Maglev on the Development Track for Urban Transportation

By Arnie Heller, November 2003, LLNL Science & Technology

THE Inductrack magnetic levitation (maglev) system, conceived by Livermore physicist Richard Post as a safer, cheaper, and simpler means to levitate urban and high-speed trains, is moving down the development track on the way to a full-scale demonstration. Using unique configurations of powerful, permanent magnets, called Halbach arrays, to create its levitating fields, Inductrack is under development by General Atomics (GA) in San Diego. The project is sponsored by the federal government to showcase a new generation of urban transportation technology. Recently, GA and Catherine Elizondo of Livermore's Industrial Partnerships and Commercialization Office have signed a licensing agreement for use of the levitation technology in Magnetic Levitation Train and Transit Systems.

Inductrack was conceived by Post in the mid-1990s as a new type of maglev technology, one that would use Halbach arrays located on the underside of train cars. (See S&TR, June 1998, A New Approach for Magnetically Levitating Trains — and Rockets.) The magnetic fields generated by these arrays interact with a track composed of shorted circuits to create levitating and centering magnetic forces. The system is fail-safe upon loss of power, and simpler and lower in cost than current maglev systems.

The Inductrack concept for mass transportation was first demonstrated at Livermore in 1998 with a subscale model using a 22-kilogram levitated test cart and a 20-meter-long track. Early Inductrack work was funded by the Laboratory Directed Research and Development Program. The tests were so successful that the National Aeronautics and Space Administration (NASA) awarded the Laboratory a contract to study the technology as a means to help launch rockets into space. The rockets would be sent up an inclined slope to about Mach 0.8 before firing. Post's team built a second test track to investigate the rocket-launch idea; the track was shipped to a NASA contractor this year. The Inductrack will be set up and tested by engineering graduate students at the Florida Space Institute, which is a technical training institution for NASA.

In 2000, GA won a contract from the Federal Transit Administration's Low-Speed Urban Maglev Program to develop magnetic levitation technology that would be cost-effective, reliable, and an environmentally sound option for urban mass transportation. GA concluded that Inductrack was the levitation approach that best met its needs, based on factors such as simplicity, weight, capital and maintenance costs, and design flexibility. Sam Gurol, General Atomics program manager, notes that GA has worked with Livermore scientists, including Post, for years on a variety of research projects, most of them related to magnetic fusion.

Studies at GA, Livermore, and other institutions have shown that a maglev system using Inductrack offers many benefits, including its ability to operate in all weather conditions and in terrain with steep grades and tight turns, its low maintenance, and its rapid acceleration. Also, its quiet operation allows elevated tracks to run through neighborhoods, thereby eliminating the need to tunnel underground for noise abatement. For many urban environments, the maglev system can result in significant cost savings over conventional transportation systems.

In May 2003, General Atomics broke ground on a 120-meter-long Inductrack test track, which will feature both straight and curved sections.

Full-Scale Test Track under Construction

In May 2003, GA broke ground at its San Diego facility on a 120-meter-long, full-scale test track, which will feature both straight and curved (50-meter radius) sections. In June, a test vehicle consisting of a single, full-scale chassis unit (a mass transit vehicle has two chassis units) was shipped to GA from Hall Industries in Pennsylvania. The vehicle chassis is composed of upper and lower Halbach arrays, additional Halbach magnet arrays for the propulsion system, auxiliary wheels, and secondary suspension components.

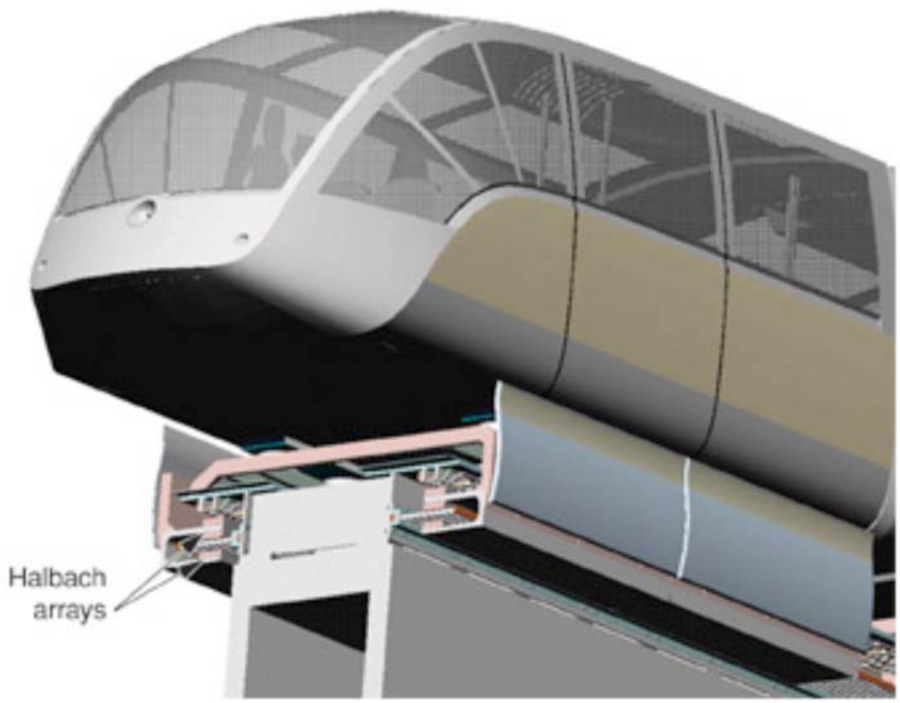
The test vehicle's chassis is equipped with water tanks for varying the weight during the test. The initial tests will be conducted on the first 15 meters of the test track. Once the entire 120-meter track is completed, the test vehicle will be operated (remotely) at speeds sufficient for levitation.

"The purpose of the test track is to validate integrated levitation, propulsion, and guidance," says Gurol. "Each of these has already been successfully demonstrated individually." Upon successful completion of trials, GA hopes to construct a demonstration system at California University of Pennsylvania in California, Pennsylvania.

Post notes that the concept of magnetically levitated trains, based on other technological approaches, has been studied in several nations for decades. "Demonstration systems in Germany and Japan, while impressive for the high speeds they attained, have proven to be both technically complex and unusually demanding from an engineering standpoint. What's more, they have a high capital cost and are difficult to maintain and to operate safely."

For example, the Japanese maglev system requires costly cryogenic equipment to cool its superconducting coils and must accelerate to speeds exceeding 100 kilometers per hour before it levitates. Also, passengers must be shielded from the high magnetic fields generated by its superconductors. The German maglev uses an electromagnetic design, which is based on magnetic attraction rather than repulsion and requires control systems to maintain a stable air gap of less than 10 millimeters. A breakdown of the magnet control circuits or cryogenic systems could lead to a sudden loss of levitation while the train is moving.

General Atomics' full-scale Inductrack test vehicle on the first section of the test track.



Drawing of the front end of urban maglev vehicle showing the vehicle's levitation/propulsion module. Dual Halbach arrays of permanent magnets are positioned under the train car to provide the levitating force.

Permanent Magnets Mean Fail-Safe Operation

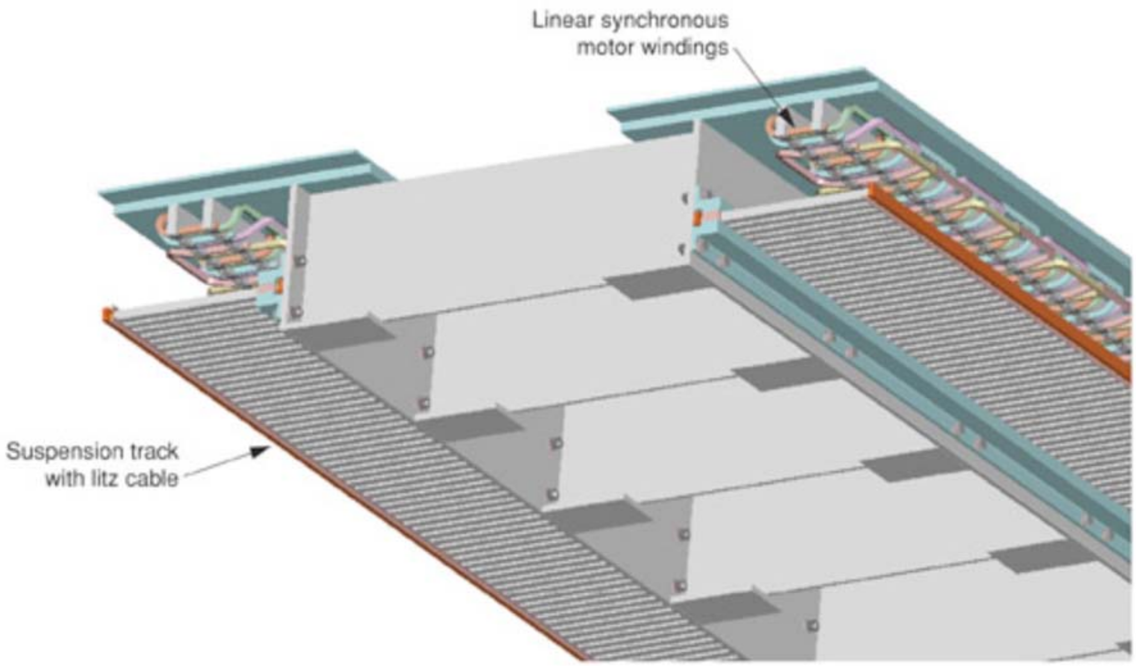
Unlike the German and Japanese maglevs, no on-board power is required to generate Inductrack's levitating magnetic fields because it uses permanent magnets. The permanent magnets also ensure fail-safe operation. If the system were to lose power, the train would remain stably levitated until it slows to walking speeds, at which point it would settle down on auxiliary wheels. Also, the use of permanent-magnet Halbach arrays allows a 2.5-centimeter air gap between them and the levitated train car. Such a large gap has advantages in foul weather and permits the construction of tracks with looser tolerances.

Post says engineers rejected using permanent magnets for maglev systems decades ago because the lifting forces developed by the magnets were not powerful enough relative to their weight. That situation was changed by two developments. First, the theoretical analyses in the 1980s conducted by physicist Klaus Halbach of Lawrence Berkeley National Laboratory resulted in his invention of the Halbach array. Originally intended for use in particle accelerators for focusing and controlling particle beams, the Halbach array is a special configuration of permanent magnets. Each bar is at right angles to adjacent bars so that magnetic field lines combine to produce a strong field below the array and cancel out one another above the array.

Second, at about the same time as the Halbach arrays were conceived, permanent magnets made of an alloy of neodymium, iron, and boron were developed and put into large-scale production for such applications as computer hard drives. Because they have a much higher magnetic field than other permanent magnets, neodymium–iron–boron magnets substantially enhanced the value of Halbach's invention.

Inductrack features a Halbach array of permanent magnets positioned under a train car. The cars ride on a track of ladderlike construction consisting of closely spaced "rungs" composed of tightly packed bundles of insulated wire (litz wire). The conductors of each rung are connected at both ends into a common bus bar, thereby forming an array of shorted circuits. When the train starts to move, the magnets induce electrical currents in the track's circuits. These currents produce a magnetic field that repels the array, thus levitating the train car. This repulsive force lifts the cars 2.5 centimeters or more above the track's surface.

As long as the train is moving above a few kilometers per hour, a bit faster than walking speed, the car will be levitated by the motion-induced currents and their resulting magnetic field. The train will run on auxiliary wheels along rails until it reaches the transition speed, at which point it will begin levitating. If the power suddenly fails, the train cars remain levitated while slowing down to a low speed, at which point the cars come to rest on their wheels.



Schematic of General Atomics' test track showing motor windings embedded in the track. The windings are used with a linear synchronous motor to power and brake the train. Train cars ride on a track of ladderlike construction (suspension track) consisting of closely spaced "rungs" composed of tightly packed bundles of insulated wire (litz wire). When the train starts to move, the magnets induce electrical currents in the track's circuits that produce a magnetic field. This magnetic field repels the array, thus levitating the train car 2.5 centimeters above the track.

Inductrack II Doubles Magnetic Field

After the first Inductrack system was tested, Post introduced Inductrack II, which features dual Halbach arrays straddling the track to nearly double the magnetic field. Inductrack II, which is the design used by the GA urban maglev system, requires half the current to achieve the same levitation force per unit area as that required when using the single-sided Inductrack I configuration, without substantially increasing the weight or footprint area of the Halbach arrays. Inductrack II thus has lower drag forces (higher levitation efficiency) at low speeds than Inductrack I, an important asset for an urban maglev system.

With Inductrack, the train needs only a source of drive power to accelerate it to levitating speed, keep it powered, and provide braking. GA has selected an energy-efficient, linear synchronous motor composed of a separate Halbach array underneath the train car that interacts with motor windings embedded in the track.

Analyses by Post and Dmitri Ryutov at Livermore and colleagues at GA and Carnegie Mellon University show Inductrack has an important advantage over other maglev systems: Its performance can by analyzed theoretically with a high degree of confidence. The theory has been compared against subscale test results and then incorporated in simulation codes. These codes can be used to design full-scale systems without the need for expensive and time-consuming tests and modifications as was the case for German and Japanese demonstration maglev systems.

Theoretical analyses show that, if required by the application, Inductrack systems can be designed to levitate more than 40 metric tons per square meter of Halbach array, with up to 50-to-1 ratio of levitated weight of a train car to magnet weight. These levitation forces are close to the theoretical maximum that can be exerted by permanent magnets. Actual values achieved in a test run at GA are about 30 metric tons per square meter, in close agreement with the theoretically predicted levitation force for the configuration that was tested.

Inductrack's first commercial application is expected to be for an urban train transport system. Other potential applications include intercity high-speed trains, people movers, high-speed intercity shipment of high-value freight in "pods" that would be levitated in evacuated tubes, and maglev-assisted launching of rockets carrying satellites.

While work on the demonstration effort proceeds in San Diego, the Livermore team is optimizing the design of the magnets and the track. In particular, the team is working on a novel laminated track composed of a stack of slotted sheets of copper reinforced by fiber composite. The new design is simpler and should be lower in cost to manufacture than the litz-wire ladder track.

Safer, simpler, and cheaper than other designs, Inductrack increasingly appears to be the right track to the future of urban transportation systems.

Key Words: Halbach array, high-speed train, Inductrack, magnetic levitation (maglev), permanent magnets, urban transportation.

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