Main Components for the Maglev-2000 System

Figure 1 shows a cross section of the Maglev-2000 superconducting quadrupole, the unique heart of the Maglev-2000 system. The M-2000 quadrupole magnet module has 2 superconducting loops of width W, separated by the distance W. The 2 loops carry oppositely directed superconducting currents, resulting in 4 magnetic poles, alternating as one proceeds around the circumference of the quadrupole. The 2 loops can be separate electrical circuits, or be connected together to form a single circuit. The 4 pole feature enables the superconducting quadrupole to magnetically interact with aluminum guideway loop panels positioned vertically on the sides of a monorail guideway beam, using the magnetic pole from the vertical face of the quadrupoles, or with aluminum guideway loop panels positioned on a planar guideway beneath the Maglev vehicle, using the magnetic pole from the bottom surface of the quadrupole (Figure 2).

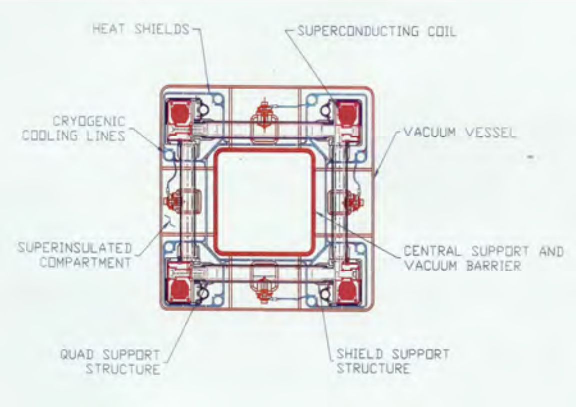

Figure 1 Cross-Section of Quadrupole Magnet

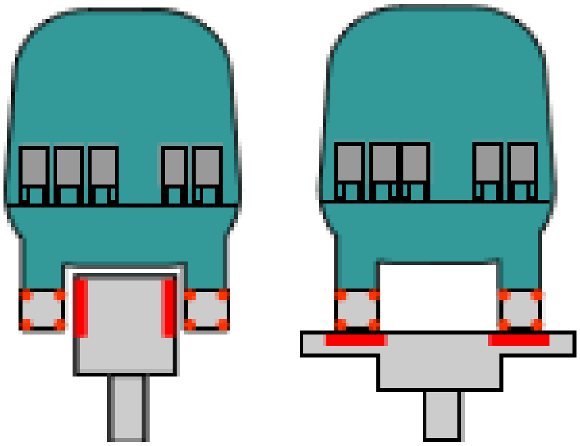

Figure 2 Maglev-2000 Vehicle on Monorail and Planar Guideway Using Quadrupole Magnets

Maglev-2000 vehicles can smoothly transition between the 2 types of guideway, from monorail to planar, and back to monorail. For high speed operation on elevated guideways, for most of the route (90% or more), the vehicles will operate on the monorail guideway (Figure 3). It is lower in cost, visually more attractive, and easier to erect.

Figure 3 Artist's Drawing of Maglev-2000 Passenger Vehicle on Monorail Guideway

At locations where switching to off-line stations is desired, vehicles would transition to a planar 2guideway holding 2 lines of planar guideway loops. Initially closely overlapping, the 2 lines would gradually diverge laterally. The straight ahead line of loops is the main high speed guideway, while the laterally diverging line of guideway loops leads to the off-line station.

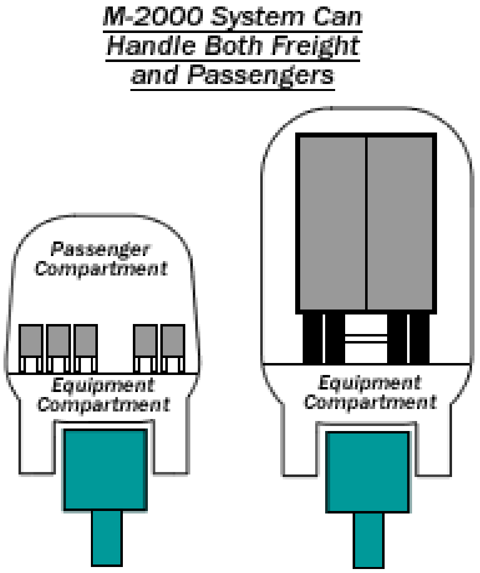

Figure 4. Maglev-2000 Passenger and Truck Carrier Vehicles on Dual-Use Guideway

Figure 4 shows passenger and truck carrying Maglev vehicles on the same monorail guideway segments to access off-line stations for unloading/loading operations.

The guideway panels can also be mounted on cross-ties of existing RR tracks (Figure 5), enabling levitated travel of Maglev-2000 vehicles along existing RR tracks. The panels do not interfere with conventional trains, which could use the tracks for bulk freight transport, given appropriate scheduling. Maglev-2000 vehicles traveling as individual units would allow much more frequent and convenient passenger service, rather than long trains of many RR cars. Also, because Maglev loads are distributed along the vehicle and not concentrated at wheels, local track loading is much less than with conventional trains, greatly increasing track life and reducing maintenance.

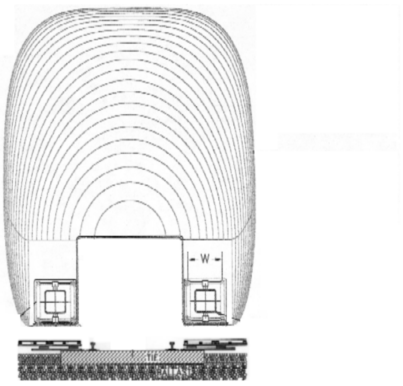

Figure 5. Drawing of levitated Maglev-2000 vehicles traveling on convention RR track to which aluminum loop panels have been attached to the cross times.

Figure 6 shows one of the two wound superconducting loops used for the Maglev-2000 quadrupole. The loop has 600 turns of NbTi superconducting wire. At the design current of 1000 Amps in the NbTi wire, the Maglev-2000 quadrupole has a total of 600,000 Amp turns in each of its 2 superconducting (SC) loops. The SC winding is porous, with small gaps between the NbTi wires to allow liquid Helium flow to maintain their temperature at 4.2 K, and to stabilize them against flux jumps and micro movements.

Figure 6 NbTi Superconductor Loop for

Maglev-2000 Quadrupole

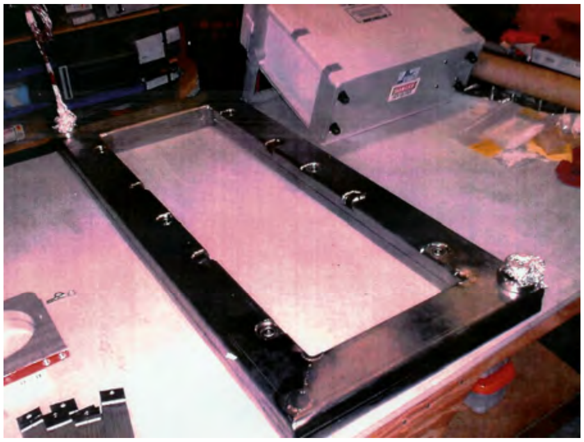

Figure 7 NbTi Superconducting Loop Enclosed in Stainless Steel Jacket

Figure 7 shows the SC loop enclosed in its stainless steel jacket. Liquid Helium flows into the jacket at one end and exits at the end diagonally across from the entrance providing continuous Helium flow through the SC winding. Before insertion of the SC loop into the jacket, it is wrapped with a thin sheet of high purity, aluminum (5000 residual resistance ratio) to shield the NbTi superconductor from external magnetic field fluctuations. After closing the jacket, a second layer of high purity aluminum is wrapped around it for additional shielding.

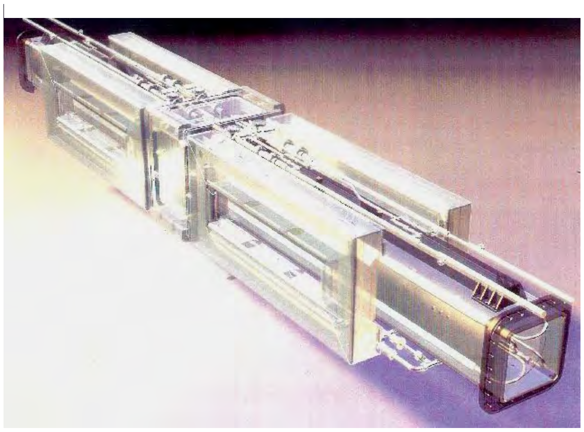

Figure 8 CAD-CAM Drawing of Maglev-2000 Superconducting Quadrupole

Figure 8 shows a CAD-CAM drawing of the complete Maglev-2000 cryostat that holds 2 superconducting quadrupoles. The magnetic polarity of the front SC quadrupole is opposite to that of the rear quadrupole. This allows levitation at lower speed than if the 2 quadrupoles had the same polarity, due to less L/R decay of the currents induced in the aluminum guideway loops. The 2 SC loops are supported by a graphite-epoxy composite structure that resists the magnetic forces – due both to the forces in a loop from its self-current, and to the forces between the 2 loops – that act on them.

Figure 9 Assembly of Maglev-2000 Superconducting Quadrupole

Figure 9 shows the SC loops, support structure, and cooling currents for the Maglev-2000 quadrupole being assembled in Maglev-2000's facility on Long Island. The SC loops have a 10 K thermal shield, which is cooled by Helium exiting from the jacket holding the SC loop. The SC quadrupole structure is then enclosed by an outer layer of multi-layer insulation (MLI) consisting of multiple alternating layers of glass fiber and aluminum foil. A second thermal shield encloses the SC quad, and maintained at ~70 K by the helium out-flow from the 10 K primary thermal shield.

Figure 10 shows the completed SC quadruple enclosed in its vacuum cryostat, while Figure 11 shows testing of the quadrupole magnetic levitation and propulsion forces using DC current in the aluminum loop guideway assembly beneath the quadrupole as a stand-in for the induced

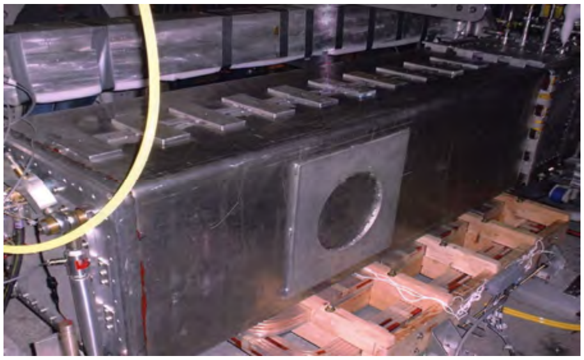

Figure 10 Completed Maglev-2000 Quadrupole Enclosed in its Cryostat

Figure 11 Testing of Magnetic Forces on Maglev-2000 Quadrupole Using DC Current in Aluminum Loop Panel

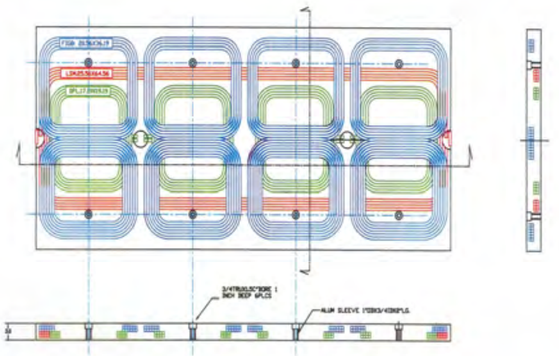

Figure 12 Drawing of aluminum loop guideway panel providing vertical lift and stability, lateral stability, and linear synchronous propulsion

currents. The quadrupole was successfully tested to its full design current of 600,000 Amp turns. The magnetic forces between the quadrupole and the guideway loop assembly were measured as a function of vertical separation and lateral displacement from the centered position, and longitudinal position in the direction of movement along the guideway. The measured forces agreed with 3 D computer analyses.

Since the Maglev-2000 quadrupole tests, high temperature superconductors have become much more capable, and are being commercially produced. Using YBCO high temperature superconductor wire, Maglev-2000 quadrupoles would be much simpler to construct, with much easier refrigeration. The YBCO superconductor would operate at 65K with pumped liquid nitrogen coolant and a much simpler on-board cryocooler.

Figure 12 shows a drawing of the Maglev-2000 aluminum wire loop guideway panels. It has 3 sets of multi-turn aluminum loops: 1) a sequence of 4 short independent Figure of 8 loops; 2) a sequence of 4 short dipole loops; and 3) 1 long dipole loop.

When the panels are on the vertical sides of the monorail guideway beam, the Figure of 8 loops provide levitation and vertical stability. The dipole loop on each side of the beam are connected together into a null flux circuit that maintains the vehicle in a centered position on the beam – when centered no current flows in the aluminum null flux circuit, when an external force (wind, curves, etc) acts to push the vehicles away from its centered position, a magnetic force develops that opposes the external force. The long dipole loop is part of the Linear Synchronous Motor (LSM) propulsion system, in which the loops on a sequence of panels are connected in series to form an energized block along which the Maglev vehicles travels. The energized block is typically on the order of 100 meters in length; as the vehicle leaves an energized block, its AC propulsion current is switched into the next block that the vehicle is entering.

For the planar guideway, the same panel design is used, with the panel laid flat on the planar surface beneath the line of quadrupoles on the moving vehicle. The Figure of 8 loops now provide lateral stability, generating magnetic restoring forces if an external force acts to displace the vehicle from its centered position on the guideway. The dipole loops act individually, with inductive currents that levitate and vertically stabilize the vehicle as it passes overhead. The LSM loops function in the same way as they do on the monorail guideway.

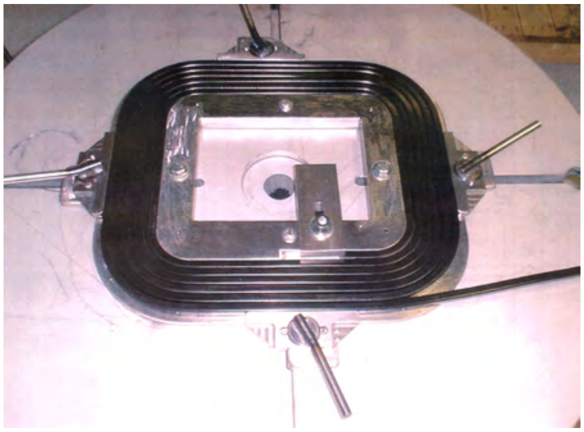

Figure 13 Wound Dipole Loop for Guideway Panel Using Nylon Coated Aluminum Conductor

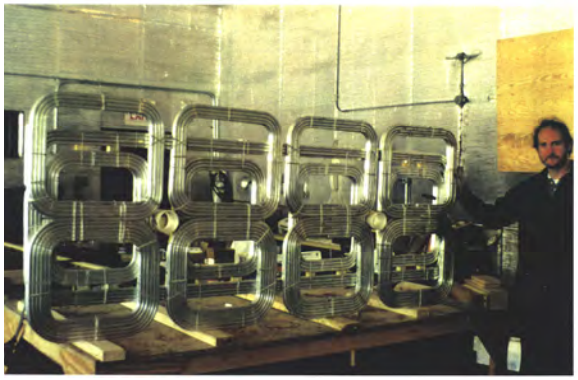

Figure 14 Completed Guideway Panel with Figure of 8 Dipole, and LSM Propulsion Loops

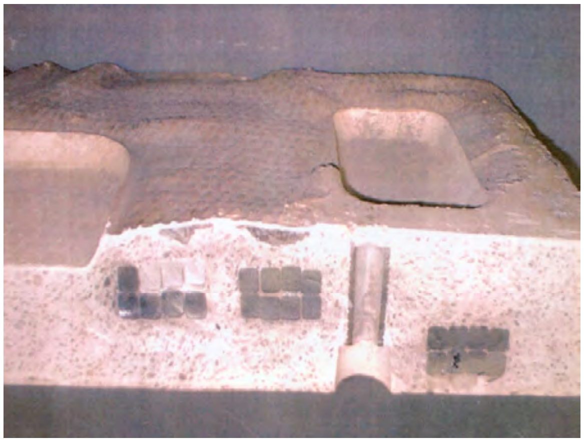

Figure 15 Guideway Loop Panel Enclosed in Polymer Concrete Matrix

The planar guideway panel configuration can also levitate and propel Maglev vehicles along existing RR tracks, with the panels attached to the cross-ties of the RR tracks.

Figure 13 shows a wound dipole loop, to be used in the panel. The aluminum conductor has a ~10 mil layer of nylon using a dip process to coat the conductor. The nylon insulation withstood 10 Kilovolt tests without breakdown. Figure 14 shows a completed guideway loop panel with all of its 9 loops.

The completed panel is then enclosed in a polymer-concrete structure for handling and weather protection (Figure 15) Polymer concrete – a mixture of aggregate, cement and plastic monomer – can be cast into virtually any form as a slurry. When the monomer polymerizes (the rate of polymerization is controlled by the amount of added promoter), the resulting concrete-like structure is much stronger – a factor of 4 or greater – than ordinary concrete and not affected by freeze thaw cycles, salt, etc.

Figure 16 shows a completed polymer concrete panel left outside of the Long Island facility for 2 years. It was subjected to a wide range of weather conditions and multiple freeze-thaw cycles over the 2 year period, without any degradation. After

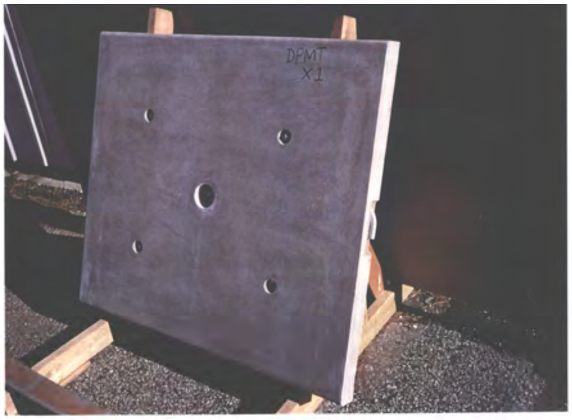

Figure 16 Polymer Concrete Panel with Enclosed Aluminum Loop Exposed for 2 Years to Outdoor Environment with Multiple Freeze-Thaw Cycles

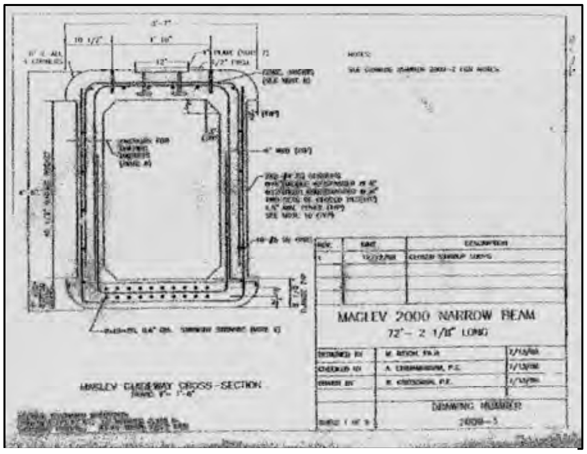

Figure 17 Design for 72 Foot Long Monorail Guideway Beam

Figure 18 Photo of 72 Foot Long Monorail Guideway Beam Delivered to Maglev-2000 Facility in Florida from Fabrication Site in New Jersey

being fabricated at the Maglev factory, the guideway panels would be attached to the sides of the monorail or the surface of planar guideway beams to be shipped to a construction site for an elevated guideway, or transported to existing RR trackage that was to be modified for use by Maglev-2000 vehicles.

Based on fabrication experience at Maglev-2000's facilities on Long Island and Florida, using hand operated tooling, the 9 loops for a 2.2 meter long guideway panel can be fabricated in less than 1 week by one person. At $25 per hour, fabrication would then cost less than $1000 per loop. Per mile of 2-way guideway (2800) this amounts to less than 2.8 million dollars if made by hand. With automated tooling, the fabrication cost of the aluminum loops can be brought down considerably, to the order of 1 million dollars per mile. At $4 per kg for the aluminum conductor and $1 per kg for polymer concrete, the cost of the materials for the monorail guideway panels would be approximately 5 million dollars per 2-way mile.

Figure 17 shows the basic design for the monorail guideway beam. It is a hollow box beam made with reinforced concrete. Beam length is 22 meters and weight is 34,000 kg. It uses post tension construction, which allows the tensioning cables in the base of the beam to be re-tightened if some stretching were to occur. The beam is tensioned to have a 0.5 cm upwards camber at the midpoint of the beam when it is not carrying a Maglev vehicle. When the Maglev vehicle is on the beam, the beam flattens out to a straight line condition, with no vertical dip or camber along its length.

Figure 18 shows a photo of the fabricated beam after transport by highway truck from the manufacturing site in New Jersey to Maglev-2000's facility in Florida. No problems in transport by highway were encountered.

Figure 19 shows a CAD-CAM drawing of the aluminum chassis that was constructed for a 20 meter long Maglev-2000 test vehicle, designed to carry 60 passengers in urban and suburban service.

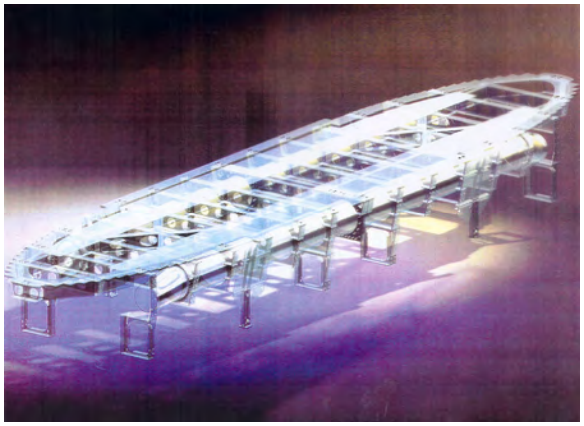

Figure 19 CAD-CAM Drawing of Aluminum Chassis for 60 Foot Long Maglev-2000 Vehicle

Figure 20 shows a view of the fuselage for the test vehicles. If the Maglev-2000 Florida route program had been down selected by the FRA for continuation, the assembled vehicle would have been tested on a short section of guideway. The Maglev-2000 components are presently in storage.

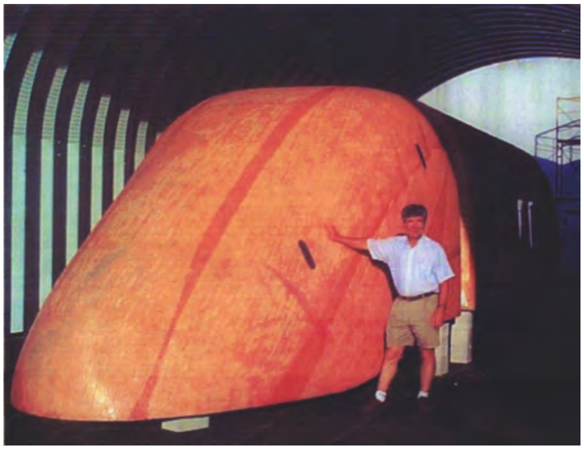

Figure 20 Photo of Fuselage for 60 Foot Long Maglev-2000 Vehicle

Fabrication and testing of the basic Maglev-2000 components – superconducting quadrupole magnets, aluminum loop guideway panels, monorail guideway beam, and vehicle body – have been successfully carried out. The next step for the development of the commercial 2nd generation Maglev-2000 system is to test operating vehicles on a guideway.

All in all, our development work and experiments at the Florida and Long Island Laboratories went very well. We built and successfully tested the quadrupole magnets, aluminum guideway panels, guideway beam, and vehicles body without any significant problems. That is unusual in most R&D projects. Doing new things often results in major problems that have to be overcome. As a colleague once remarked, “If you know that your research and development would have no problems, you wouldn’t have to do it.”