Maglev Trains On Permanent Magnets

Forget superconducting maglevs.The humble permanent magnet is the real ticket to 400-mph train travel.

Illustration by Jeff Mangiat

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The Inductrack system could be retrofitted to existing railways. Power would be provided by overhead wiring or, as shown here, on-board diesel generators.

Simple permanent magnets like those you played with as a child could usher in a new era in railroading by providing the first practical and inexpensive maglev (magnetic levitation) train technology. Researchers Dick Post and J. Ray Smith invited Popular Mechanics to the Lawrence Livermore National Laboratory (LLNL) for an exclusive first look at this radically new concept. Called Inductrack, it is the first levitated train to use passive permanent magnets. That's right, permanent magnets. Big brothers–really big brothers–of the ones that hold your kid's artwork on the refrigerator.

PM followed Post and Smith to their sub-basement laboratory–once used for radiation experiments–where they have assembled the first proof-of-concept prototype. "The transition speed, which is the point where the magnetic lifting forces of the train really begin to take off, can be as little as about one mile per hour," Post says as he walks across the floor at a slow, measured pace. "And I'm walking at twice that speed right now." It is a speed that promises to change railroading as dramatically as the switch from steam locomotives to diesel engines.

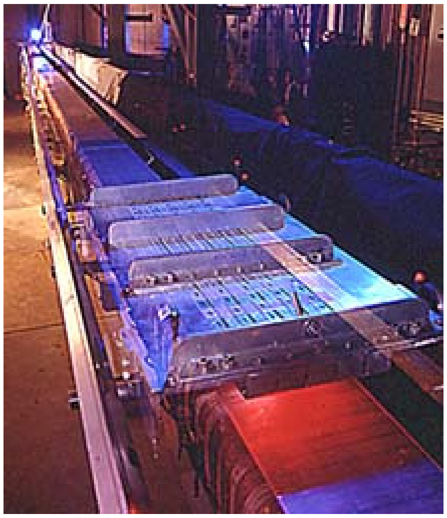
Maglevs are, of course, old news. Prototypes have been in various stages of development in the United States, Germany and Japan for about 20 years (see diagram on page 70). These prototypes work well enough, but maintenance and power are killers–they require too much of both. The problem is not the engineering, but the underlying approach to levitation. Up to now, maglevs have fallen into two general categories, says Smith. One type uses superconducting magnets that lift the vehicle to within a fraction of an inch of a rail guide. Keeping the train airborne and in motion requires accurate feedback circuits and very high tolerances. Post explains that this design tends to be somewhat unstable. "It can be done, but it's expensive and difficult," he says. The other generic type of maglev takes superconducting coils and runs their magnetic field past a conductive plate to achieve levitation force. Inductrack has some similarities, but its inventors stress that it has higher lifting efficiency relative to the drag forces.

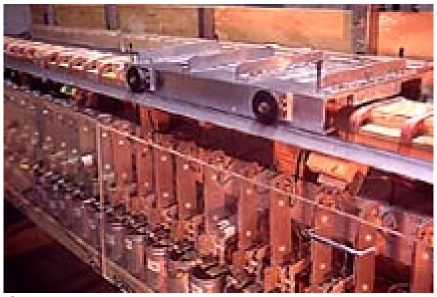
Inductrack's other big advantage is that it eliminates superconducting coils and their attendant ultralow temperature cooling systems, which are very expensive to operate. Inductrack is simplicity itself. It consists of unpowered, passive magnet arrays attached under a vehicle, and a track guideway with metallic, nonmagnetic inductive coils embedded in its surface. The train rests on auxiliary wheels when it is stopped. Ordinary train motors bring it to a speed approximating a brisk walk. At this point, the magnets and inductive coils repel each other. The train begins to float. Energized coils make the track function like a linear motor, providing both acceleration and braking–the latter by flowing energy back into the mains, or, say, into batteries or flywheels. If the drive power fails, the Inductrack system is fail-safe: It would merely slow down and settle back a few inches on its wheels at a low speed.

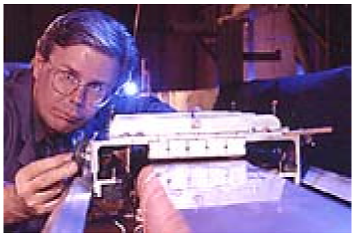
Obviously you can't levitate a train with just any magnet. Inductrack uses a permanent magnet design known as a Halbach array. These arrays were pioneered by physicist Klaus Halbach for use in particle accelerators. The uniquely efficient arrays of permanent magnet materials concentrate the magnetic field on one face of the array, while nearly canceling it on the opposite side.

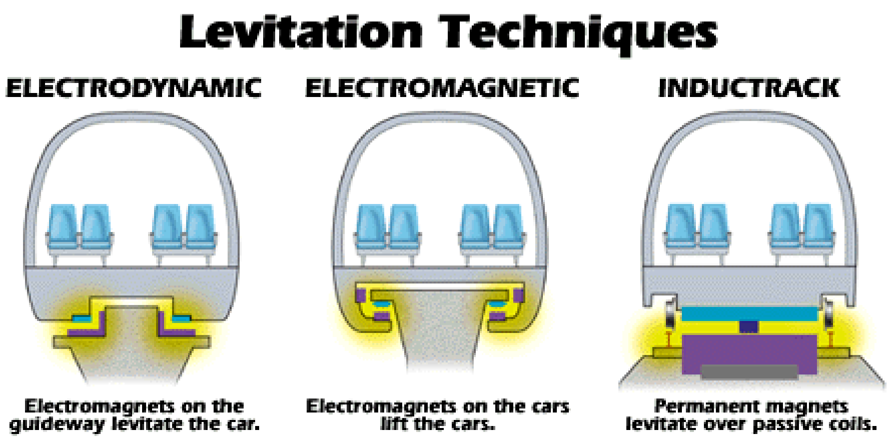
When mounted on a moving cradle–say, the bottom of a railcar–and passed over passive coils on a rail track, the Halbach arrays generate a periodically varying magnetic field that induces currents in the closely packed track circuits. When made from modern permanent magnet materials, 50 pounds of load can be lifted with 1 pound of magnet. "That's far better lifting force with much less drag than the ones that use superconducting coils and a plate of conducting material," says Post. He points out that at high speeds the Inductrack has up to 10 times the lift force relative to its electromagnetic drag force compared to the lift of a modern jet aircraft wing relative to its aerodynamic drag force.

In addition to its high performance potential, the unusual properties of the Halbach array magnetic field offer other tangible benefits for passenger train application. "That field is concentrated at the lower surface of those magnets and it's virtually zero above those magnets," explains Post. "So you don't have to worry about the passengers if they're concerned about a magnetic field at all. Whereas if you have big superconducting coils, that makes quite a magnetic field you'd have to shield your passengers against."


A proof-of-concept model of an Inductrack train rises to the occasion during a test at the Lawrence Livermore National Laboratory.


Coils create a magnetic field as the car speeds past.


The scale model needs to achieve higher takeoff speeds than a full-size train.



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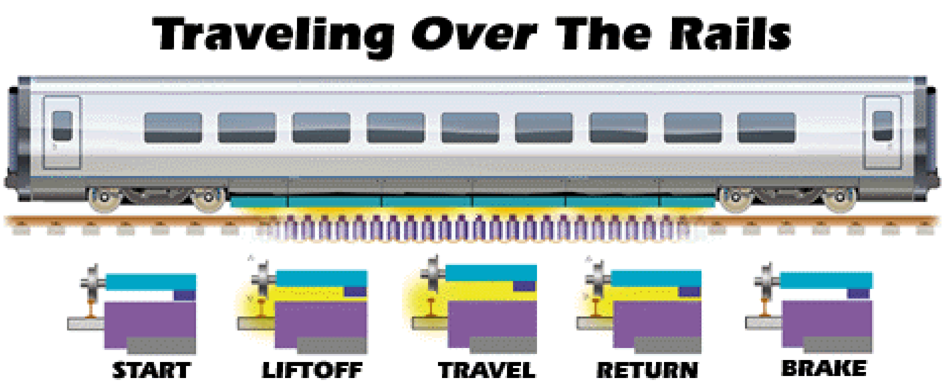
The proof-of-concept prototype for Inductrack consists of a 60-ft. wooden guide rail wrapped with approximately 1000 inductive wire coils. Each of the rectangular coils is about 7 in. wide x 4 in. high. They are shorted together to form a circuit with no outside electric connection. It is the passage of the cart with its Halbach arrays that induces current in the coils which then produce the levitating force.

Another advantage of Inductrack is that it can use powerplants already in use. "You can think of areas where moving trains all electrically makes the most sense, like the BART [Bay Area Rapid Transit] trains," Smith said. "You would certainly do those electrically. But if you were going cross country on a high-speed system, maybe the initial phases wouldn't be all electric. Maybe that would be magnetic levitation with the Inductrack principle, using a gas turbine to drive it."

As Bill Kent, the LLNL mechanical technician who helped build the model, prepares to "launch" a 48-pound model cart at the far end of the rail, Smith explains that the transition speed varies inversely with the size of the vehicle. For this reason, the proof-of-concept model needs to attain a higher transition speed than will an actual train. Magnetic levitation occurs when the vehicle reaches transition speed. At this point, the two Halbach arrays on the bottom of the car provide levitation and one on each side create lateral stability.

The demonstration confirms what the calculations have already predicted. Before transition speed is reached, the electromagnetic currents are out of phase, resulting in considerable drag on the vehicle. This drag becomes apparent when the car is pushed by hand. Pushed slowly, it rolls freely on its wheels. Pushed faster, the currents begin to create drag. Below the transition speed, the harder the push, the greater the drag, while above the transition speed, the opposite holds: The higher the speed, the lower the electromagnetic drag force. The lab model needs to reach about 22 mph before it transitions off its wheels and levitates. Post believes an actual train could transition at speeds as low as 1 to 2 mph. To get its model moving fast enough, the LLNL team has rigged up a 3:1 pulley system energized by the gravitation tug on a bucket of bricks dropped from the main floor. "Archimedes would have been proud," Smith jokes.

Since PM visited the lab, the researchers have replaced the gravity drive with an electromagnetic drive using condensers and pulsed drive coils. The laboratory and the Department of Energy were sufficiently impressed by Inductrack to invest about $500,000 in the project over the past three years. Smith and Post are currently awaiting word on followup funding that would enable them to collect data for planning a commercial-scale system. In the meantime, their novel approach to maglev has caught the eye of a government agency not known for its interest in railroading: NASA. The space agency has given the researchers a $1.5 million contract to build a model high-speed Inductrack. The idea is that NASA would use a scaled-up version to help launch satellites. The tracks would run up a ramp, accelerating a rocket to near Mach 1 before its main engines fired. Post and Smith say this application is well within the limits of Inductrack, making it truly a track to the future.



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