MAGNETIC LEVITATION VEHICLES

Submitted to

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INTRODUCTION

Magnetic levitation, or “maglev,” is a technology used for high-speed trains in which the vehicle is lifted from the roadway or “guideway” by a magnetic field. Propulsion is by means of a moving magnetic field. This paper discusses the development of magnetic levitation vehicles in Germany, Japan, and the United States.

BACKGROUND

The first patent for a magnetically levitated vehicle was granted in 1968 to U.S. scientists Gordon Danby and James Powell [1]. Funding for their project lasted only a few years, allowing Japan and Germany to take the lead in maglev development. U.S. interest was revived in the 1980s but funding was lost around 1992. Interest in maglev transportation is again on the rise in the U.S. as evidenced by a recent $1 billion appropriation bill. $55 million is designated for feasibility studies in 1999. This sum will be divided among five project teams presenting the best proposals. Based on the results of these studies, the Department of Transportation will designate one project eligible for $950 million in funding [2].

THE GERMAN SYSTEM

In 1979, the German Ministry of Research and Technology produced the Transrapid International TR05, the first magnetic levitation vehicle licensed to carry passengers. In 1988, the model TR06 (see Figure 1) set a speed record of 257 mph. In 1989 a prototype commercial service vehicle, the TR07, set a new speed record of 271 mph. The Transrapid vehicle frame wraps around the guideway and the car is levitated by magnetic attraction to the underside of the guideway. A closed-loop control system maintains a clearance of 3/8” from the guideway. The power for levitation is supplied by on-board batteries charged by linear generators. Propulsion is by syncronous linear induction using active long-stator coils mounted on the guideway, and passive rotors on board [3, p. 2; 4, p. 87].

Advantages of the Transrapid maglev system are low power requirements, magnets that do not require supercooling, relatively simple guideway construction, and derailment-proof design.

Disadvantages are the small guideway to vehicle clearance and high vehicle weight. The small guideway clearance complicates guideway construction and increases the possibility of guideway contact at high speeds or in windy conditions [5, p. 12].

Figure 1. Trial run of the Transrapid TR06, near Lingen, Germany [9]

A 20-mile long test route is in operation where passengers pay $15 and wait up to a year to take a 250 mph maglev ride [6]. There are currently plans to build a maglev system to connect Berlin and Hamburg. The cities are 180 miles apart; travel time will be one hour. The cost of the project is projected to be $5.5 billion [7; 8].

THE JAPANESE SYSTEMS

Japan has two principle maglev development projects. The Yamanashi system uses on-board superconducting electromagnets and a guideway with coils in the base and the side beams [10, p.56]. The HSST system is similar to the German Transrapid system.

HSST Development Corp.

Japan Airlines initiated the High Speed Surface Transport (HSST) project in 1974. JAL was seeking a solution to the problem of transporting airline passengers between large urban areas and distant airports. In 1975, JAL began testing the HSST-01, a two-passenger magnetic levitation vehicle, which achieved a speed of 191 mph. The next model, the HSST-02, was an eight-passenger vehicle. The 50-seat HSST-03 carried passengers at the Tsukuba Science Expo in 1985, and at the Vancouver Transportation Expo in 1986. It continues to operate near Nagoya as a tourist attraction [11; 12, p. 80].

The HSST Development Corporation was formed in 1985. In 1987, the HSST-04, a 70-seat model, was built. It operated at the 1988 Saitama Expo near Tokyo. The first commercial service began in 1989 at the Yokohama Expo with the HSST-05, a 158-seat, two-car train (see

Figure 2). From March to October, 1.26 million passengers were carried. The planned HSST-200 will use the HSST-05 as its two end cars with additional cars in the middle. Maximum operating speed for the HSST-05/HSST-200 is 143 mph [11; 12, p. 80-82].

Figure 2. HSST-05 [11, p. 82]

The HSSTs use attraction levitation and linear induction motor (LIM) propulsion. The stationary rotor on the guideway consists of an aluminum reaction plate located on top of the steel track. Tractive force is induced in the aluminum plate by a traveling magnetic field provided by 3-phase short stator coils on board the vehicle. 280 VDC power for levitation is picked up by conductors under the track. Closed loop sensors maintain lateral stability and a 3/8" vertical air gap. Braking is by LIM regeneration and hydraulically-actuated brake shoes on guideway rails [12, pp. 80-82].

Advantages of the HSST system are low power requirements, non-superconducting magnets, relatively simple guideway construction, and derailment-proof design. Disadvantages are higher weight, dependence on electrical guideway contacts for onboard power, and limited speed due to the close tolerances of the guideway [12, pp. 80-82].

Yamanashi Maglev

Yamanashi systems use onboard superconducting magnets to perform the functions of levitation, guidance, propulsion, and braking. The magnets are cooled by liquid helium and liquid nitrogen as shown in Figure 3. They employ an onboard helium re-liquefaction system. In 1989, Yamanashi Maglev added an aerodynamic braking system in their MLU001, consisting of large spoilers hinged on the roof of the vehicle. Figure 4 shows the model MLU002N with

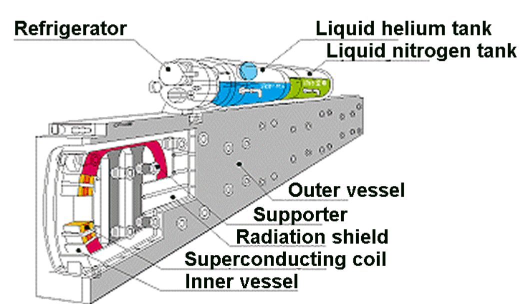

Figure 3. Yamanashi Superconducting Magnet [13]

aerodynamic brakes deployed. The MLU002N achieved a speed of 268 mph in 1994. Yamanashi vehicles are operated on a 26.6-mile test line between Sakaigawa and Akiyama, Japan [14].

Figure 4. Yamanashi MLU002N with aerodynamic brakes deployed [13]

The Yamanashi guideway employs coils in the sidewalls and base, which complicates train switching, increases construction expense, and creates problems in shielding occupants from magnetic fields. Figure 5 shows the test line guideway [13].

Yamanashi engineers are exploring three methods of guideway construction, all of which employ levitation and propulsion coils mounted in concrete sidewalls as shown in Figures 5 and 6.

1 Beam Method - Sidewalls are cast concrete with coils installed at the factory. Figure 6 shown a diagram of this method.
2 Panel Method - Coils are installed after installation of the concrete sidewalls.
3 Direct-Attachment Method - Concrete sidewall is produced and fitted with coils onsite [15].

All methods are been shown to provide 4mm vertical and horizontal coil-location accuracy. This accuracy is required to achieve a smooth ride [16].

Figure 5. Yamanashi test line guideway [13]

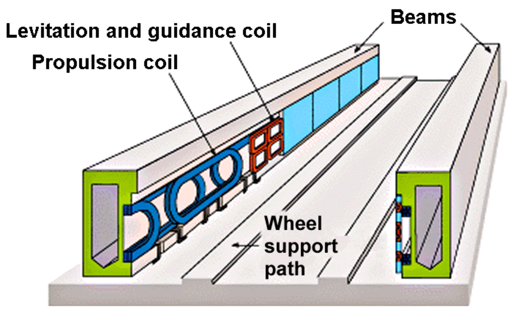

Figure 6. Yamanashi beam method of guideway construction [13]

U. S. INITIATIVES

The U. S. government has allocated $55 million for pre-construction planning activities of maglev systems. Funds will be awarded to five selected project groups. Application deadline is December 31, 1998 [2; 7].

The National Maglev Initiative, a coalition of the Department of Transportation, the U.S. Army Corps of Engineers, and the Department of Energy, found that "maglev technology has been demonstrated as a technically feasible transportation system and could be deployed with reasonable risk" [17].

The *"Inductrac" System*

The Lawrence Livermore National Laboratory near San Francisco is developing the "Inductrac" system which uses permanent magnets for levitation. The train rests on wheels when stationary, but when in motion, permanent magnets on the vehicle induce current in passive coils mounted in the guideway to provide levitation. This levitation comes at the expense of electromagnetic drag, yet the lift-to-drag ratio at high speeds is up to 10 times better than that of a modern jetliner. The permanent magnets can lift 50 times their own weight. The Inductrac system eliminates the need for heavy and expensive superconducting coils used in repulsive levitation, or the complicated feedback circuits used in attractive levitation. Forward motion is provided by powered coils mounted between the levitation coils in the guideway. The powered coils do no interfere with levitation [18, p. 7; 19].

The configuration of rare-earth cobalt magnets, called a Halbach array, concentrates the magnetic field on one side of the array as shown in Figure 7. Magnetic field strength is $\sqrt{2}$ times greater than a conventional ironless array of the same volume. The squares in Figure 7 represent magnets, with arrows showing

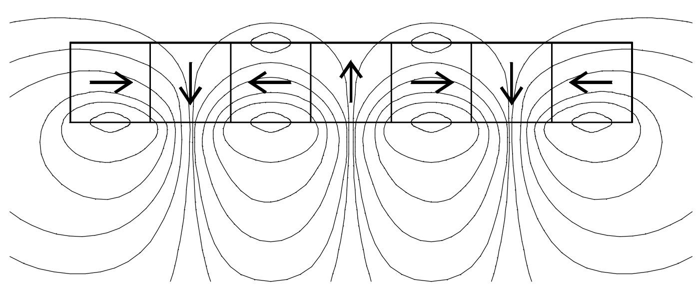

Figure 7. Halbach array [19]

magnetic field direction. The Halbach array was developed by physicist Klaus Halbach for use as an optical element in particle accelerators. Virtually all of the magnetic field is concentrated on one side of the array. This makes the Halbach array, using either permanent magnets or electromagnets, suited for maglev applications where powerful magnetic fields are required beneath the vehicle while passengers must be shielded [20, p. 9; 21, p. 376].

In the Inductrac system, the permanent magnets beneath the vehicle produce both horizontally-aligned and vertically-aligned magnetic fields. The horizontally-aligned field reacts with passive coils in the guideway to provide levitation, while the vertically-aligned field reacts with the powered coils in the guideway to provide locomotion. A small proof-of-concept model, pictured in Figures 8 and 9, showed the ability to levitate at 22 mph. Researchers believe the effect will be more easily produced in a full-sized vehicle, with levitation occurring at speeds as low as one mph. The research team plans to test the concept with a larger scale model. NASA has also shown interest in this technology to provide initial acceleration for rockets launching satellites. [18, p. 7; 19].

Advantages of the Inductrac system are low weight, low power requirements, and absence of on-board electromagnets. Its disadvantage is its early development status. The lack of control over levitation, and the possible complications of varying load conditions and wind effects do not appear to have been explored.

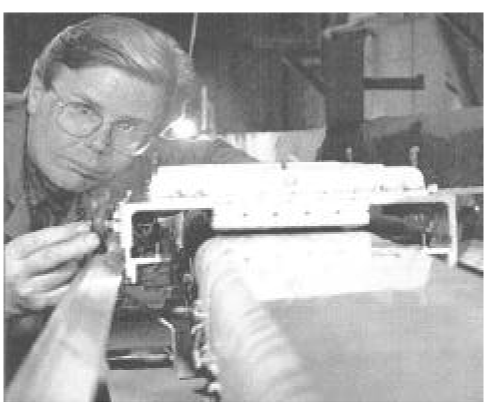

Figure 8. Inductrac test model on its guideway at the Lawrence Livermore National Laboratory [18, p. 71]

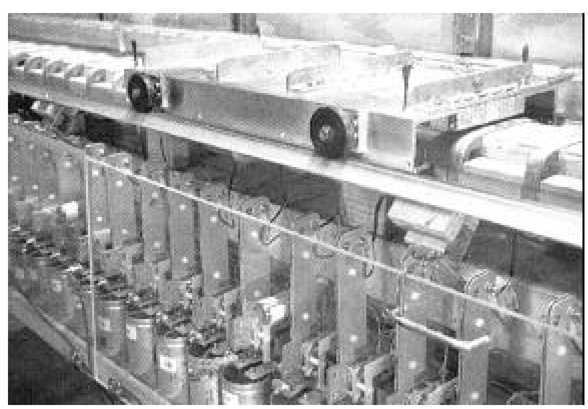

Figure 9. Inductrac laboratory test model levitates at 22 mph using permanent magnets on the car and passive coils in the guideway [18, p. 70]

Maglev 2000 of Florida Corp.

At Maglev 2000 of Florida Corp., Dr. James Powell, Dr. Gordon Danby, and associates are designing a maglev train using repulsion levitation and on-board superconducting coils. Powell and Danby pioneered the use of superconductors in maglev vehicles in 1966. Although this is the same method that the Yamanashi vehicle uses, Maglev 2000 claims to have a more economical system. They plan to construct a test model and 70 feet of guideway at the Space Center Executive Airport in Titusville, Florida, under a $2 million grant from the State of Florida. Maglev 2000 calls its system the American Maglev Star (AMS) [22; 23; 24].

CONCLUSIONS

Even though three maglev train designs have been developed to commercial readiness, we have yet to see any maglev systems in continuous commercial operation. Obstacles to commercial use of the maglev trains include

- Expense, especially in guideway construction
- Existence of conventional high-speed rail systems, such as the French TGV
- Health concerns regarding exposure to electromagnetic fields
- Absence of a commercially successful example to reassure investors
- Possibility of selecting a guideway design that will be incompatible with future systems

It appears that maglev transportation will not become popular without further government funding and additional advances in technology. The Japanese and German systems were developed at considerable government expense, but still lack a clear commercial advantage over conventional high-speed rail. The Inductrac technology shows promise but will require a long and expensive development period before it can be evaluated as a candidate for commercial use. With the recent $1 billion commitment to maglev research and development by the U.S. Government, there is renewed hope for magnetic levitation transportation.

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