Magnetically Levitated Train Takes Flight

SINCE the 1960s, transportation industry planners have sought an energy-efficient design for a train that can glide through air at speeds up to 500 kilometers per hour. This type of train, called a magnetically levitated (maglev) train, is thought to be a viable solution to meet the nation's growing need for intercity and urban transportation networks. However, despite some promising developments, unresolved concerns with the operation and safety of maglev trains has prevented the transition from demonstration model to commercial development.

Inductrack, a maglev system originally conceived by Livermore physicist Richard Post, is designed to address these issues. (See *S&TR*, June 1998, pp. 20–22; November 2003, pp. 14–17.) Post's work on Inductrack began with funding from Livermore's Laboratory Directed Research and Development Program, and in 2003, the technology was licensed to General Atomics (GA) in San Diego for train and transit system applications. This year, members of the Livermore–GA team received an R&D 100 Award for Inductrack's development.

Inductrack uses permanent magnets to produce the magnetic fields that levitate the train and provides economic and operational advantages over other maglev systems. It can be adapted to both high-speed and urban-speed environments. In the event of a power failure, the train slows gradually until it comes to rest on its auxiliary wheels. The maintenance requirements for Inductrack are also lower than they are for other systems, plus it has a short turning radius and is designed for quiet operation.

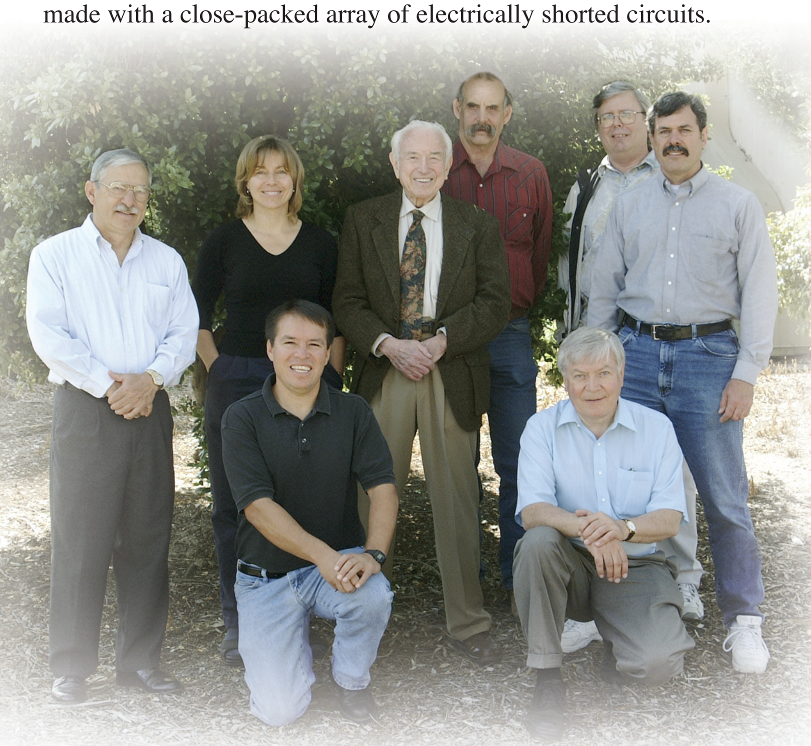
Previous designs for maglev systems did not offer the energy efficiency or safety protections that are in the Inductrack design. Electromagnetic systems (EMS) use powered electromagnets to levitate the train. However, these systems are based on magnetic attraction rather than repulsion and thus are inherently unstable. In EMS trains, the levitation gap—the separation between the magnet pole faces and the iron rail—is only about 10 millimeters and, during operation, must be maintained to within ±1 millimeter. Position sensors and electronic feedback systems are required to control the magnetic current and to compensate for the inherent instability. This requirement, plus the onboard source of emergency power required to ensure operational safety during a sudden power loss, increases the complexity of EMS trains.

In contrast, in electrodynamic systems (EDS), large superconducting magnet coils mounted on the sides of the train generate high-intensity magnetic field poles. Interaction of the current between the coils and the track levitates the train. At operating speeds (above a liftoff speed of about 100 kilometers per hour), the magnetic levitation force balances the weight of the car at a stable position. EDS trains do not require the feedback control systems that EMS trains use to stabilize levitation. However, the superconducting magnetic coils must be kept at temperatures of only 5 kelvins, so costly electrically powered cryogenic equipment is required. Also, passengers, especially those with pacemakers, must be shielded from the high magnetic fields generated by the superconductors.

Levitating by Magnets

Inductrack is classified as an EDS because it achieves levitation when the magnetic fields on the train interact with the conducting circuits in the track. But the similarity with conventional EDS trains ends there. Inductrack is a passive system in that it uses no superconducting magnets or powered electromagnets. Instead, it has an array of permanent room-temperature magnets.

Inductrack's other distinguishing feature is that the track is made with a close-packed array of electrically shorted circuits.



Livermore members of the Inductrack team: (standing, from left) J. Ray Smith, Louann Tung, Richard Post, Don Podesta, William Kent, and Edward Cook; (kneeling, from left) Joel Martinez-Frias and Dmitri Ryutov.

In one design, these circuits form a ladderlike array of "rungs" containing cabled insulated wire. As the train moves over the track, permanent magnets induce a current in the track circuits. This current generates a magnetic field that repels the magnet arrays, causing levitation and inherent stability. As long as the train is moving above a few kilometers per hour—a little faster than walking speed—it is levitated 25 millimeters above the track's surface. Such a large gap allows more leeway than systems that require a narrower gap. This advantage is crucial in foul weather such as wind and rain, which could affect the gap size. It also permits looser tolerances for track specifications than are allowed for the EMS designs.

Previous research teams had rejected permanent magnets for maglev systems because designers believed the magnets would yield too little levitating force relative to their weight. Two developments resolved that problem. In the 1980s, the late Klaus Halbach, a physicist at Lawrence Berkeley National Laboratory, invented the Halbach array to focus accelerator particle beams. In this array, permanent magnets are configured so that the field intensity is concentrated below the array but canceled above it. Post says, "Our use of Klaus's array in Inductrack is a good example of basic research being put to practical use to help meet a national need."

At about the same time, a magnet material was developed using the alloy neodymium–iron–boron. Permanent magnets made with this alloy generate a much higher intrinsic magnetic field than those made with other materials.

Although permanent magnets do not require power to produce a magnetic field, Inductrack uses a power source, such as an electrical drive system or a jet turbine, to accelerate the train until it is levitated and to overcome aerodynamic drag. Unlike other maglev systems, the amount of power needed depends only on the train's weight and its maximum speed.

GA is working with the Federal Transit Administration, a division of the U.S. Department of Transportation, to develop an urban transit system. In 2000, GA chose Inductrack as the best approach for a maglev system and, in May 2003, broke ground in San Diego for a 122-meter test track. GA plans to conduct full-scale tests of Inductrack later this year.

Members of the General Atomics team onboard the full-scale model of Inductrack: (from left) Volus McKenna (standing), Richard Hutsell (face obscured), Dave Doll, In-Kun Kim, Robert Kratz, Karl Kehrer, and Sam Gurol. (McKenna and Kehrer are employees of Hall Industries, which is responsible for the vehicle car body and chassis for this project.)

Improving Performance Even More

Livermore researchers have continued to improve on the system's design. Inductrack II, which uses a dual Halbach array straddling the track, nearly doubles the levitating magnetic field. This design requires half the current used in the single-sided Inductrack I configuration to achieve the same levitation force per unit area, without substantially increasing the weight or footprint area of the Halbach arrays. Thus, Inductrack II has lower drag forces (higher levitation efficiency) at low speeds than Inductrack I, an important asset for an urban maglev system.

The National Aeronautics and Space Administration (NASA) is also considering Inductrack technology for launching rockets. NASA studies have shown that if a large rocket could be accelerated up to about Mach 0.8 before its engines are fired, the amount of rocket fuel used could be reduced 30 to 40 percent. Other potential applications include people movers; spark-free mine cars; and high-speed, intercity freight shipments, where sealed capsules are levitated within 1-meter-diameter underground tubes.

A maglev system using Inductrack may one day provide a more efficient means of high-speed intercity travel. Inductrack's ability to operate on grades and level ground and to make tight (short-radius) turns makes it versatile for intercity or high-speed distant travel. Reduced operation and maintenance costs may soon allow transportation planners to finally reach the long-term goal of an energy-efficient transportation system.

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