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MAGLEV FREIGHT – ONE POSSIBLE PATH FORWARD IN THE U.S.A.

Background: As high-speed rail and other transportation technologies are moving forward and gaining funding in the United States, the push for MagLev is not receiving the necessary support that would make it a viable alternative in the near future. Major changes in the approach to implementing MagLev could make a better case for it, specifically for carrying freight. One alternative that has been considered in the past is the modification of existing freight railways to support MagLev. For this to be economically feasible and practical, such a solution has to be able to support both conventional freight trains and MagLev freight.

Aim: The successful application of Partially Magnetically-Levitated Freight (PMLF) technology achieved by integrating superconducting MagLev technology with current railroad design and operations.

Methods: A MagLev freight system that is envisioned to use existing rail routes must be designed to be compatible with the existing railway infrastructure. To accomplish this, every component utilized by the railroads must be examined in detail to determine if and how it could be affected by the proposed PMLF. In addition, components that will need to be modified for PMLF operation must undergo a retrofit design and testing process. The design scope must also include an examination of all existing tasks and activities that are being performed by the railroads such as track maintenance and repair. Any procedures that affect or are affected by the addition of PMLF will need to be modified. Finally, superconducting MagLev technology must be optimized and advanced for application to PMLF.

Opinions and Discussions: The dual use of railway lines has substantial cost advantages when compared to building new dedicated MagLev freight corridors. In fact it could make the entire proposition very appealing if proven to be technically feasible. However, there are certain limitations and concerns that would cause policy makers to reject such a proposal unless such obstacles can be shown to be temporary and non-critical. Essential rail installations such as switches are presently difficult to modify in a way that would ensure reliable functionality for both MagLev and conventional freight trains, and grade crossings pose safety risks. It is difficult to envision the tremendous leap forward of merging MagLev with existing freight rail lines when much more basic technologies such as positive train control are not even fully implemented. Consequently, it is a challenge to advance MagLev in the United States where new dedicated freight corridors are considered to be cost-prohibitive and dual use railway lines pose uncertainties that railroad companies simply do not want to solve. However, there is one more solution has not been considered that would allow a MagLev freight train to navigate on existing railway infrastructure without disrupting traditional rail utilization. This solution is a partially magnetically-levitated freight train.

Results: After reviewing the fundamental components, systems and operations of the railways in the United States, it will be feasible and practical to introduce magnetic levitation

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technology to assist in moving freight on existing rail routes. PMLF trains will be able to take advantage of magnetic levitation on sections where the track has been upgraded to allow its use and much higher speed while still being able to travel on unmodified sections with the same speed as traditional trains.

Conclusion: Modifying existing freight rail with magnetic "quasi-lift" technology is a much lower cost alternative to building an entirely new MagLev infrastructure. This alternative will provide very important benefits including enhancing safety in the rail industry. In its first phase of implementation, the proposed PMLF system will levitate a significant portion of the weight of the train but still utilize the existing steel rails for traction and guidance. The most evident advantages of this approach include reduced wear on rail and other supporting elements, and a significant reduction in friction and energy use. Locomotives, freight cars and all other components could be made lighter and travel speeds will increase dramatically due to less impact and other effects. Later phases of implementation will focus on magnetic traction and guidance. The acceptance and success of this partially levitated system will eventually lead to fully levitated freight transport technology. Sometimes it is necessary to take smaller steps to achieve the desired future.

Keywords: MagLev Freight, MagLev Cargo, Partially Magnetically-Levitated Freight, Positive Train Control

INTRODUCTION

This is the first of what is hoped will be a series of papers that focuses on partial magnetic levitation as the most viable way forward to the transport of goods using MagLev freight in the United States. The basic concept of the system is presented in this paper. The key design parameter that will be maintained throughout the development of this system is compatibility with existing track infrastructure. This is a crucial aspect that this introductory paper focuses on. Using existing rail lines will allow the advancement of MagLev technology for the purpose of carrying cargo more efficiently and in greater quantities than would be possible with the current generation of freight trains. This advancement will also have a relatively low cost. Furthermore, partial magnetic levitation will help to optimize and to maximize the system safety components. Safety features already in place for existing rail infrastructure will be utilized and married to additional safety mechanisms that magnetic levitation can provide, enhancing the overall redundancy in safety. This is critical since freight trains using partial magnetic levitation will need to eventually travel many times faster than their traditional steel-on-steel counterparts in order to justify the investment. Accidents in emerging technologies are scrutinized to a greater extent than in established technologies which will ultimately affect funding and progress.

This is not the first attempt at proposing to modify existing rail lines for the purpose of MagLev freight but it may be the first that bases this approach on partial

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magnetic levitation. In fact there have been several different proposed solutions presented by various research organizations and private institutions in numerous countries that sought to utilize existing rail lines for MagLev. In the United States, the proposed MAGLEV 2000 system was based on superconducting magnetic quadrupoles that would allow the MagLev vehicle to travel on a planar surface such as existing railroad tracks with added aluminum loop panels. This solution and others represented almost a quantum leap from existing railway technology. A quantum leap can be very expensive and also easy to derail if problems abound during development and implementation.

Partial magnetic levitation provides a more gradual and practical approach rather than a revolutionary paradigm shift. Positive aspects of partial magnetic levitation in freight transport such as lower track maintenance and repair costs will help reduce the overall operating cost of freight trains assisted with magnetic levitation. Energy costs will be much lower as well. The major negative aspect of this gradual approach is that the greatest advantages of using MagLev such as high speeds will take longer to realize. A very important positive aspect of this gradual approach is that the three main components of MagLev technology – levitation, guidance, and propulsion – can be safely tested independently of each other and without the need for any expensive test tracks. Everything can be evaluated using existing railroad tracks with small and inexpensive modifications. Although the initial phase of the research and testing will focus on magnetic levitation, later phases will integrate magnetic guidance and magnetic propulsion into this proposed system and all three components will be continuously tested and improved until one day the technology will demonstrate that it can safely and effectively be used in full MagLev mode to transport cargo on existing rail corridors at tremendous speeds and efficiencies.

PARTIALLY MAGNETICALLY-LEVITATED FREIGHT TRAIN CONCEPT

The success of using a partially magnetically-levitated freight (PMLF) system on existing rail corridors in the United States will depend on the ability of this system to be integrated into the existing rail infrastructure without impeding on the operation of this infrastructure.

In determining the most effective and practical adaptation of magnetic levitation technologies for implementation of PLMF on existing rail corridors, it is important to consider not only the components of the existing rail infrastructure but also the operational maintenance and repair activities that are constantly being performed on this infrastructure. Geometric constraints also need to be

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considered. A brief synopsis of componentry and activities that are essential to the existing rail infrastructure is presented in below in the EXISTING RAILWAY INFRASTRUCTURE section of this paper. Major North American freight railroads are shown in Fig. 1.

The first question that must be considered is which MagLev technology is the most capable of fulfilling its function in the PLMF system while satisfying the constraints established by the existing railway infrastructure or if this is even reasonably possible.

The "parts bin" for MagLev currently includes four different systems [2]. The first system uses electromagnets on the MagLev vehicle that are attracted to metal rails on the guideway. The second system consists of permanent magnets on the MagLev vehicle and on the guideway and uses repelling forces between these permanent magnets for levitation. The third system uses permanent magnets on the MagLev vehicle and aluminum loops on the guideway and generates repelling forces by inducing currents in the aluminum loops. The fourth system

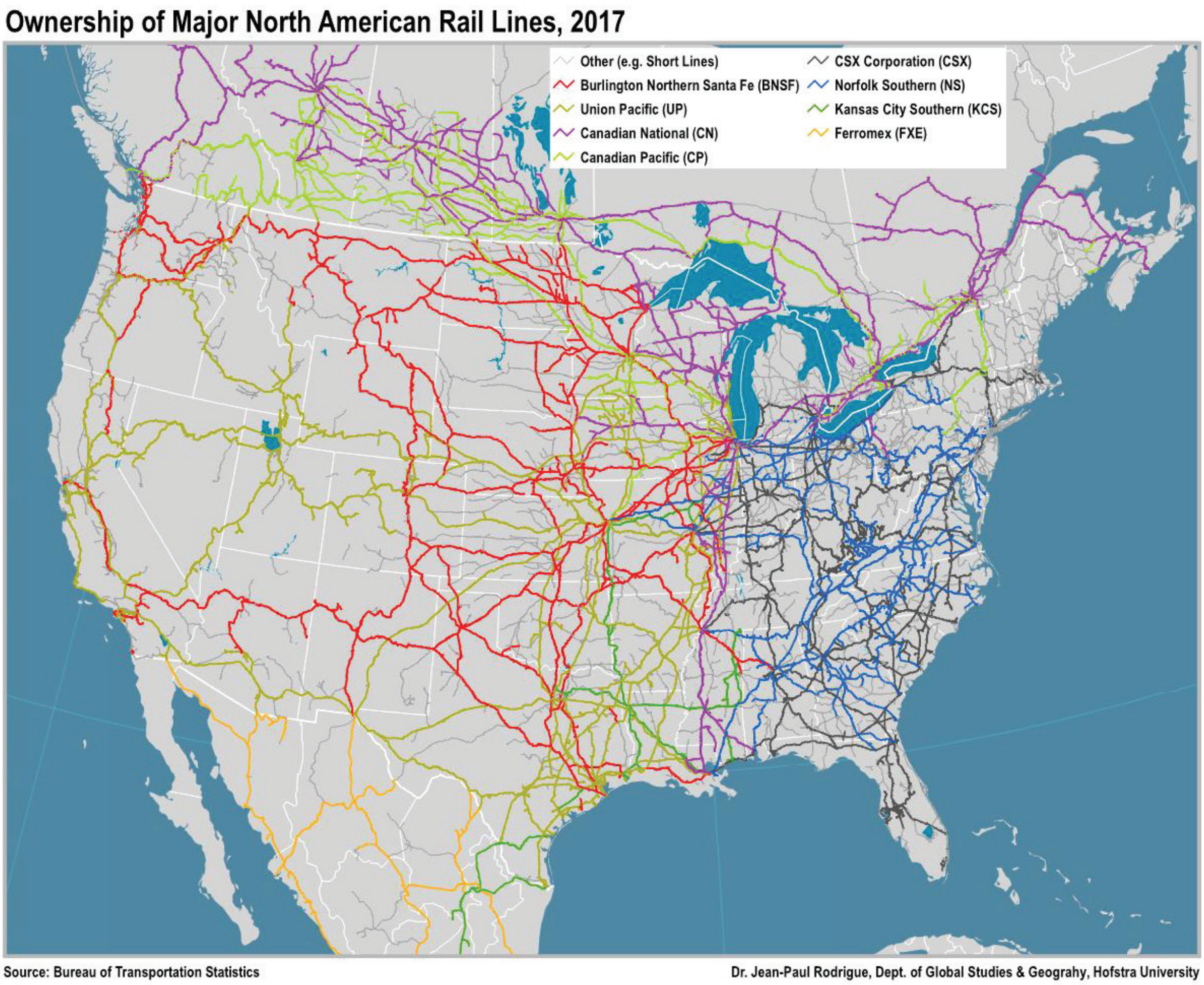

Fig. 1. Ownership of Major North American Rail Lines, 2017 [1]

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uses superconducting magnets on the MagLev vehicle that induce currents in the aluminum loops that are embedded in the guideway to generate repelling forces.

Clearly PMLF must utilize repelling magnetic forces for partial levitation since the rail track is a horizontal surface. The first system uses attractive magnetism and is not applicable. The second system that places magnets on the track is not very promising because it would be prohibitively expensive to implement. The intent is to have many thousands of miles of rail corridors available for PMLF so that placing metal loops on the track will be orders of magnitude less expensive than placing magnets on the track if such a quantity of permanent magnets can be even produced. In addition, track maintenance and repair operations will be much more complex if the magnets will have to be removed and replaced before and after such operations. The third system will not be practical because the gap between the permanent magnets on PMLF vehicles and the metal loops installed on the track will need to be on the order of about 0.13 m (½ inch.) The same limitation applies to the first and second system. In addition, the lifting power of permanent magnets is limited and could not generate the 80 % to 99 % levitation that is required to make PMLF advantageous. Superconducting magnets have this capability of lifting very heavy loads and with larger separation distances between magnets and coils. Thus, the fourth system is the only existing MagLev technology that is suitable for this application.

In addition to being very powerful with low energy requirements, superconducting magnets will allow system operation with gaps between magnets and coils as large as 0.1 m (4 inches) or more. Bare aluminum coils or coils with thin protective cover would not last very long after being attached to the railroad tracks and will likely be stolen due to the cost of aluminum. Aluminum coils that will have currents induced by superconducting magnets may be embedded in concrete panels with an inch or more of protective cover, leaving 0.76 m (3 inches) for the gap between the superconducting magnets under the PMLF vehicles and the concrete panels that are attached to the track ties. This should provide sufficient tolerance for the variability in the track's vertical alignment. It is also important to note that the track ties are not rigidly supported and could deflect 0.03 m (1/8 inch) or more vertically due to actions of concentrated wheel loads from traditional freight trains. The concrete panels must be able to accommodate differential motion and settlement between adjacent ties. The concrete panels with embedded aluminum coils must also be durable and capable of withstanding various track maintenance activities such as rail grinding. It is recommended that the concrete panels use steel pre-stressing strands in both horizontal directions to enhance durability and flexibility. Certain maintenance activities such as ballast tamping may require the panels to be temporarily removed. The ample construction tolerance due to the

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large 0.1 m (4 inch) gap that is allowed means that track maintenance and repair crews can remove and re-attach the concrete panels containing the coils without the need for expensive surveys and vertical adjustments. The next question becomes where should the panels with aluminum loops be positioned on the track – inside the rails or outside the rails or both?

The least expensive solution for positioning concrete panels with aluminum loops would be to place a single strip of panels between the rails. However, this configuration will not be as stable as placing the panels on the outside of the rails when the PMLF train is in a state of nearly full levitation. The most effective and robust solution would be to position the panels both on the inside and outside of the rails but this would be a very expensive solution. It seems that the optimal solution in terms of cost and function is to place the concrete panels with aluminum coils on the outside of the rails. Placing the coil panels used for magnetic levitation on the outside of the rails will also allow plenty of space between the rails for testing future equipment such as traction and guidance panels if it is determined that the coil panels outside the rails will not be adequate for fulfilling these functions. It is also important to note that failure of the coil panels on the track or failure of the superconducting magnets on the PMLF train will not result in damage to the PMLF train or track since the PLMF train will be able to carry its weight on wheels.

This fact that the PMLF system uses flanged wheels in addition to magnetic levitation is a tremendous advantage in terms of adapting the PMLF system to the various railway track devices and components such as turnouts, crossovers and crossings. Guidance of the PMLF train at these locations will be identical to the mechanical guidance used by traditional freight trains. It may also be very difficult to install loop panels at these locations, making mechanical guidance essential. As a result, the PMLF train will need to rely on its wheels to carry its full load at these locations. Rather than trying to solve the problem of installing loop panels at these challenging and discrete locations, relying on flanged wheels will allow the focus of PMLF development to be placed on preparing the remaining 99 % of the rail route for effective PMLF operation.

Eliminating 90 % or more of the normal contact force between the PMLF trains wheels and the supporting steel track will result in a very significant drop if friction. Moreover, PMLF cars will be significantly lighter than traditional freight rolling stock because magnetic levitation will support over 90 % of the PMLF cars' weight during 99 % of the travel time, allowing the various mechanical and structural components to be designed and manufactured to a much lighter duty service than traditional freight rolling stock, including wheels and bearings. In addition, PMLF trains are intended to transport cargo at high speeds so it is unlikely that PMLF will be initially used for transporting heavy bulk items such as

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coal, stone, cement, wood and other materials that do not require rapid transport. Energy efficiency for transporting items that require refrigeration and insulation will benefit significantly from PMLF, especially cryogenic liquids and liquefied natural gas (LNG).

The PMLF project will implement partial magnetic levitation first before integrating magnetic guidance and magnetic propulsion into the system. As a result, the first phase of the PMLF project will require locomotives that can generate considerable traction forces. These locomotives may also take advantage of partial magnetic levitation on tangents and on descending grades. Reducing concentrated contact forces between the steel wheels and rails means that there will be less impact and wear on the tracks, allowing longer maintenance intervals which will result in less disruption of rail routes and much lower maintenance costs. Electricity for the superconducting magnets mounted to PMLF cars will be supplied by fuel cells and from any excess electricity generated by the locomotives. Solar panels on top of PMLF rail cars may also be used to supplement the electricity supplied by the fuel cells. LNG has a greater energy density than rocket fuels such as kerosene and may be used to power both the fuel cells and the internal combustion engines (ICEs) on the locomotives if ICEs continue to be used on locomotives. Later phases of the project will transition completely to fuel cells (80 % + efficiency) and other energy sources. Emergency braking will be facilitated by diminishing the magnetic repulsive forces in order to increase friction between the wheels and rail. It may also be possible to have some magnets generate attractive forces to increase wheel to rail contact forces and enhance braking. Stopping distances will be much shorter than for traditional freight trains once magnetic propulsion is introduced into the system and wheel contact with rail will no longer be required for stopping. Finally, PMLF can transition to being fully magnetically levitated once both magnetic propulsion and magnetic guidance are fully implemented in later phases of this project, greatly increasing the maximum speed that the train can travel at in rural and unpopulated areas. As noted before, wheels will continue to be required unless the mechanisms for rail crossings, turnouts and crossovers are completely redesigned to include MagLev hardware to run continuously through these locations.

SAFETY SYSTEMS

Positive Train Control – Railroad safety has improved dramatically over the past few decades thanks to enforcement and development of safety regulations as well as due to the implementation of advanced safety technologies. In the United States, railway accident rates have reduced by over 80 percent within the last

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four decades. Many of the more recent accidents have been caused by human error. Positive Train Control is designed to prevent train accidents attributable to human error and to improve the operational safety of both freight and passenger railroads. PTC has the ability to slow or stop the train automatically and to safeguard against train-to-train collisions, derailments, unauthorized travel in work zones and movements of trains through faulty railroad switches [3]. The complete implementation of PTC in the United States would include about 113,000 route km (70 000 route miles) of the nearly 234,000 route km (145,000 route miles) that exist in the country. It is important to note that the United States has about 25 % of the world's rail routes which is the main reason why implementation of PTC has been slow and expensive in the United States. The original implementation deadline was December 31, 2015. The revised deadline is December 31, 2018 but the Federal Railroad Administration may approve an individual railroad's extension to an alternative deadline of December 31, 2020. What this means is that any proposed MagLev freight trains designed to share railways with other trains must be fully integrated within the PTC systems and networks if MagLev freight is not to have any restrictions on the type of cargo it carries or if it wants to use the primary rail routes. The basic system architecture for PTC is shown in Fig. 2.

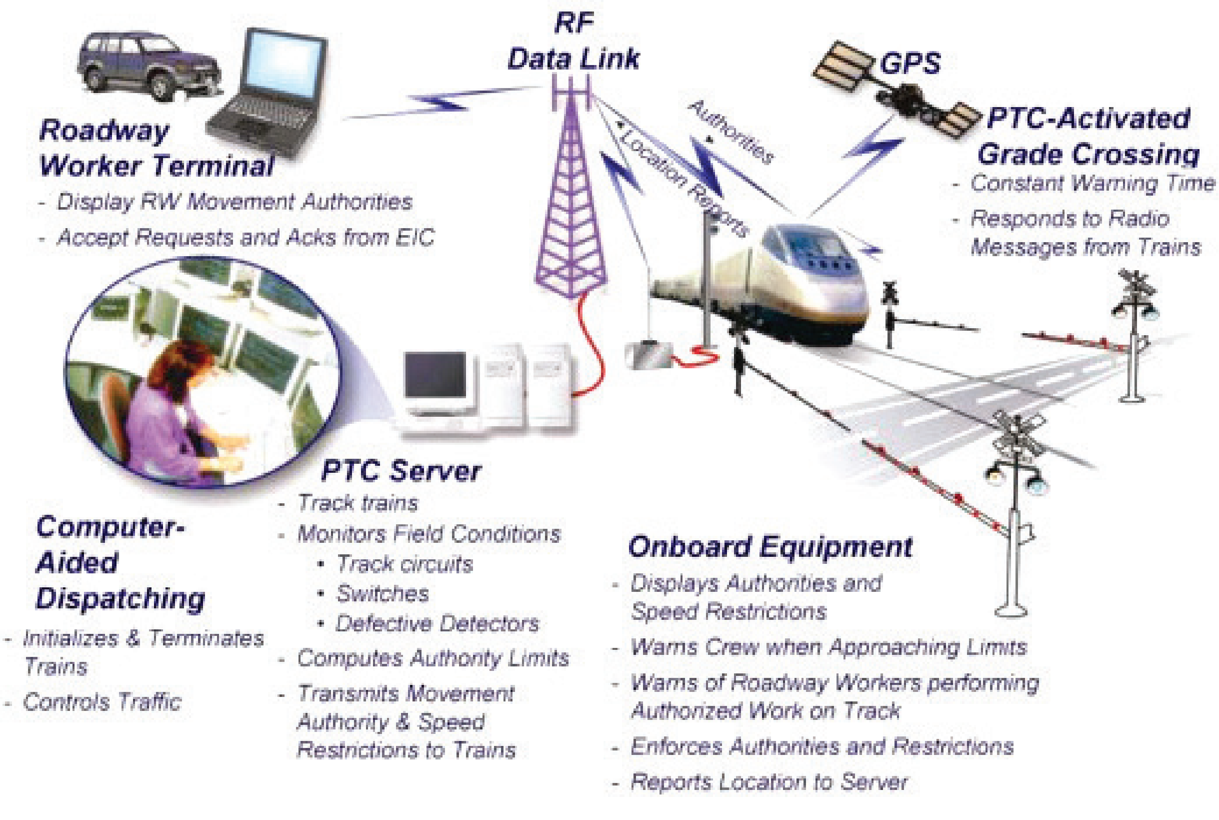

Fig. 2. Positive Train Control System Architecture [4]

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Partially levitated MagLev freight is readily adaptable to the various types of PTC that have been developed for traditional trains. Although magnetically assisted freight trains are envisioned to operate at much higher speeds than other freight trains, the PTC system is already set up for high-speed operations including high-speed rail. Operating speeds for PMLF will not exceed maximum HSR speeds. The fact that PMLF physically uses the steel tracks, switches and signals means that it will be able to take full advantage of the safety mechanisms provided by PTC. Thus, from the onset, PMLF will be able to achieve at a minimum the level of safety offered by traditional train operations. It must be emphasized that because PMLF also uses magnetic systems in addition to existing rail hardware, its safety capabilities will exceed those of its conventional counterparts. A simple example of this is a misaligned or broken rail that could be catastrophic for a traditional train but not so for PMLF that relies to a great extent on repelling magnetic for stability.

Scout Rail Vehicle – As reliable as PTC may become, there will always be some risk of error or malfunction. One of the greatest safety concerns for railroads in the United States are railroad grade crossings. This is especially true for higher speed operations. PTC is intended to eliminate human error in controlling the movement of trains but PTC has little control over human error when it comes to cars, trucks and other roadway vehicles that use railroad grade crossings. Although PTC does interface with signals and gates that are used to control vehicle entry at railroad crossings, these measures may not always prevent roadway vehicles from attempting to cross or being stopped directly over a crossing when a train is approaching. There are over 200,000 railroad grade crossings in the United States.

Suppose a small un-manned rail vehicle travels a short distance ahead of the PMLF train to scout the tracks ahead and forewarn the train of any approaching hazards. Not only could it detect damage or obstacles on the tracks and signal this information to the PTC system (this could be very useful for traditional trains in seismic zones such as California) but it could also be used as an additional safety measure at railroad grade crossings. This scout rail vehicle could physically stop at a rail crossing as the PMLF train approaches, assuring that nothing else gets on the tracks. Its light weight and small size will allow it to accelerate rapidly ahead of the PMLF train once the train is nearly at the grade crossing. Its performance could also be enhanced through partial magnetic levitation, magnetic guidance and magnetic propulsion.

Magnetic Forces – Magnetic technology can be used to enhance traction, reduce stopping distance and to supplement guidance. As a result, PMLF has the inherent safety attributes of a freight train guided by steel rails complemented by

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the additional performance benefits that can be obtained using magnetic fields. In addition, PMLF will exert much smaller concentrated forces on the tracks and other supporting elements, reducing fatigue and prolonging the service life of rail infrastructure.

EXISTING RAILWAY INFRASTRUCTURE

Unlike previously proposed MagLev concepts that were intended to partially share railway routes with traditional trains, the PMLF train concept is envisioned to be completely compatible with existing railway infrastructure and requires no additional routes or track. Furthermore, changes to the existing track components necessary to accommodate the PLMF will be initially limited to modifications or additions and will not require complete replacement. Any such alterations or additions will not affect the operation of traditional trains that PLMF trains will share the rail routes with. It is important to identify and consider the function of each prime component used in a railway track in order to determine how it will affect or be affected by the addition of PMLF.

Track Components [5].

The majority of railway infrastructure consists of track. PMLF can become a reality because the track itself is relatively simple to modify for use by PMLF trains. There is ample space to the outside of the rails to install panels housing metal loops and the loads from PMLF trains will be lighter and more evenly distributed to the ties, ballast and underlying layers.

Rail: The most expensive material in the track is the steel rail. The rail's primary function is to transfer the train's weight to the cross ties and to guide the train's wheel flanges. It also provides a smooth riding surface. Rail may vary in shape and weight. Heavy rail uses a 0.1525 m (6 inch) wide base and the preferred section weighs 70 kg/m (141 pounds per yard) of length. Light rail uses a 0.14 m (5 ½ inch) wide base and typically weighs 50 kg/m (100 pounds per yard).

Ties: Ties are typically made of timber, concrete, steel or alternative materials. Ties cushion the load of the train and distribute it from the steel rail to the ballast. Ties also maintain the gage (spacing) of the rail. Ties made from concrete require impact absorbing pads between the rail and the tie in order to achieve the desired level of cushioning. Wood ties provide impact absorption through the depth of the tie itself. Steel ties are very expensive and are used in areas not favorable to the use of timber or concrete ties including track sections with extreme curvature where the gage is prone to widening. Alternative material ties are typically made from recycled materials and are currently being tested for light rail applications. The two main types of ties are Track Ties and Switch Ties. Track Ties are typically

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2.6 m (8 feet 6 inches) long but may be 2.75 m (9 feet) long on curved sections. Switch Ties vary in length from 2.75 m to 7 m (9 feet to 23 feet.) Heavy rail timber ties are 0.178 m by 0.229 m (7 inches by 9 inches) nominal in section. Typical tie spacing is 0.495 m (19 ½ inches) for heavy rail and 0.54 m (21 ¼ inches) for medium tonnage.

Ballast Section: The ballast section anchors the ties and stabilizes the track in lateral, longitudinal and vertical directions. It also serves to rapidly and properly drain any water from the track, to facilitate track maintenance and to distribute the load from the ties to the underlying subgrade. The preferred materials used for ballast are granite, hard limestone, open hearth and blast furnace slags. Important characteristics of the ballast particles include size and shape, degree of sharpness, angularity and roughness. Typical depth of the ballast section is 0.46 m to 0.61 m (18 to 24 inches) and extends 0.254 m to 0.305 m (10 to 12 inches) past tie ends.

Rail Joints: Rail joints are used at rail discontinuity points to hold in place and align two ends of rail. They consist of two joint bars that prevent lateral and vertical movement of the rail ends while allowing longitudinal movement of the rails due to thermal expansion or contraction. Standard rail joint bars connect two identical sections of rail. Compromise rail joint bars connect two rails that have different sections (weights). Insulated rail joints are used when track circuits are present in order to prevent the track circuit's electrical current from flowing between the ends of the joined rail.

Tie Plates: Tie plates provide a uniform bearing surface between the rail and the tie so that the rail does not damage the tie.

Rail Anchors: Rail anchors attach to the base of the rail and control longitudinal and transverse movement of the rail due to thermal effects, braking, grades and train traffic patterns.

Fasteners: Fasteners can be spikes, bolts and screws that are used to connect rail or track components together including fastening rails to ties.

Derails: Derails prevent unauthorized or unsecured rolling stock from entering specific tracks by guiding its wheels off the track.

Wheel Stops and Bumping Posts: Wheel stops prevent rail cars from rolling off the ends of tracks or into structures. Bumping posts are rail car stops that consist of braced blocks that are at the elevation of rail car couplers. These are heavy duty stops that are placed on track to prevent rail cars and other equipment from running off the track.

Gage Rods: Gage rods supplement ties in maintaining the gage of the track. They are also used to temporarily retrofit a defective tie until it can be replaced. Gage rods are either insulated where track circuits are used or non-insulated.

Sliding Joints: Also called Conley joints, these are used instead of rail anchors to allow longitudinal expansion and contraction of the rail on open decked

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bridges. Sliding joints have beveled rail ends that move but still provide continuity and support.

Mitre Rail: Mitre rails allow track to be opened and closed at frequent intervals. These are most often used on draw bridges and swing span bridges.

Guard Rails: These are derailment rails typically used on bridges, in tunnels and for overpasses. These prevent derailed equipment from falling off a bridge or an overpass or from impacting the sides of a tunnel or structure. Inner guard rails are placed between the running rails and typically use a T-rail section. Outside guard rails may use timber members.

Turnouts.

Turnouts allow trains to pass from one track to another track. They consist of a switch, a frog, rails connecting the switch and the frog, guard rails, and a switch stand for operating the switch. The three basic types of turnouts are Lateral, Equilateral and Lap. Lateral right hand turnouts have the diverging track running to the right. Lateral left hand turnouts have the diverging track running to the left. Equilateral turnouts have both tracks diverging and are often used in regions of higher operating speeds since the curvatures of the Equilateral turnouts are half of those required for Lateral turnouts. Lap turnouts are typically used in rail yards where maximum track lengths are required and contain two sets of switch points and three different frogs.

Designing turnouts to accommodate metal loops used by PMLF will require significant research and testing due to all the existing components that are present at these locations. Again, PMLF trains will initially cross these locations without relying on magnetic forces. Turnouts have a limited service life and a good opportunity to upgrade these to provide full PMLF functionality is during replacement.

Switch: A switch deflects the wheels of a train from the track upon which the train is running. The most common switch is the split switch in which two point rails are connected by switch rods and are supported on metal plates fastened to ties. The switch (point) rails taper to 64 mm (1/4 inch) or 32 mm (1/8 inch) point at the end which is appropriately called the point of the switch. The other ends of the switch rails are called the heel where the switch rails connect to the lead rails using joint bars about which the switch pivots. The switch stand controls the movement of the switch rails which is about 0.127 m (5 inches.) Switch rails are typically from 3.4 m to 11.9 m (11 feet to 39 feet) in length, but can be longer for high turnout numbers. Switches may be hand operated, power operated or both.

Turnout Rails: Turnouts are made from several special rails. Stock rails are the outside rails in a switch that the point rails bear against. Closure rails connect

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the heel of the switch points and the toe of the frog. Knuckle rails are the rails that the movable point in a frog bears against.

Frog: A frog is used at an intersection of two running rails and it allows the flange of a wheel moving on one rail to cross onto the other rail. Frogs are classified as either rigid, spring rail or movable point frogs. Spring frogs provide continuous support for the wheel as it rolls over the frog flangeway. These frogs have a movable wing rail that is held closed by springs and a guardrail that pulls the wheel over, forcing the wing rail to open on the diverging side. Rigid frogs may use one piece castings as inserts or may be bolted together using machined rails. Movable point frogs are used where the angle between the two sets of crossing tracks is very acute and would result in an excessively long throat if conventional crossing diamond frogs were used. Movable point frogs use two movable center point rails to maintain the flangeway.

Switch Ties: Special standardized switch tie layouts are used for turnouts. Two head block ties are used under the switch mechanism. Heel block ties are used under the heel block assembly. Frog ties are used to support the frog.

Stock Rails: Stock rails have the same section shape as the switch point rails. The stock rail on the diverging side of the switch point is bent to assure a proper fit so that there is no wheel impact on the point.

Switch Points: Switch points are moveable rails that allow a change of route direction to occur within the turnout. Switch points typically consist of a tip, heel, planed (machined) portion, reinforcing bar, switch clips and stop blocks. Switch points are comprised of machined rails that are snug fit against the stock rail. The change of direction is achieved when the point is moved away from the stock rail. Stop blocks are used for lateral support due to the wheel pushing outward on the planed rail.

Turnout Plates: Different types of turnouts use a specific set of supporting and bracing plates, including gage, switch, heel, hook and frog turnout plates.

Guard Rails: Turnout guard rails are used to prevent misrouting or derailing at the frog. They also prevent the wheels from striking the frog point.

Switch Stands: Switch stands are used for operating the switch. High stand switch stands are used on main line applications and ground throw stands are used in yards or at industrial locations. Main line switch stands have a target that is colored green when the switch line is set for the normal route and red if the switches are reversed. A power switch is operated by an electric machine that lines the switch and can be operated remotely or manually. A spring switch is a hand thrown switch that uses a spring mechanism instead of a rigid connecting rod.

Railway Crossings and Crossovers.

A railway crossing is used at an intersection of two tracks. A crossing requires four frogs and connecting rails. Crossings may be straight, single curve or double

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curve. When crossing angles are greater than 25 degrees, rails and manganese castings are cut to fit against each other and are secured using filling blocks and well-bolted straps. For crossing angles smaller than 25 degrees, regular frog point devices are used and these crossings are designated as frog crossings. The end frogs of a frog crossing are similar to a rigid frog. The middle frogs have two running points and are often described as double pointed frogs. Crossovers are simply two turnouts except that the track between the frogs follows the frog angle. Crossovers pose the same challenges as turnouts in terms of installing PMLF components.

Road Crossings.

Road crossings occur where roads, streets or highways intersect the track at grade and are thus often called grade crossings. These locations have increased maintenance requirements and present a very important safety concern. Different types of materials are used for road crossings including timber, asphalt, concrete and pre-manufactured rubber. Some crossings may be unsurfaced. The type of material used at a crossing is dependent on the amount of vehicular traffic that uses the crossing. Road crossings will be easy to modify to include embedded metal loop panels for PMLF use.

Crossing Warning Devices: Warning signs, signals and pavement markings are important means of warning motor vehicles approaching the crossing. Automatic warning flashers and gates are used at road crossings with higher vehicular volume or where higher speed trains use the track. It is important to note that a large number of road crossings in the United States do not use gates.

Utility Crossings.

Various utilities such as pipes, cables, conduits and wires cross the railways at many locations. Utilities often also run along the track right of way. Utilities may be overhead or underground. There are numerous general and safety standards for utility crossings. These are not expected to be impacted by converting the track to PMLF use.

Maintenance and Restoration Activities.

Railways must be maintained and rehabilitated at regular cycles with minimal disturbance to the track. Maintenance and rehabilitation programs include spot replacement of ties, correction of gage deficiencies, smoothing, elimination of joints, adjustment of continuous welded rail (CWR), turnout maintenance, repair of battered rail ends, and grinding of rail.

Major restoration and track renewal activities are performed using specialized production gangs. These activities include rail replacement, tie replacement, undercutting/ballast replacement, surfacing, road crossing renewal and turnout renewal.

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Each activity will need to be evaluated in terms of how it affects the addition of PMLF service and how it needs to be modified in the future to better optimize PMLF utilization. A good example is tamping which is an activity that vibrates the ballast surrounding the ties. Initially, the concrete panels with embedded metal loops used by PMLF to generate repelling forces will need to be removed from the rail ties so that the ballast tamper can perform its function. However, it will not be difficult to modify the tamping machine to tamp the ballast without having to remove these panels.

Affects on Passenger and Commuter Trains.

It should be noted that one specific area of concern regarding MagLev vehicles is the stray magnetic fields produced by the magnets and electrical components and how these could affect passengers [6]. This will not need to be considered for PMLF since all the superconducting magnets will be mounted to a freight train that will not carry passengers. The metal loops embedded in the concrete panels that will be attached to the track will not have any magnetic effects on passengers in trains that will pass over these regardless if the track is electrified either by overhead catenary or third rail systems.

FUTURE RESEARCH DEVELOPMENT

There are three principal areas of research and development that are critical to the effective future implementation of PMLF on existing rail corridors:

- Superconducting MagLev Technology;
- PMLF Impacts on Railway Operations;
- Integration with Communication and Safety Systems.

First, superconducting magnetic levitation technology utilizing dipole and quadrupole magnets must be evaluated in detail and adapted to the design of a new fleet of freight rail cars and locomotives. This also includes research on the modification of existing rail infrastructure to accommodate PMLF, such as the installation of inductive loops and other components. Later phases of the project will require comprehensive R&D of magnetic propulsion and guidance.

Second, the effects of PMLF on all existing railroad activities must be considered in detail to assure that there is no disruption of service, maintenance, repair and other operations. This research will also allow future improvements and modifications to be made to the railroad infrastructure and to the equipment used. This will benefit both traditional freight and PMLF operation. The successful development of high speed PMLF will also provide more funding to maintain the rail infrastructure due to additional revenue from cargo shipments that require rapid transport.

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Third, PMLF must be fully integrated with all railway communication, signaling and safety systems. This complete integration must be in place when PMLF trains are first entered into service. Much research, development and testing needs to be performed to meet this requirement, including incorporation of PMLF into the Positive Train Control network. However, the general approach for integrating PMLF with these systems will be based on the approach that is being used for traditional trains, making the process more efficient.

Finally, many MagLev researchers and contributors do not feel that it is feasible for any form of MagLev to share existing railway infrastructure and that MagLev systems must be designed as completely independent transportation systems [7]. However, the United States has such an extensive rail network that the possibility of sharing it with MagLev should be considered. In fact, other researchers have already considered this as being feasible but with a different approach than PMLF. The MAGLEV 2000 system proposed vehicles that could function on planar surfaces and modified railroad tracks by using quadrupole superconducting magnets.

CONCLUSION

The United States has the largest rail network in the world. The successful application of Partially Magnetically-Levitated Freight (PMLF) technology in the United States would allow MagLev technology to be tested and used on nearly a quarter of the world's rail routes that exist in the United States without having to build a single kilometer of a test track. It is essential that any MagLev freight system that is designed to utilize existing rail routes be fully compatible with the existing railway infrastructure. PMLF makes this possible by combining superconducting MagLev technology with traditional wheels-on-steel-rail locomotion. PMLF will be able to take advantage of near full magnetic levitation and high speed on long stretches of rail routes while being able to rely on mechanical means used by traditional trains to navigate congested urban and industrialized areas with numerous turnouts and rail crossings. This backward-compatibility will assure that PMLF can be integrated into the Positive Train Control network and other safety systems used and required by railroads.

PMLF will allow goods to be transported by rail more efficiently than ever before and it will also allow freight operation on rail routes to achieve speeds many times higher than were ever achieved before in the USA. Similar systems could be adopted in other countries. Continued research and development of PMLF, including magnetic propulsion and guidance, will eventually allow fully magnetic operation of freight trains on rail routes that have been updated with MagLev equipment.

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