Magnetic Levitation Space Propulsion

I. <u>Introduction To Maglev Technology And Application</u>

1.1 Principle of Maglev System

Maglev is a system in which the vehicle runs levitated from the guideway (corresponding to the rail tracks of conventional railways) by using electromagnetic forces between superconducting magnets on board the vehicle and coils on the ground. The following is a general explanation of the principle of Maglev.

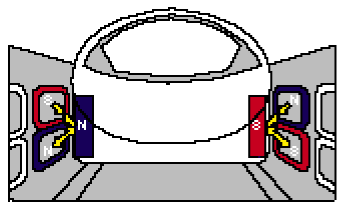

fig. 1.1

1.1.1 Magnetic Levitation

The "8" figured levitation coils are installed on the sidewalls of the guideway. When the on-board superconducting magnets pass at a high speed about several centimeters below the center of these coils, an electric current is induced within the coils, which then act as electromagnets temporarily. As a result, there are forces which push the superconducting magnet upwards and ones which pull them upwards simultaneously, thereby levitating the Maglev vehicle.

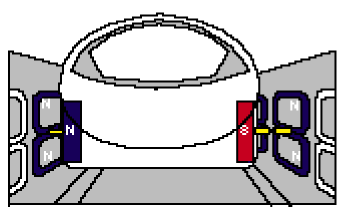

fig. 1.2

1.1.2 Lateral Guidance

The levitation coils facing each other are connected under the guideway, constituting a loop. When a running Maglev vehicle, that is a superconducting magnet, displaces laterally, an electric current is induced in the loop, resulting in a repulsive force acting on the levitation coils of the side near the car and an attractive force acting on the levitation coils of the side farther apart from the car. Thus, a running car is always located at the center of the guideway.

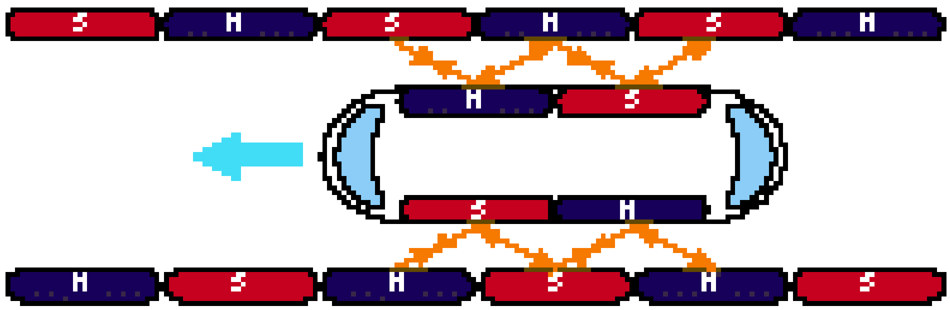

fig. 1.3

1.1.3 Propulsion

A repulsive force and an attractive force induced between the magnets are used to propel the vehicle (superconducting magnet). The propulsion coils located on the sidewalls on both sides of the guideway are energized by a three-phase alternating current from a substation, creating a shifting magnetic field on the guideway. The on-board superconducting magnets are attracted and pushed by the shifting field, propelling the Maglev vehicle.

1.1.4 Floatation

The electrodynamics, repulsion-type maglev system, originally patented by American scientists in the 1960s, is the focus of the development program of the Japan Railway Technical Research Institute. In this approach, levitation magnets on the top of a guideway or as is the case with present Japanese prototype designs, in the guideway sidewalls push away superconducting magnets grouped underneath or at the bottom sides of the vehicles. Linear synchronous propulsion coils in the guideway propel the vehicles. This type of system allows for a large air gap (about 15 cm) between opposing magnets. In the electromagnetic, or attraction-type, Maglev developed by Transrapid International in Germany, conventional iron-core magnets in the vehicle's wraparound arms are pulled up to magnets under the guideway. A relatively small air gap (1 cm) separates the vehicle and guideway magnets. Although not part of the present Transrapid design, superconducting magnets can be incorporated in attraction-type Maglev systems.

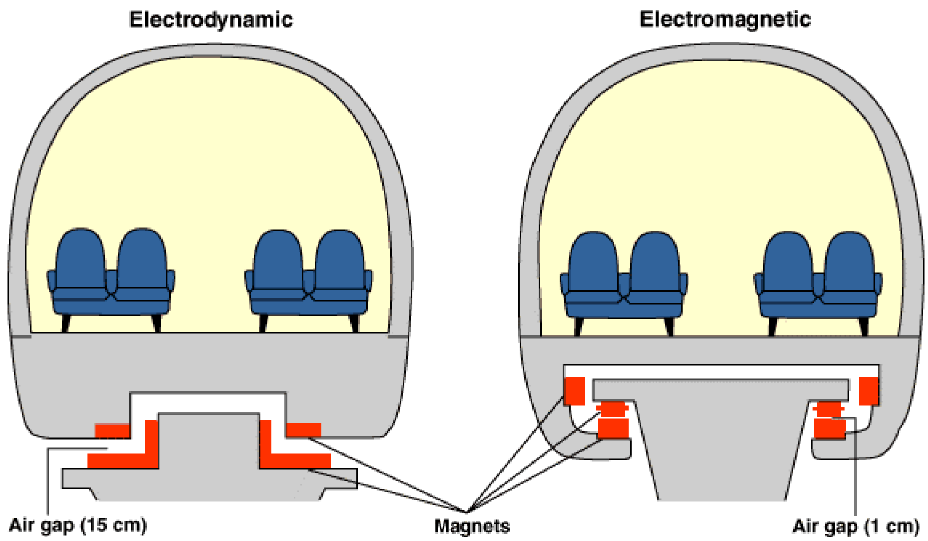

fig. 2.1

1.1.5 Maglev Technology Some Facts

Q. How does low-speed Maglev technology work?
A. Maglev technology employs powerful superconducting magnets to levitate or "float" cars about 2 inches above a guideway. Liquid helium in a special encasement cools the magnets to near absolute zero (or about -400 degrees Fahrenheit), enabling relatively small magnets to create very powerful fields.
Linear induction motors using magnetic fields propel the cars. Such motors are already adapted to transit, such as in Vancouver's automated SkyTrain Light Rail system.
Electrodynamics involving the interaction of electrical currents and magnetic forces, state-of-art computers and microprocessors maintain guidance (vertical and horizontal spacing) during travel. Low-speed Maglev travels up to 60 mph. In Pittsburgh's case, top speed will be about 40 mph.

Q. Why do the superconducting magnets have to be super-cooled?
A. It's a matter of complex physics. But by bathing superconducting magnetic coils in liquid helium, a refrigerant, scientists can create large magnetic fields that produce no electrical resistance – they don't lose power and they use very little energy. "It happens almost like magic," one scientist said.

Q. Does low-speed Maglev have advantages over light rail or a rubber-tire "people mover" system?
A. Supporters cite lower capital costs, lower operating costs, tight turning capabilities, virtually no noise pollution, smooth rides because levitated vehicles create no friction, less intrusion on land and an opportunity to showcase the city and establish it as world leader of transit technology.

Critics of the Pittsburgh project are questioning the use of public money, the philosophy of building the largest parking garage in Pittsburgh near Downtown rather than on the outskirts, competing with the Port Authority for funds and riders and whether any short transit system to the Civic Arena serves a worthwhile purpose.

Q. What happens if I'm aboard the Civic Arena Maglev shuttle and it breaks down?
A. If there's a real emergency, riders could open car doors manually to reach a combination emergency/maintenance walkway between the parallel Maglev "tracks."
The Maglev plan proposes using a customized tow vehicle in case a car dies because of lost power or a mechanical problem. It could go out on the track to push or tow a crippled car. Meanwhile, Maglev would maintain service on the opposite track.
Maglev cars are to contain recessed emergency wheels, so if the cars lose their levitation, they can still ride on the guideway. Plans for the Civic Arena showcase project call for building a third Maglev car to use as a spare.

Q. Will ice and snow cause operating problems?
A. Not likely. Ice and snow don't affect superconducting magnets or linear induction motors. The guideway will be designed with angles so most snow falls off or through holes that also allow natural light to penetrate below. If there's an accumulation of snow, the tow vehicle mentioned above can be equipped with a snowplow and a rotating broom to clear the path.

Q. How does Maglev collect its power?
A. Just as a light rail vehicle uses a Z-shaped pantograph to collect electricity from overhead wires and transfer it to the car, Maglev will use an arm like device to collect power from a small "power rail" incorporated into guideway construction. Lower voltage power used for car doors, lights, heating, ventilating and air conditioning is created through the use of transformers.

Q. What impact will the low-speed Maglev guideway have on the city landscape?
A. Since low-speed Maglev cars are one-sixth the weight of high-speed Maglev and since magnetic coils don't have to be imbedded in the guideway, the much lighter elevated dual guideway can be built on T-shaped concrete columns 3 feet in diameter.
Columns would be up to 120 feet apart on a straightaway. They could be built within the area of a single parking space if the elevated system were to be built on a busy street such as Fifth Avenue. That is partly why supporters say Maglev would be a perfect fit in Oakland.

1.2 Maglev: Launching Rockets Using a Magnet

A magnetic levitation track is up and running at NASA’s Marshall Space Flight Center in Huntsville, Ala. The experimental track is installed inside a high-bay facility at the Marshall Center. Marshall’s Advanced Space Transportation Program is developing magnetic levitation or Maglev technologies that could give a space launch vehicle a "running start" to break free from Earth’s gravity.

1.2.1 Principle of Maglev Space Propulsion

A Maglev launch system would use magnetic fields to levitate and accelerate a vehicle along a track at speeds up to 600 mph. The vehicle would shift to rocket engines for launch to orbit. Maglev systems could dramatically reduce the cost of getting to space because they’re powered by electricity, an inexpensive energy source that stays on the ground — unlike rocket fuel that adds weight and cost to a launch vehicle.

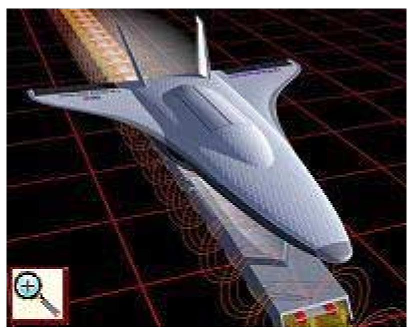

Fig. 5.1

1.2.2 The Experimental Track

The Foster-Miller experimental track accelerates a carrier to 57 mph at its peak traveling 22 feet in 1/4 second, the equivalent of 10 times the acceleration of gravity. The tabletop track is 44 feet long, with 22 feet of powered acceleration and 22 feet of passive braking. A 10-pound carrier with permanent magnets on its sides swiftly glides by copper coils, producing a levitation force. The track uses a linear synchronous motor, which means the track is synchronized to turn the coils on just before the carrier comes in contact with them, and off once the carrier passes. Sensors are positioned on the side of the track to determine the carrier’s position so the appropriate drive coils can be energized. Engineers are conducting tests on the indoor track and a 50-foot outdoor Maglev track installed at Marshall last September by NASA and industry partner PRT Advanced Maglev Systems Inc. of Park Forest, Ill. The testing is expected to help engineers better understand Maglev vehicle dynamics, the interface between a carrier and its launch vehicle and how to separate the vehicle from the carrier for launch. **Future work on large systems will be led by NASA’s Kennedy Space Center, Fla.**

Rockets of the future might be launched using a Magnetic Levitation (Maglev) launch track similar to the test track recently built at NASA's Marshall Space Flight Center in Huntsville, Alabama.

1.2.3 Magnetic Space Propulsion and its Advantages

A Maglev system uses magnetic fields to levitate and accelerate a vehicle along a track. Similar systems are in use today as high-speed trains and some of the newer, radical-ride roller coasters. Maglev systems use high-strength electro-magnets to lift a vehicle a few inches above a track and then propel it forward with high acceleration.
By using a Maglev for launching, the spacecraft would be accelerated up to speeds of 600 mph (965 kph) without using any on-board fuel. When the spacecraft nears the end of the track, it could take off like an airplane and then switch to more conventional rocket engines to continue to orbit.
Sherry Buschmann, manager of Marshall's launch technologies says, "The weight of propellant is a major culprit in the high cost of conventional rocket launches. But because Maglev uses off-board electricity for launch assist, the weight of the vehicle at liftoff is about 20% less than a typical rocket." This makes getting to space less expensive. Sherry says, "Each launch using a full-scale Maglev track would consume only about $75 worth of electricity."

fig. 5.2

1.2.4 The Test Track at Marshall Space Center

The test track at Marshall, which is 50 feet (15 meters) long, about 2 feet (0.6 meters) wide and about 1.5 feet (0.5 meter) high, is mounted on concrete pedestals. It consists of 10 identical, 5-foot-long (1.5 meter) segments that weigh about 500 pounds each. Most of the weight is iron used in the motor. The track is shrouded with nonmagnetic stainless steel.

Some time in future, a larger 400-foot (122 meter) track will be installed at Marshall. "Now, with larger-scale experiments, we want to demonstrate that control can be maintained at high speeds along the Maglev track. To limit energy use, we are evaluating methods for distributing power to small sections of the track at a time," said Bill Jacobs, Maglev lead engineer at Marshall.
Through demonstrations on Marshall Center's track, NASA seeks to learn more about aerodynamics, magnetic fields, and energy storage devices associated with Maglev.

1.3 Necessity of Advanced Propulsion

1.3.1 Scope

One might be inclined to wonder why advanced propulsion is necessary. Current propulsion systems seem to be adequate, safe, and relatively reliable. But what of the future? Advanced propulsion is becoming a necessity, for both economic reasons and mission requirements.

Advances in propulsion systems will ultimately reduce the cost of launching payloads into orbit. They will also reduce the propulsion system mass for satellite orbit maintenance and attitude control will be easier to maintain for extended periods of time, and reduce the cost of Low Earth orbit (LEO) to geosynchronous Earth orbit (GEO) orbit transfers. Advanced propulsion will extend our ability to explore the solar system and ultimately, enable interstellar missions.

1.3.2 Future Technology

Advanced Electric Propulsion
Micro-Propulsion
Propellant Production From Extraterrestrial Resources
Solar Sails
High Power Electric Propulsion
Fusion/Fission Antimatter
BreakThrough Physics

1.3.3 Future Missions

Planetary Orbit Raising
Planetary Micro- Spacecraft
Mars Sample Return
Deep space Planetary, Mars Cargo
Lunar, Mars Cargo
Fast piloted Mars, Interstellar
Interstellar

1.3.4 Facts

Current Launch Costs more than $10,000/kg to LEO and more than $60,000/kg to GEO with Existing Launch Vehicles. Contemporary launch vehicles have launch costs of $10,000 to $20,000 per kilogram of net payload to low Earth orbit (LEO) and $60,000 to $120,000 per kilogram of net payload to geosynchronous Earth orbit (GEO). NASA has initiated two activities aimed at identifying technologies and systems capable of producing dramatic reductions in launch costs. The Highly Reusable Space Transportation Systems (HRST) study goal is $200-400/kg to LEO (a factor of 50 reduction from current systems); the Affordable In-Space Transportation (AIST) study goal is $2,000-4,000/kg to GEO (a factor of 30 reductions).

Future Missions Will Require High Specific Energy and High Exhaust Velocity Propulsion Systems. Launch from the surface of the Earth to low Earth orbit (LEO) and return is just barely within the capability of conventional chemical propellant single-stage-to-orbit (SSTO) launch vehicles. However, an SSTO launched from Earth directly to geosynchronous Earth orbit (GEO) would require a high energy density matter (HEDM) chemical propellant. Ambitious missions of the next century, such as interstellar precursor missions out to 1,000 astronomical units (AU) in 50 years, and fast, 60-day round trip Mars missions, will require mission velocities on the order of 100 to 1,000 km/s, which are a factor of 10-100 greater than current mission requirements. A flyby mission to Alpha Centauri in 50 years requires a velocity of 30,000 km/s (one-tenth the speed of light, c). Because the optimum exhaust velocity is typically on the order of the mission velocity, and the specific energy required increases exponentially with mission velocity, these missions are well beyond the reach of chemical propulsion systems.

1.3.5 Research Objectives

- Significantly improve safety and cost of space transportation
- Reusable space shuttles
- Reduce trip time for in-space missions
- Enable new missions

Scope of potential mission applications include Earth to orbit, In-space transfers, Interplanetary, and Interstellar precursors.

II. Applications Of Maglev

2.1 Trains

While Maglev transportation was first proposed more than a century ago, the first publicly used Maglev trains will not debut until at least 2005. Germany and Japan are at the forefront of Maglev train technology and both are currently testing prototypes of their Maglev trains. Although based on similar technology the German and Japanese trains have distinct differences.

2.1.1 Different Technologies

In Germany, engineers are building an electromagnetic suspension (EMS) system, called Transrapid. In this system, the bottom of the train wraps around a steel guideway. Electromagnets attached to the train's undercarriage are directed up toward the guideway, which levitates the train about one-third of an inch (1 cm) above the guideway and keeps the train levitated even when it's not moving. Other guidance magnets embedded in the trains body keep it stable during travel. Germany has demonstrated that the Transrapid maglev train can reach 300 mph with people on board.

Japanese engineers are developing a competing version of Maglev trains that use an electrodynamics suspension (EDS) system, which is based on the repelling force of magnets. The key difference between Japanese and Germany Maglev trains is that the Japanese trains use super-cooled superconducting electromagnets. These kinds of electromagnets can conduct electricity even after the power supply has been shut off. In the EMS system, which uses standard electromagnets, the coils only conduct electricity when a power supply is present. By chilling the coils at frigid temperatures, Japan's system saves energy.

Another difference between the systems is that the Japanese trains levitate nearly 4 inches (10 cm) above the guideway. One potential drawback in using the EDS system is that Maglev trains must roll on rubber tires until they reach a liftoff speed of about 62 mph (100 kph). Japanese engineers say the wheels are an advantage if a power failure caused a shutdown of the system. Germany's Transrapid train is equipped with an emergency battery power supply.

2.1.2 Industry Update

Despite American interest in Maglev trains over the past few decades, the expense of building a Maglev transportation system has been prohibitive. Estimated costs for building a Maglev train system in the United States range from $10 million to $30 million per mile. However, the development of room temperature superconducting supermagnets could lower the costs of such a system. Room temperature semiconductors would be able to generate equally fast speeds with less energy.

2.2 The Florida Maglev Project

2.2.1 Florida Maglev Deployment Planning/Design

Leading-edge American scientific and practical know-how are once again being joined together on the Space Coast of East Central Florida to open new horizons. It is time to embrace the transportation "mode of the future" and decisively pull it into the present. This reach to the future has succeeded before right here, where our space program was born.
About the time of the Gemini and Apollo programs, Drs. James Powell and Gordon Danby invented the magnetic levitation transportation system that would use repelling superconducting magnets to move vehicles quietly and efficiently along a guideway at over 380 km/h (240 mph). Years later, the Japanese advanced these design breakthroughs further and are now building the maglev system that will supplement their bullet trains with an even faster 300 mph connection.

MAGLEV 2000 of Florida Corporation, in partnership with Florida Department of Transportation and other agencies, is currently validating the next generation of the Danby-Powell Maglev Technology at Titusville's Space Coast Regional Airport.

The Federal Railroad Administration (FRA) has also selected the MAGLEV 2000 technology to connect the Space Coast Regional Airport to Port Canaveral via the Kennedy Space Center Visitors Center as one of seven candidate projects for its current Maglev Deployment Program.

Up to now, Maglev technology has been limited to test tracks in opposite parts of the world. Germany built a test track to showcase a different Maglev technology and is participating in FRA deployment studies in other states. The Central Japan Railway Company is conducting full-scale tests along pats of its new mountain tunnel route, as mentioned above, using the Danby-Powell Maglev principles. But the Maglev 2000 system represents a second generation of Maglev development, an all-American application designed to meet specific American challenges. The sheer distances of this country and the spread-out living patterns of America call for a transportation system that is fast, reliable, economical to build, easy to operate and maintain and capable of hauling heavy freight.

2.2.2 Public/Private Partnership

A hallmark of the FRA Maglev Deployment Program is the close cooperation of the public and private sectors in the high-tech startup of maglev development and operation.

The FRA expects that its federal investment will contribute not just to the construction of a single project. Rather they also wish to support the development of a unique body of knowledge and expertise that will launch a new American industry for domestic infrastructure renewal and global export opportunities.

MAGLEV 2000's partnership with the Florida Department of Transportation (FDOT) in Tallahassee and its continued sup- port by the Technology Research and Development Authority (TRDA) in Brevard County points to a similar goal for economic development in East Central Florida.

In the current preconstruction planning phase, MAGLEV 2000 has enlisted the support of numerous local agencies and private companies.
Public partners include:

- **Florida Department of Transportation**
- **Technology Research and Development Authority**
- **Space Coast Regional Airport Authority**
- **NASA Kennedy Space Center**
- **Canaveral Port Authority**
- **Brevard Metropolitan Planning Organization**

Private companies have also expressed willingness to invest their expertise and resources in the project:

- **MAGLEV 2000 of Florida Corporatioin**
- **URS Greiner Woodward Clyde**
- **Tilden Lobnitz Cooper**
- **Salomon Smith Barney**
- **Transportation Economics and Management Systems, Inc.**

Still other partners will join in specialized roles as the project design becomes more firmly fixed. It is expected that the project management team will be reformulated in each of three distinct phases:

- Planning and environmental clearance
- Design and construction
- Operations and maintenance

2.2.3 Project Schedule and Organizations

MAGLEV 2000 expects to have its 20-mile Minimum Operating Segment up and running by the beginning of 2009. This makes allowances for about two years of environmental work and engineering development, four years of construction, plus another two years for certification and testing of the initial segment. Extensions to Orlando or other parts of Central Florida could follow soon after.

fig. 8.6

The Florida Maglev Deployment Project has the potential to shine the technological spotlight on the Space Coast again. It is THE American maglev project and it has the greatest potential to reshape our nation's transportation services and will again let a locally developed product achieve national significance.

The 20-mile MAGLEV 2000 system will perform a useful and safe transportation service at an attractive cost for a new technology start up of great industrial promise. And the environmental benefits of the project ensure that the quality of the environment will remain unpolluted and the beauty of the region unspoiled.

MAGLEV 2000 is a strong partner for the future of Brevard County, Central Florida and the United States. This is only the beginning.
MAGLEV 2000's ability to haul container freight, its application to lower-speed circulator uses, such as a university campus or urban activity centers, and its efficiency in specialized industrial tasks, such as mining and even space launches, promise a bright future and a significantplace in the nation's transportation system.

III. Major Research Subjects

3.1 Development Of A Modified Superconducting Magnet For Maglev Vehicles

3.1.1 Overview

In superconducting magnets for magnetically levitated transports system's (Maglev) vehicles, mechanical loss occurs due to the vibration caused by electromagnetic forces during the train's operation. The heat load including the mechanical loss needs to reduce within the capability of the onboard refrigerator. It is necessary that the vibration phenomena of the superconducting magnet during the train operation are made clear for the reduction of the mechanical loss.

Superconducting magnets should be operated with no supply of either liquid helium or liquid nitrogen. To meet the requirement, we have been developing a new type on-board GM refrigeration (GM refrigerator application) system.

3.1.2 Theory

The main source of mechanical loss for the coil unit is considered to the frictional heat load caused by micro sliding between the superconduction coil and the clamps.

Therefore, the heat load is proportional to the multiplication of amplitude X (sliding length) and angular frequency w (sliding frequency). The dimension of X*w corresponds to the velocity. Moreover, the heat load has strong correlation with the torsional deformation of coil unit, and therefore the coil unit vibrations are evaluated by means of the torsional velocity.

The targets of the development are demonstrations of the operation without supplying and cryogen by the multiple operations and the construction of almost same size as the usual refrigeration system. For this purpose, the countermeasures to improve the refrigeration capability and efficiency have to be taken into consideration and reliability as well.

The new system can keep high reliability by applying the same construction as the usual compressor, considering the reliability already confirmed with the operation in the test line.

A self-circulated cooling system with optimum structure and distribution of the cooling pipes to promote the circulation was adopted to cool the radiation shield plates of the SCM instead of the conventional system designed can provide a high reliability with no necessity of pump and control system and coolant circulation.

3.1.3 Approach

In order to confirm the analytical model accuracy, the vibration characteristics between the analyzed and the test results of the electromagnetic vibration test were compared. In addition, it was confirmed that the vibration analysis is accurate enough in comparison with the measured results in the running test.

The substructure synthesis method was applied to the vibration analysis. In the substructure synthesis method, the whole structure is divided into some substructures. Eigen value analyses are performed on these substructures and the results are used to determine the vibration characteristics of the whole structure by putting together these models is connected by spring and damping elements simulating supports.

3.1.4 Conclusion

It was confirmed that the vibration analysis is accurate enough in comparison with the test results of the electromagnetic vibration test and the measured results. The vibration phenomenon of the SCM during the train operation is to be made clearer using this vibration analysis to improve the reliability of the SCM further.

The model SCM without supply of liquid helium or liquid nitrogen demonstrated the continuous stable operation of the new type refrigeration system. It was confirmed that the control and the characteristic of the system are excellent.

For application of the SCM is the future, the new type refrigeration system is to be improved further and the reliability of the system is to be verified.

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H. Nakashima, K. Isoura, "Superconducting Maglev Development in Japan." Proceedings of the 15th International Conference on Magnetically Levitated Systems (Maglev '98), pp 25-28, 1998.

M. Terai, S. Inadama, H. Tsuchishima, E Suzuki, T. Okai, "Development of New Superconducting Magnets of the Yamanashi Test Line." Proceedings of the 14th International Conference on Magnetically Levitated Systems (Malev '95), pp. 267-273, 1995.

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3.3 Electromagnetic Coil Design

3.3.1 Overview

Electrodynamics Maglev Systems are distinguished from electromagnetic systems in that the currents yielding lift and the movement of the vehicle induces guidance forces. It is desired to develop a reliable electromagnetic coil track so that it can provide the Maglev system stable and flexible to system construction above the threshold speed.

3.3.2 Theory

Dandy and Powell were the first to introduce the system of a null flux or flux-eliminating coil to produce lift in Maglev application.

The null flux coils are in fact figure 8 shaped coils. When the vehicle based magnet drops below the midline of figure 8 coil, the lower window begins to link more flux than upper window. Current is induced by Lenz law to restore the vehicle to nearly its midline position, because the current that flows in that coil is such as to oppose or eliminate any flux change within the coil, it is some times referred to as flux eliminating coil. Yet another variation to the flux eliminating to the coil is that employed to America Maglev. <u>The main issue is, what are the forces on the coils as the system function of system geometry due to passage of set of magnets past these coils?</u>

3.3.3 Approach

It is introduced that a stacked magnet design is considered which couples into a state of interleave coils which are interconnected in such a way as to yield both lift and guidance forces [ref 1.1]. A mutual coupling analysis is embraced wherein the mutual inductance between the permanent magnets on board the vehicle and the coils are computed using closed from analytical expressions from filaments. The derivative of these expressions is then averaged to compute both the induced current and the forces on the coils as the function of system geometry and speed. A full transient analysis has to be performed to accurately account for entry and exit affects. The results are compared to those experimentally measured on the test track and extrapolations are offered to suggest future design considerations.

3.3.4 Conclusions

Approaching these electrodynamics Maglev design though coupled coil attack allows for an assessment of entry and exit effects in a true transient eddy current problem. The technique is dependent on an accurate computation of the mutual coupling between the magnets, which must be thought as number of discrete filaments and the coil, which also must be isolated in number of discrete filaments using analytical approximations for the mutual couplings.

3.3.5 References

Dandy and Powell, “Levitation with null flux coils” US patent 3, 470 Oct 1996

Hiroshi Nakashima and Akio Seki “ The status of technical development for Yamanashi Maglev test line”

H. Nakashima, “ The Superconducting Magnet for the Maglev Transport System”, IEEE Trans. on Magnetics., Vol. 30, no. 4-pp. 1572-1578, July 1994.

3.4 A Scheme Of Maglev Vehicle Using High Tc Superconductors

3.4.1 Overview

High Tc Superconductors are highly attractive because they can operate at liquid nitrogen temperature. The high performance of high Tc bulk superconductor is exciting to people in the application research work on superconducting magnetic levitation (Maglev) vehicle. Schemes relating to the use of high Tc YbaCuO superconducting bulk materials for Maglev vehicle are discussed. First, the YbaCuO bulk superconductors are arranged above the rail using NdFeB permanent magnets. The second scheme is the electromagnetic suspension (EMS) Maglev vehicle using high Tc superconducting permanent magnets (SCPM) or high Tc superconducting wire. The third scheme is the EMS Maglev using Tc SCPM. The third scheme is chose after making a comparison. The key problems of the EMS Maglev vehicle using high Tc SCPM are discussed.

3.4.2 Theory

A large levitation force and a stable equilibrium are obtained with a permanent magnet and a high Tc YBaCuO bulk superconductor, because the levitation force based on flux pinning for type-II superconductors in mixed state is large enough. The bulk high Tc YbaCuO superconductors may be cooled using liquid nitrogen as a cryogen. This makes high Tc superconductors particularly attractive for the applications in magnetic bearings, rotating electrical machines, flywheel energy storage devices, and magnetic levitation vehicles using high Tc bulk superconductors above the guideway of normal permanent magnets (NPM) have been described.

There is a large levitation force between two normal permanent magnets, but these forces are in scattering situation. There is a large guidance force between high Tc superconductors and applied magnetic field when superconductors are cooled in the magnetic field. Both the levitation forced between two NPMs and the guide force of high Tc superconductors can be used for Maglev vehicles.

The principle drawback of the TR-07 EMS system using normal electromagnets in Germany is the small gap (8mm) between the vehicle and the guideway rail. The EDS Maglev system using low Tc superconducting magnets in Japan has large gap (100mm), but the operating temperatures is very low and it is not static suspension. The superconducting EMS Maglev scheme with high Tc SCPMs possesses a number of the merits.

The superconducting YbaCuO bulk materials can trap higher magnetic fields than both Bi-based and Ti-based superconductors at liquid nitrogen temperature can. So YbaCuO bulk as superconducting permanent magnets (SCPM) is particularly useful for magnetic levitation vehicles. A possibility of Electromagnetic suspension (EMS) Maglev vehicles using high Tc SCPM is described.

The Maglev vehicles for high Tc superconductors may be realized by various schemes, for example, the magnetic levitation of high Tc bulk superconductor above the NPM, the EDS Maglev vehicle using high Tc SCPMs or superconducting wire material, the EMS Maglev vehicle using high temperature SCPMs, etc.

3.4.3 Approach

The levitation force of a quasi-crystal bulk YBaCuo superconductor is above 10 N/cm^2 (77K). The shortcoming of the electrical magnet is both complex guideway and high electric energy. If the applied magnetic field is provided by the normal permanent magnet (NPM), then a larger levitation force between high Tc superconductors and applied magnetic field can be achieved. The levitation gap of this design is small, because of the inherent property of the high Tc bulk superconductors. The magnetic field of the guideway can be increased by application of the flux concentration scheme of the magnet arrangement. In order to increase the field strength on the topside of the guideway it is effective to introduce ferromagnetic elements as magnetic conductors between two NPMs. The aerial guideway of the NPM is used for some engineering applications in order to reduce the NPM's effect on environment.

There is a large levitation force between two NPMs, but this levitation is unstable. The bulk superconductors in the condition of the field cooling (FC) have a high stability. It perhaps is a valid scheme to combine the large levitation force between both NPMs and the high stability of the bulk superconductor. The combining levitation schemes using both NPMs and high Tc bulk superconductors may be:

1. All suspension force is generated force is achieved by the interaction between NPMs. High Tc bulk superconductors in field cooling achieve the guidance force.
2. The suspension force is generated by the interaction between two NPMs and by the interaction between NPM and the bulk superconductors in zero field cooling (ZFC). The bulk superconductors in field cooling achieve the guidance force.
3. Both the forces of levitation and guidance are achieved by the whole, consisting of NPM and bulk superconductor above NPM's guideway.
4. Both the forces of levitation and guidance are achieved by bulk superconductors on NPM's guideway.

3.4.4 Conclusion

An understanding of the first scheme is relatively easy. The levitation using NPM is very attractive all the time, because its levitation force is high. There is independence between the suspension force and the guidance force. An advantage of this scheme is that the levitation force is higher than the other schemes when the quality of high Tc bulk superconductors is not very good.

The second scheme is complex. The third scheme perhaps is better theoretically, but it is difficulty to design the best combination of both NPMs and bulk superconductors. The fourth scheme is ordinary, and it is presented elsewhere.

The guidance forces of high Tc bulk superconductors are used in each of the above-mentioned schemes, because this is an important characteristic of high Tc bulk superconductors. All four schemes are limited. Both height and weight of the levitation are crucial questions for Maglev vehicle. The Maglev vehicle using high Tc SCPMs is a forceful competitor.

3.4.5 References

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3.5 Development of Maglev Superconducting Magnet Vibration Characteristics for Design

3.5.1 Overview

A high-performance and high-reliability magnetically levitated superconducting magnet (SCM) is developed. Its heat generation per unit time by the electromagnetic forces due to magnetic fields from levitation coils is under 2 W at the frequency range in which vehicles are levitated. The vibration mode of inner vessels that makes the largest contribution to heat generation in SCM's is clarified, the torsion mode. A modeling method to analyze SCM vibration, is examined, and heat generation is SCM's is calculated from the vibration of the inner vessel. Using the numerical analysis method, SCM's combined with new bogie frames for the Maglvev track are designed. Good performance in vibration and heat generation of these SCM's is predicted by numerical analysis.

3.5.2 Effects

One of the most important areas of Maglev technology is the development of reliable SCM's, which depends heavily on reducing heat generation due to structural vibration in SCM's. Vibration in SCM's causes mechanical loss due to friction between the structures that compose the SCM and electrical loss due to eddy currents induced in the conductive structures. These losses lead to heat generation in SCM's which increases evaporation of liquid helium used to refrigerate the superconducting coils at 4 K.

3.5.3 Structure of a Maglev System

Numerous ground coils, active coils for propulsion and passive coils for levitation (and guidance), are placed along the tracks in the ground. Superconducting magnets are located on both sides of a vehicle. Maglev vehicles are propelled by the magnetic forces between the SCM's and the levitation coils, and the vehicles are levitated by these magnetic forces.

A superconducting magnet mainly consist of four superconducting coils made of copper and noibum-titanium, four inner vessels (liquid helium containers made of stainless steel covered by aluminum to reduce eddy current loss, four radiation shields (liquid nitrogen refrigeration cases made of aluminum) and other vessel (a vacuum case made of aluminum alloy). Each inner vessel is supported and fixed to an outer vessel through a radiation shield with a variety of mechanical support structures (cone type, rod type, and cylinder-rod type). The superconducting coils have a shape like a racetrack in an athletic field. An SCM is equipped with a compact refrigerator to liquefy evaporated helium.

3.5.4 Problems

A Maglev SCM is subjected to many external forces. In particular, variation electromagnetic forces due to ripple magnetic fields from ground coils affect the dynamic behavior of SCM's. The component of ripple magnetic fields that causes the largest electromagnetic forces is called the spatially fifth ripple from levitation coils. Arranging six levitation coils between two poles of superconducting coil causes the spatially fifth ripple. This ripple component produces electromagnetic forces that have spatially five changes of peak value between two poles of the supercounducting coils causes the spatially fifth ripple. Ripple magnetic fields induce a number of eddy currents in the structures that compose an SCM, especially the outer vessel. The induced eddy currents interact with the magnetic fields of the superconducting coils to produce Lorentz foreces, and structural vibration occurs in the SCM's. Vibration in the SCM's leads to heat generation and evaporates the liquid helium.

Heat load increase per SCM when Maglev vehicles are levitated must be less than 3 W. This limit is determined by the refrigerator capacity. Heat generation per unit time is generally called heat load increase.

3.5.5 References

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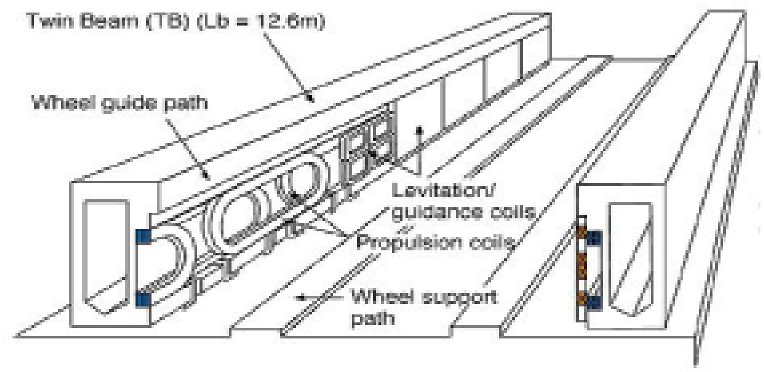
3.6 Different Guideways of Maglev Train

3.6.1 Overview

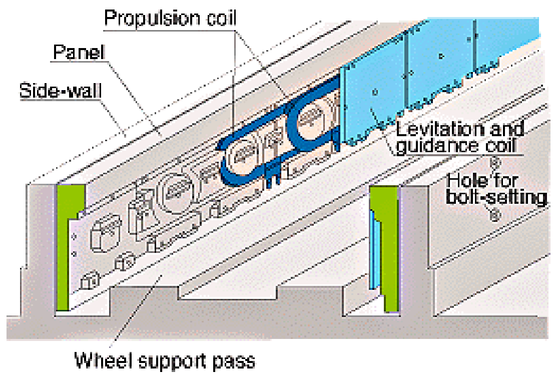
The guideway consists of a structure corresponding to the conventional track and ground coils corresponding to the conventional motor. It is a vital element of Maglev.
The following three methods of installing the ground coils for propulsion, levitation, and guiding to the guideway are adopted

3.6.2 Beam Method



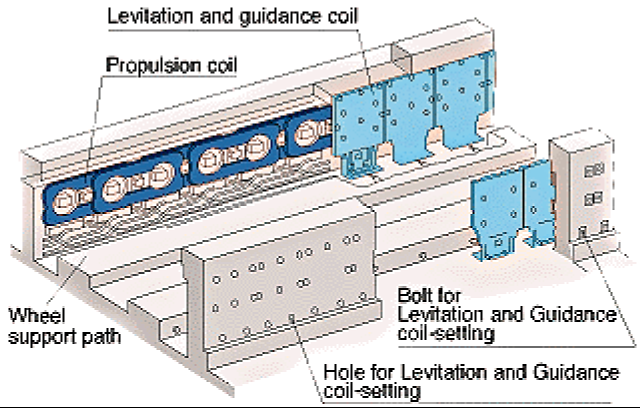
In the beam method, the sidewall portion will be constituted solely of concrete beams. The entire process from beam manufacturing to installation of the ground coils take place at the on-site factory (provisional yard). A finished beam is transported to the work site within the guideway, to be placed on two concrete beds set up in advance there.

3.6.2 Panel Method



In a factory set up on-site (provisional yard) the concrete panel is produced and attached with ground coils. The finished assembly is carried to the work site, where it is fixed, with 10 bolts, to the concrete sidewall erected in advance there.

3.6.3 Direct-Attachment Method



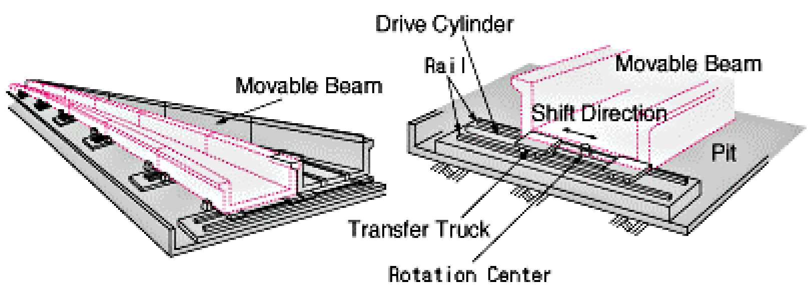
At the work site in the tunnels or on the bridges a concrete sidewall portion is produced. At the same site the finished sidewall is directly fitted with the ground coils. With no need for the factory or transport vehicle, this method is economically superior to the other two, but its drawback lies in that it allows only slight adjustments of individual ground coils to correct the irregularities.

3.7 Turnout Facility In Maglev Train

3.7.1 Overview

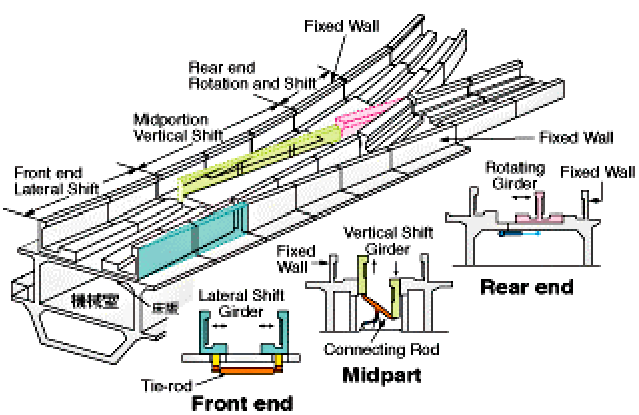
The turnout facilities (switches) are an indispensable element for distributing the train routes. Depending on the train speed dictated by the purpose, there are two types, for high speed, for low speed, and for the train depot.

3.7.2 High-speed (Traverser) Type



A traverser is installed to switch routes between the straight main line where the vehicle runs levitated at high speed and the curved branch line where the vehicle runs on wheels at low speed. In the high-speed (traverser) type, the guideway is divided into several laterally movable beams, which shift to switch routes. On the Yamanashi Maglev Test Line, two shift-drive systems, electrical and hydraulic, are tested.

3.7.3 Low-speed (sidewall-shifting) type



The sidewall-shifting type is employed at terminals where the line starts and ends; and where low-speed wheel runs takes place on the straight main line and curved branch line. In this type the route is formed by merely shifting the sidewalls, instead of the girder, vertically or laterally. The front and rear ends permit the sidewalls to be moved laterally, while the midpart permits the sidewalls to be moved vertically.

IV. <u>Major Players</u>

4.1 Major Players in Space Propulsion

1. PRT, Inc of Chicago
2. Lawrence Livermore National Labs
3. Foster Miller, Inc. of Boston
4. Boeing, Rockwell.

4.2 NASA Centers

1. Ames Research Center, Moffett Field, CA
2. Dryden Flight Research Center, Edwards, CA
3. Glenn Research Center at Lewis Field, Cleveland, OH
4. Goddard Institute for Space Studies, New York, NY
5. Goddard Space Flight Center, Greenbelt, MD
6. Independent Validation & Verification Facility, Fairmont, WV
7. Jet Propulsion Laboratory, Pasadena, CA
8. Johnson Space Center, Houston, TX
9. Kennedy Space Center, FL.
10. Langley Research Center, Hampton, VA
11. Marshall Space Flight Center, Huntsville, AL
12. Moffett Federal Airfield, Mountain View, CA
13. Stennis Space Center, MS
14. Wallops Flight Facility, Wallops Island, VA
15. White Sands Test Facility, White Sands, NM

4.3 Industry

1. Lockheed Martin: Skunk Works
2. Lockheed Martin: Missiles and Space
3. Lockheed Martin: Technical Operations
4. Boeing: Rocketdyne Division
5. GenCorp Aerojet
6. Allied Signal Defense & Space Systems
7. Sverdrup

4.4 On Going Research At Major Centers

4.4.1 Marshall Space Flight Center

A magnetic levitation track is up and running at NASA’s Marshall Space Flight Center in Huntsville, Ala. The experimental track is designed and built by Foster-Miller Inc. of Waltham, Mass. and installed inside a high-bay facility at the Marshall Center. Marshall’s Advanced Space Transportation Program is developing magnetic levitation or maglev technologies that could give a space launch vehicle a "running start" to break free from Earth’s gravity. A maglev launch system would use magnetic fields to levitate and accelerate a vehicle along a track at speeds up to 600 mph. The vehicle would shift to rocket engines for launch to orbit. Maglev systems could dramatically reduce the cost of getting to space because they’re powered by electricity, an inexpensive energy source that stays on the ground — unlike rocket fuel that adds weight and cost to a launch vehicle.

Facilities and The Experimental Track at MSFC

The Foster-Miller experimental track accelerates a carrier to 57 mph at its peak traveling 22 feet in 1/4 second, the equivalent of 10 times the acceleration of gravity. The tabletop track is 44 feet long, with 22 feet of powered acceleration and 22 feet of passive braking. A 10-pound carrier with permanent magnets on its sides swiftly glides by copper coils, producing a levitation force. The track uses a linear synchronous motor, which means the track is synchronized to turn the coils on just before the carrier comes in contact with them, and off once the carrier passes. Sensors are positioned on the side of the track to determine the carrier’s position so the appropriate drive coils can be energized. Engineers are conducting tests on the indoor track and a 50-foot outdoor Maglev track installed at Marshall by NASA and industry partner PRT Advanced Maglev Systems Inc. of Park Forest, Ill. The testing is expected to help engineers better understand Maglev vehicle dynamics, the interface between a carrier and its launch vehicle and how to separate the vehicle from the carrier for launch. ***Future work on large systems will be led by NASA’s Kennedy Space Center, Fla.***

4.4.2 Boeing, Rockwell

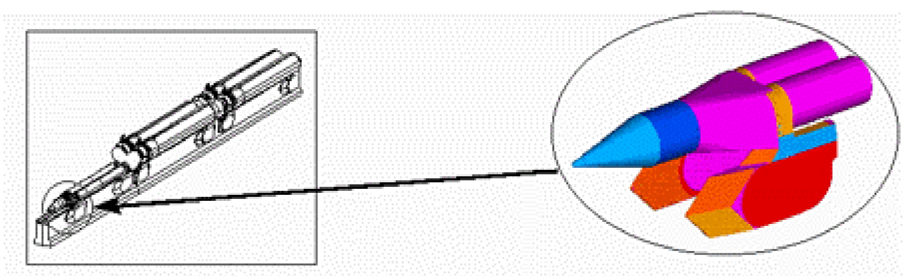
Boeing is part of the General Atomics/Bechtel/Foster-Miller team designing and building a magnetic levitation upgrade to the Holloman High Speed Test Track at Holloman Air Force Base, New Mexico. The MagLev system will not only provide important test capability for national defense, but will also establish many of the design parameters needed to understand this technology's potential for launch assist. Boeing is working to leverage this MagLev technology for the benefit of NASA programs such as the Highly Reusable Space Transportation Phase II study.

Current Activity

The MagLev team is nearing the end of the Phase II, Task 1 full-scale engineering development effort.

Two products being developed,

1. Fabrication drawings for a three-stage, three-kilometer-per-second system (shown below left)
2. Preproduction test track demonstrator hardware (shown below right).



Facts

The Holloman High Speed Test Track holds the land speed record at 8,978 feet per second (6,121 miles per hour)
Holloman's existing dual rail track extends 50,788 feet in a nearly North-South orientation.

Benefits

The Magnetic Levitation upgrade to the Holloman High Speed Test Track is a multi-team, multi-task contract that provides several critical benefits,

1. Expansion on technology data base on high-speed physics, controllability, and materials.

2. Knowledge and understanding on superconducting, magnetic levitation, propulsion, and integration issues.

3. A new high-speed ground technology which offers advanced launch assist possibilities for horizontal take-off space transportation vehicles.

The MagLev system is essentially a high-speed (hypersonic) vehicle flying in close proximity to the ground (within one inch of the guideway). As such, the knowledge and information obtained are applicable to a wide variety of access to space opportunities.

4.4.3 Lawrence Levemore National Laboratory

Overview

Magnetically levitated (maglev) trains cruising at up to 400 kilometers per hour have pointed the way to the future in rail transport. Their compelling advantages include high speeds, little friction except aerodynamic drag, low energy consumption, and negligible air and noise pollution.
However, maglev trains also pose significant drawbacks in maintenance costs, mechanical and electronic complexity, and operational stability. Some maglev train cars, for example, employ superconducting coils to generate their magnetic field. These coils require expensive, cryogenic cooling systems. These maglev systems also require complicated feedback circuits to prevent disastrous instabilities in their high-speed operation.

New Approach

Lawrence Livermore scientists have recently developed a new approach to magnetically levitating high-speed trains that is fundamentally much simpler in design and operation (requiring no superconducting coils or stability control circuits), potentially much less expensive, and more widely adaptable than other maglev systems. The new technology, called Inductrack, employs special arrays of permanent magnets that induce strong repulsive currents in a "track" made up of coils, pushing up on the cars and levitating them.

Technology

A Livermore team, headed by physicist Richard Post, has successfully demonstrated the Inductrack concept in test trials. The test runs demonstrated the system's totally passive nature, meaning that achieving levitation requires no control currents to maintain stability, and no externally supplied currents flowing in the tracks. Instead, only the motion of train cars above the track is needed to achieve stable levitation. The results have been so promising that NASA has awarded a three-year contract to the team to explore the concept as a way to more efficiently launch satellites into orbit.

Inductrack involves two main components,
A special array of permanent, room-temperature magnets mounted on the vehicle and a track embedded with close-packed coils of insulated copper wire. The permanent magnets are arranged in configurations called Halbach arrays, Originally conceived for particle accelerators, Halbach arrays concentrate the magnetic field on one side, while canceling it on the opposite side. When mounted on the bottom of a rail car, the arrays generate a magnetic field that induces currents in the track coils below the moving car, lifting the car by several centimeter and stably centering it. When the train car is at rest (in a station), no levitation occurs, and the car is supported by auxiliary wheels. However,

as soon as the train exceeds a transitional speed of 1 to 2 kilometers an hour (a slow walking speed), which is achieved by means of a low-energy auxiliary power source, the arrays induce sufficient currents in the track's inductive coils to levitate the train. To test the Inductrack concept, Post, project engineer J. Ray Smith, and mechanical technician Bill Kent assembled a one-twentieth-scale model of linear track 20 meters long (Figure 1). The track contained some 1,000 rectangular inductive wire coils, each about 15 centimeters wide. Each coil was shorted at its ends to form a closed circuit but not otherwise connected to any electrical source. Along the sides of the track, they attached aluminum rails on which a 22-kilogram test cart could ride until the levitation transition velocity was exceeded (Figure 2). Finally, the team secured Halbach arrays of permanent magnet bars to the test cart's underside for levitation and on the cart's sides for lateral stability.

The cart was then launched mechanically at the beginning of the track at speeds exceeding 10 meters per second. High-speed still and video cameras revealed that the cart was consistently stable while levitated, flying over nearly the entire track length before settling to rest on its wheels near the end of the track. Post says the test results are consistent with a complete theoretical analysis of the Inductrack concept he performed with Livermore physicist Dmitri Ryutov. The theory predicts levitation forces of up to 50 metric tons per square meter of magnet array using modern permanent magnet materials such as neodymium-iron-boron. The theory also shows levitation of loads approaching 50 times the weight of the magnets, important for reducing the cost relative to maglev vehicles.

Maglev space Propulsion

LLNL with NASA will build a new Inductrack model at Lawrence Livermore to demonstrate the concept at speeds up to Mach 0.5 (170 meters per second).which will be used for magnetic space propulsion rocket launching.
As conceived, a track would use a reusable launcher to propel a rocket up a ramp to almost 600 miles/hr speeds before the rocket's main engines fire.

Ongoing Development

The Livermore team is designing a 150-meter-long track, to be built at the Laboratory site, on which a scaled launch cradle and rocket will be accelerated. Unlike the present track, the one for NASA will interleave powered drive coils with passive levitation coils to reach the required speeds. The team is partnered with computer scientists at Pennsylvania State University, who are developing an integrated design code that includes magnetics, aerodynamics, stresses, and control stability to assess full-scale systems.

Post believes Inductrack offers NASA the potential for a far less expensive technology for magnetic levitation launchers than approaches using superconducting coils however, that while the existing Inductrack model has demonstrated the principle of the concept, there are new issues to be addressed in launching rockets. Among these are high g forces, sustained speeds of 600miles/hrr higher, the effects of fluctuating aerodynamic forces on the launching cradle and its payload, and aerodynamic and other issues associated with detachment and flight of rockets.

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http://liftoff.msfc.nasa.gov/news/1999/news-maglev.asp
http://www.post-gazette.com/maglev/maglev01.asp
http://sec353.jpl.nasa.gov/apc/
www.highway2space.com/partners.html
http://liftoff.msfc.nasa.gov/news/1999/news-maglev.asp
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http://web.yuntech.edu.tw/~wangyj/PQ/HST/22.htm
http://www.ee.mtu.edu/~wrstandf/theory.htm
http://www1.msfc.nasa.gov/NEWSROOM/news/releases/2000/00-023.htm
http://web.yuntech.edu.tw/~wangyj/PQ/HST/21.htm
http://bmes.ece.utexas.edu/~jcamp/physics/

http://www.perpetual.net/kyle/index.asp?Section=engineering
http://www.iinc.com/~obwan/htc/htclinks.htm#Linear
http://www.oz.net/~coilgun/home.htm
http://www.isd.net/anowicki/SPBI112.HTM
http://members.nbci.com/coilgun/index.html
http://www.cmn.net/~molly/railguns.html
http://www.scienceweb.org/movies/eraser.html
http://students.washington.edu/hlyphong/coilgun.html

5.3 Journals

IEEE transactions on applied superconductvity, vol7
IEEE transactions on magetics, vol33
IEEE transactions on magetics, vol34
Development of Maglev System in Japan: past, present and future
IEEE transaction on applied superconductivity, vol9
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Conference on electromagnetic Guns and Launchers

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1985-2000

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3. "Maglev: a new approach." R. F. Post. diag il Scientific American v282 no1 p82-7 Ja '2000

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VI. Appendix- 1

VII. Appendix- 2