to realize smoother riding comfort, and aims for the commercialization of the product in the spring of 2008." As Toshiba focuses on the advantages of a smoother and quieter ride, they also point out that because the car-to-track relation is contact-less, the functioning of the system and movement of the car are not affected by machining accuracy and/or the installation of the rails. The company has many advanced engineering projects on the boards in attempts to realize this technology. Earthtimes.org reports that Toshiba's elevator system, when complete, will travel at 984 ft/min, a substantial increase from MagneMotion's advanced weapons elevator, but still far behind Taipei 101's cable-hoist system.

Also, on January 13, 2007, the China Economic Information Network reported that China will test its first maglev lift as early as June 2007. Located in Wuhan, the capital of the Hubei province, a 128-meter tall tower has begun construction that will include five elevator wells, one of which will be used to test a maglev elevator. An engineer with the elevator company said that they "have been researching and developing the use of maglev technology on elevators in the past two years."

The Future

It is possible to imagine the full potential of maglev elevators. The lack of cables, gears and counterweights frees up the elevator car so that it can move like never before. As well as multiple cars within a single shaft, it is possible to imagine an elevator car moving in a direction other than vertical. MagneMotion's QuickStick LSM has managed the diagonal so why not develop an elevator system that can also travel along a diagonal path? The concept could be approached from the standpoint of increasing MagneMotion's QuickStick's loading capacity to handle passengers. And why stop there? Elevators could travel in endless directions along unique paths. One could imagine a curved path (curved in the horizontal, vertical or both) in which the platform of the elevator car interacts with the track with an incorporated ball-joint system (see Fig. 6). As the car travels along the non-linear path the ball-joint system would allow the interaction to rotate and the platform to remain level.

The ability to travel along non-linear, non-vertical paths introduces a flood of design potential when looking at the developments in non-orthogonal forms in recent high-rise buildings. Tapered, tilted and twisted forms are increasingly being proposed for tall buildings, with the need for vertical traditional elevator shafts stifling the possibilities of design somewhat. The degree of twist, turn and bend achieved by these buildings are all limited by needing to include a linear, vertical hoistway. Mag lev elevators which can traverse inclined or even curving shafts offer great potential for these new non-orthogonal buildings.

It is also feasible to imagine elevators changing hoistways: "the most important future role for LSM elevator propulsion is for designs that use horizontal switching between adjacent hoistways," (Thorton, 2004). This idea bears with it images of a continuous loop of elevator travel throughout a building. The number of cars within a continuous loop becomes unlimited and the efficiency of passenger travel increases dramatically. As an elevator car completes it ascent to the top of a building it switches over to the descending hoistway to bring passengers downward. Unnecessary travel in reaching awaiting passengers would be dramatically reduced, if not completely eliminated. One could imagine that a building's vertical egress needs, no matter how tall it is, could be facilitated with one ascending hoistway and one descending hoistway, substantially reducing the footprint dedicated to elevator shafts.

Challenges

Although the development of maglev elevators has already advanced significantly and is beginning to see applications, there are still a number of issues that need to be addressed. Even more so, while the ideas of non-linear paths and horizontal switching open up many doors of technological potential and design possibilities, they too bring up new concerns. First, considering that elevators must conform to an extremely high standard of passenger comfort, the forces endured during travel need to be addressed and resolved. Lacking cables and a counterweight, a vertical maglev elevator carrying passengers must address the forces resulting in a sudden power loss. Mike Godwin, former head of Lerch Bates, states that we must find "a possible solution to the problem of sudden loss of power with the elevator traveling in the up direction and the physical effect that [a sudden loss of power] has on the passengers bearing in mind that they [the passengers] may be traveling at 5 m/s, yet the platform on which they are standing is arrested with a force greater than 1 g. due to friction and magnetic stiction." (Godwin, 2007)

Similarly, if an elevator were to travel with any component of horizontal direction, new lateral forces would be introduced on the passengers. These forces would need to be resolved as they affect a passenger's balance. Mick Watts of Dunbar & Boardman states that "accelerations rates have to be very low otherwise people lose their balance and fall over due to the lateral forces." He also points out that "unlike a transit or subway system where you know roughly when braking will occur and hence can maintain balance, in a lift this is a lot more difficult." (Watts, 2007). A possible solution to the loss of balance would be to have secure seating similar to that on a train, however this increases the time it takes to load and unload the car.

Another concern facing an elevator traveling horizontally is the current elevator codes. Steven Edgett of Edgett Williams Consulting Group, Inc. states that off-vertical elevator travel "is a difficult proposition as elevator codes all over the planet are based on emergency stopping theory where loads are applied only vertically and thus exert no horizontal moment on passengers." (Edgett, 2007). Codes would need to be re-examined to deal with horizontal emergency braking and the forces exerted on the passengers. Overall, there are remaining unresolved issues with regard to passenger maglev elevators, most notably how to achieve a successful emergency braking system and how to deal with a variety of new forces experienced by the passenger.

Conclusion

Maglev technology has reached a developed state. It is currently applied in trains, assembly lines and prototype elevators with successful results. At the same rate, the full potential of the technology and its implications have yet to be explored. Traditional elevator systems that use cables and counterweights are noisy, restrictive with respect to building design, an inefficient use of space within the buildings footprint and consume large amount of energy to operate (up to 15% of the total building's energy consumption). Maglev elevators provide a sustainable solution with a multitude of design possibilities. As maglev elevators become more economical and the remaining inherent issues are resolved, this technology has the potential to revolutionise tall building design.

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