GUIDEWAY SWITCH APPARATUS FOR MAGNETICALLY LEVITATED VEHICLES

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ABSTRACT

A switch is used, at the divergent zone, to cause the vehicle bogie to follow one path or the other in the guideway. This is accomplished by substituting an attracting magnetic array on the side that the vehicle bogie is desired to follow. The switch may operate without moving parts, so there is no inertial penalty to limit operational frequency. The switch is designed to fail gracefully in the absence of activation power or control signals. Further, the switch is designed to ensure that there would be no derailment or dropping of a vehicle.
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CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] The present application claims benefit to U.S. Provisional Patent Application No. 60/870,884, filed Dec. 20, 2006, the complete disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention is directed to transportation or transit systems, and more specifically, to networked guideway transit systems designed to enable the movement of large numbers of passengers or parcels in a flexible manner.

[0003] Guideway-based transportation systems have been used to transport people or goods. One example is a “Personal Rapid Transit” (PRT) system. In the PRT system, each vehicle carries just one party or small group (or payload) from their origin directly to their destination, starting at a time determined by the party’s arrival at its origin. Vehicles are typically piloted by computer and move non-stop along guideways with diverging and merging paths. At origin and destination access points (termed “portals”) vehicles stop on separate siding guideways so they do not impede the progress of other vehicles that are continuing to other destinations.

[0004] However, the use of wheels as the primary method of suspending vehicles continues to pose a significant barrier to PRT implementation. In addition, the unavoidable wear accompanying wheels rolling on tracks becomes a significant maintenance problem when a typical system might utilize thousands, or tens of thousands of vehicles. Further, the use of wheels imposes a speed limitation on the vehicles. Small, cheap wheels are generally not capable of even the speed range over which automobiles operate. Wheels capable of that range of speed or higher become expensive and heavy, and their potential failure becomes a serious safety issue. Thus, current PRT systems lack an economical, reliable and lightweight means to carry vehicles in slower speed, tight systems and faster, longer distance systems.

[0005] Further, in a PRT system, a switch, that is the piece of guideway that makes possible the splitting or merging of paths, may be one of the most important and valuable technological features. However, it is complicated and costly to construct switches that change the directions of vehicles traveling at any operational speed for the portion of network in which it is located. In some PRT systems, underhanging vehicles are desirable. However, the risk of a vehicle becoming detached and actually falling out of the guideway is an inherent problem of switches conventionally designed for underhanging vehicles. Thus, it is needed to construct switches that prevent the derailment, jamming or falling out of a vehicle under any conditions or circumstances.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same become better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

[0010] FIG. 1A is a perspective view of a networked guideway system in accordance with an embodiment of the present invention;

[0011] FIG. 1B is a perspective view of the networked guideway system showing an exposed view of modular guideway blocks of the guideway in accordance with an embodiment of the present invention;

[0012] FIGS. 2A and 2B are cross-sectional views of an exemplary embodiment of a bogie segment used in the networked guideway system;

[0013] FIGS. 3A and 3B are perspective views of the networked guideway system of FIG. 1A showing an exposed view of bogie segments of the vehicle bogie in accordance with an embodiment of the present invention;

[0014] FIGS. 4A and 4B are cross-sectional views of an exemplary embodiment of the modular guideway block used in the networked guideway system;
FIG. 5 depicts a cross sectional view of an exemplary embodiment of a portion of guideway showing a bogie segment nested in a modular block guideway.

FIG. 6 depicts an exemplary way of implementing the EDR centering subsystem in the networked guideway system; and

FIGS. 7A-7F are cross-sectional views of different embodiments of the bogie segment and the modular guideway block used in the networked guideway system;

FIGS. 8A-8C are cross-sectional views of a switch portion of the guideway in accordance with an embodiment of the present invention; and

FIGS. 9A-9C are cross-sectional views of a switch portion of the guideway in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

The following detailed description describes exemplary embodiments of the present invention. Although specific system configurations and flow diagrams are illustrated, it should be understood that the examples provided are not exhaustive and do not limit the present invention to the precise forms and embodiments disclosed. It will be apparent to one skilled in the art that the invention may be practiced without some or all of these specific details. In other instances, well-known process steps have not been described in detail in order not to unnecessarily obscure the invention.

A method and system to integrate magnetic levitation technologies within a networked guideway transit system is provided. The magnetic levitation is used to replace wheels as the primary means of vehicle suspension and thus the automated transit systems (e.g., PRT system) can be made commercially and economically feasible. More specifically, a method and system use permanent magnet repulsion with induction-based repulsion within the networked guideway transport system, which can levitate passively with motion.

Generally, the guideway in the networked guideway transit system includes a point where the guideway begins to split into two separate guideways, i.e. a divergent zone, the two sides of the guideway are spaced progressively farther apart. A switch is used, at the divergent zone, to cause the vehicle bogie to follow one side or the other of the diverging guideway. The switch may use electromagnet sources instead of permanent magnets so that the magnetic force can be altered to direct the vehicle bogie to either path. The switch can use any suitable magnetic sources as long as the magnetic force of the magnetic sources can be altered to direct the vehicle bogie to either path. The switch may operate without moving parts, so there is almost no inertia penalty to limit operational frequency. The switch is designed to fail gracefully in the absence of activation power or control signals. Further, the switch is designed to ensure that there would be no derailment or dropping of a vehicle. That is, vertically attracting magnets or electromagnets are used to deflect segments of an articulated vehicle bogie without causing loss of suspension stability or requirement of any moving parts or active position control subsystems. The switch operates at very high vehicle speeds and switching frequencies, i.e., short vehicle headways.

Magnetic Levitation

Magnetic levitation (hereinafter, “Maglev”) may provide advantages compared to traditional wheels on tracks. Generally, Maglev has low or zero mechanical friction and thus parts in a Maglev system do not wear from contact. It has a wide range of speeds over which it can operate and in operation it generates relatively low noise levels. Conventionally, Maglev as applied to traditional large train system architecture provides only marginally improved service characteristics, i.e., primarily shorter transit times on long runs where extreme ground speeds are attainable and practical. Because aerodynamic losses prevail at high speeds and powerful propulsion systems are required to overcome these losses, the extreme ground speeds achievable with Maglev are only feasible with large trains and large footprint guideways, and are obtained at an enormous energy cost. And with existing complex Maglev systems that require sensors, positional feedback, active control, or even active levitation power, this marginal benefit comes at much higher cost in basic infrastructure, and at increased risk for technical or operational problems.

In general, the combination of functional capabilities of Maglev technology and PRT systems may have been considered counterintuitive. The counterintuitive nature of this relationship is due to the failure of recognizing the performance potential of the respective technologies. In contrast, in forgoing described and supplied embodiments, using a proper form of Maglev technology to replace wheels as the primary means of vehicle suspension makes a networked guideway transit system both feasible and commercially achievable as a method of moving vehicles. In addition, linear motor propulsion used with the Maglev suspension allows the great majority of the guideway to have no contact and little mechanical friction. This means less wear and less dust is generated compared to conventional Maglev systems, both of which factors contribute to lowering maintenance and improving reliability.

Guideway Transit System

As will be discussed in greater detail below, a networked guideway transit system 100 includes levitation, centering and propulsion components, utilizing permanent magnets to provide primary levitation and electrodynamic repulsion to create centering forces.

With reference to FIGS. 1A and 1B, perspective views of a networked guideway transport system 100 are depicted in accordance with some embodiment of the present invention. The networked guideway transit system 100 generally includes a guideway 120 and a mating vehicle 160. The guideway 120 has a suitable geometry to support and guide the vehicle 160 at any speed reasonably associated with such a networked guideway transit system. The guideway 120 may include several modular guideway blocks that are straight and short segments of the guideway. As used herein, the modular guideway block refers to a basic unit of the guideway. As depicted in FIG. 1B, the modular guideway blocks may be loaded into a shell that forms the guideway structural beam 122 to carry the load between support columns 115.
In the networked guideway transit system 100, the vehicle 160 is supported by a vehicle bogie (not shown) that interlocks with the guideway 120. As will be discussed in detail below, the vehicle bogie is a guideway element that couples a vehicle to the guideway. The vehicle bogie used for the networked guideway transit system may include several bogie segments, each of which includes levitation, centering and propulsion components. Each bogie segment may have a finite length in order to fit in a single modular guideway block 110. One non-limiting example of the bogie segment is shown in FIGS. 2A and 2B.

It is noted that the figures described herein are not meant to show the exact or relative sizes, or the locations of the various components, but rather to illustrate the general configuration for the purposes of the discussion.

FIGS. 2A and 2B illustrate cross-sectional views of the bogie segment 200 in accordance with an embodiment of the present invention. The bogie segment 200 includes primary permanent magnet repulsion (PMR) arrays, such as a bogie lifting magnet unit 204, that provide upward forces on the vehicle bogie. The bogie segment 200 further includes clamping magnets, for example a bogie clamping magnet unit 206, that provide downward or vertical clamping forces on the bogie.

The clamping magnets of the bogie segment 200 are additional static magnetic field sources, generally high field permanent magnets with poles aligned so as to be in repulsion to magnets on the guideway. It is noted that the clamping magnets are static magnets and can be located on the guideway or the vehicle bogie. In the illustrated embodiment, the bogie clamping magnet unit 206 is located on the vehicle bogie and makes use of the bottom sides of the guideway magnets to produce repulsion. In this embodiment, the bogie clamping magnet unit 206 may be used to add a downforce to the overall vertical force on the bogie segment 200. It is further noted that the bogie clamping magnet unit 206 may be sized and positioned as appropriate such that the bogie clamping magnet unit 206 does not significantly decrease the levitation height provided by the bogie lifting magnet unit 204, but in the event the vehicle bogie rides too high because of load perturbations, the bogie clamping magnet unit 206 forces the bogie back down more rapidly than gravity alone. This may stiffen the suspension and assist to maintain the vertical position of the vehicle bogie. Also, in the case where an end of the vehicle bogie protrudes into a section of the guideway that does not contain PMR components for lifting, the bogie clamping magnet unit 206 may prevent the protruding end of the vehicle bogie tipping down into that unsupported section by holding down the opposite end.

In addition, the bogie segment 200 can include a passive centering device (e.g. a device including the electrodynamic repulsion (EDR) centering components 208) that comprises moving coils or conductor stacks. The EDR centering components 208 may primarily provide centering forces but may also provide some propulsion forces to the bogie segment 200. The bogie segment 110 may contain more PMR components (linear magnetic arrays) for mating, such as a bogie propulsion magnet unit 202, each arranged to be in opposition to corresponding PMR components (linear magnetic arrays) in the guideway.

In one embodiment, the EDR centering components 208 may also function as propulsion components. As will be discussed in greater detail below, the coils in the conductor arrays (not shown) of the EDR centering components 208 are energized to provide forward thrust or regenerative braking by interaction with the magnets arranged in the guideway. The electrical power may be delivered to the moving coil, the stationary coil or a combination thereof. In some embodiments, both stationary and moving coils are included in the vehicle bogie. In such embodiments, the stationary coils can deliver primary electrical power to the vehicle bogie, which is converted to the kinetic energy of motion, while the moving coils deliver secondary electrical power to the onboard energy supply by tapping into the same kinetic energy. In this manner, the electrical power can be transmitted from the guideway to the vehicle bogie (eventually to the vehicle) without contact. The stationary coils may be combined into a modular guideway block. It is noted that the bogie segment described in conjunction with the aforementioned embodiments may include other components well known in the transportation art but not shown for ease of illustration, such as centering rollers, skids, electric motors that provide a drive source to the vehicle, etc.

FIG. 3A depicts a perspective view 300 of the networked guideway transit system showing an exposed view of bogie segments. As shown, one vehicle bogie 360 may include a set of five bogie segments. In a preferred embodiment, the networked guideway transit system uses underhanging vehicles 160 to facilitate high-speed operation. The vehicle bogie 360 is mounted on vehicle attachment fin 362 that attaches the underhanging vehicle 160 to the vehicle bogie. The vehicle bogie 360 is used for supporting the underhanging vehicle 160 and for mating the underhanging vehicle 160 to the guideway 120. As described above, the lifting is generated by magnetic repulsion between permanent magnets of the PMR components in the guideway modular block 110 and the vehicle bogie 360. FIG. 3B depicts another perspective view 300 of the networked guideway transit system showing an exposed view of articulated bogie segments. Each bogie segment has a size such that the bogie segment can be nested in a modular guideway block 110. In order to navigate some portions of the guideway with tight radii, including diversion points of the guideway, the bogie segments of the vehicle bogie 360 may be articulated to flex in a horizontal dimension. That is, the bogie segments of the vehicle bogie 360 may be hinged along its vertical front and rear edges. This arrangement may leave the vehicle bogie rigid in the horizontal or vertical dimension. Moreover, in this way, the full mass of the vehicle 160 is distributed along the full length of the bogie segment. In addition, the bogie segments of the vehicle bogie 360 may be able to traverse sections of the guideway where there is not full magnetic levitation available.

In addition, it is possible to reduce the bogie size (the cross section of the bogie) by combining the motor propulsion and EDR centering functions. The small cross section of the bogie reduces its aerodynamic resistance. Thus, its mass can be minimized. The largest lateral dimension may be kept small, which facilitates good track switch design. It should be noted that the roll stability of the bogie is not dependent on the lateral spread between the primary lifting PMR components, but rather is achieved by the vertical spread between the EDR centering components.

In one embodiment, several modular guideway blocks may be loaded into a shell that forms the guideway structure beam to carry the load. The weight of the guideway beam is mostly static mass, not vehicle mass. Further, by using materials and methods designed to minimize the static weight, cost and physical size of the guideway beam, the
supporting structure of the guideway (guideway beam) can be easily erected and the modular guideway blocks can be inserted with simple equipment. Further, the installation cost is minimized by the modular nature of the guideway components, which can be manufactured in a controlled factory environment using mass production methods.

[0036] The modular guideway block of the networked guideway transit system will now be described in more detail. In FIGS. 4A and 4B, cross sectional views of the modular guideway block are depicted in accordance with an embodiment of the present invention. FIG. 5 depicts a cut away view 500 of a portion of guideway showing a bogie segment 360 nested in a modular guideway block 400 in accordance with an embodiment of the present invention.

[0037] The modular guideway block 400 also comprises several PMR components that may be linear arrays of high field permanent magnets. Generally, there are two or more linear static magnetic arrays in the modular guideway block 400 as the PMR components. In one embodiment, the modular guideway block 400 includes a first PMR component, for example a guideway lifting magnet unit 420, that provides primary lifting and vertical clamping forces. As will be appreciated, the primary lift forces are produced by static magnets in the first PMR component arranged in homopolar linear arrays, the long axis of the arrays aligned in the travel direction of the moving vehicle. The modular guideway block 400 further includes a second EDR component, for example a guideway propulsion magnet unit 430, that provides primary centering forces and auxiliary propulsion forces. Permanent magnets used in the guideway lifting magnet unit 420 and the guideway propulsion magnet unit 430 may vary in size depending on track locations.

[0038] The modular guideway block 400 further comprises EDR centering components, such as guideway propulsion coils 442, that passively centers a moving vehicle bogie. That is, the EDR centering components of the modular guideway block 400 and the EDR magnets of the bogie segment 200 constitute an EDR centering subsystem that controls and centers the moving bogie via the interaction between the EDR magnets and electrically conductive elements in the networked guideway transit system. There are various ways to implement the EDR centering components. For example, when the vehicle bogie is at standstill or moving at low speeds (e.g., below a few meters per second), the EDR centering components in the modular guideway blocks are not effective. In this case, centering rollers or skids (not shown) keep the vehicle bogie laterally centered. It is noted that the locations of the EDR magnets and the EDR centering components of the EDR centering subsystem may be exchanged so that various embodiments can include any suitable arrangements of the permanent magnets and coils. One non-limiting example of implementing the EDR centering subsystem is depicted later in FIG. 6.

[0039] As discussed above, the PMR components and the EDR centering components included in the bogie segments and/or the guideway modular blocks perform well as a means of conveyance in the networked guideway transport system 100. That is, the levitation (lift force) produced by the PMR components has good lift to magnet mass ratio, a significantly low drag at all speeds and can ride over small gaps between adjacent sections. As such, the PMR components used in the bogie segments and the modular guideway blocks can be compact, much smaller than wheels of the same carrying capacity and suspension stiffness. The PMR components have no rotational inertia and lower mass than a comparable wheel system.

[0040] To control possible lateral instability in the PMR components and to maintain the alignment of the lifting magnets (PMR components), one or more EDR centering subsystems are used in the described embodiments. The EDR centering subsystem comprises electrically conductive elements, for example the guideway propulsion coils 442, that are in relative motion to the magnetic sources (e.g., propulsion magnet units). As the magnetic flux varies within the conductors, electrical currents are induced to flow. The interaction of these currents with the magnetic fields produces forces with drag and repulsion components. As discussed above, the EDR centering subsystem has the advantage of producing nearly constant force over a large range of transverse displacement. Thus, the EDR centering subsystem works well when displaced in a direction normal to the travel direction and the force direction. Also, the force increases as the separation between the magnets and conductors decreases, making the arrangement stable in that axis.

[0041] In one embodiment, the networked guideway transit system may utilize a dual EDR arrangement that includes two magnetic arrays facia a set of conductors, or conversely a set of linked conductor arrays bracketing a magnetic array. The restoring force may increase as the center element moves further off the center plane in the dual EDR arrangements. These attributes make EDR centering subsystems complementary to the characteristics of the PMR components lifting arrangement in the networked guideway transit system.

[0042] As will be appreciated, there are a number of ways to implement EDR subsystems in conjunction with the networked guideway transit system. One non-limiting exemplary way of implementing the EDR subsystem is depicted in FIG. 6.

[0043] As shown in FIG. 6, the permanent magnet arrays (EDR magnets) in the bogie segment are located at the center with coils that are used as passive centering device. The coils, such as guideway propulsion coils 442, are connected in laterally opposite pairs in such a way that the motion induced voltages cancel when the magnet arrays are laterally equidistant from the coils. In this embodiment, if the permanent magnet arrays are closer to one side than the other, current flows within each coil pair and the forces tend to push the magnets back to a center position. Both arrangements are present in embodiments discussed in conjunction with FIGS. 2A, 2B, 4A and 4B above. In the embodiments, electrical energy can be transmitted from the guideway to the bogie-vehicle or vice versa.

[0044] The degree of roll stability required on any particular section of the guideway is determined by several factors, including the curvature of the guideway, the speed of travel, the mass of the vehicle, and the position of the vehicle, among others. Some of such factors can be controlled for a particular period or position of the guideway magnetic fields. For example, in a turn where the bogie-vehicle mass pushes against the outer wall of the guideway larger fixed magnets could be installed, while on the inner wall smaller magnets could be used. In this way, the centering force could be biased to anticipate and compensate for required centripetal turning force. It is also possible to drive the EDR coils, for example the propulsion coils 208, 442 (FIGS. 2A, 4A), in such a way as to produce an active lateral force. This arrangement can be used in high-speed turns to reduce the magnetic drag incurred
by the large passively induced currents that would otherwise be present. Generally, the energy required to actively drive the EDR coils to produce lateral force is on the order of one fourth that required for producing the same force by passive induction.

[0045] In an alternative embodiment, the networked guideway transit system may include a series connection of multiple coils to increase inductance of the EDR centering subsystems, which tends to reduce overall centering force but also reduce magnetic drag and the velocity at which the drag force transitions to centering force. This may be used for a lower speed section of the guideway. Likewise, the series or parallel connection of multiple coil pairs to the electrical drive or sinking circuits affects the magnitude of the induced voltage and can be optimized for the expected operational speed and power source characteristics.

[0046] Referring now to FIGS. 7A-7C, cross sectional views of exemplary embodiments of a portion of guideway including a modular guideway block and a bogie segment are depicted. As shown in FIG. 7A, an exemplary embodiment 710 includes the EDR components that are shown as inwardly pointed permanent magnet arrays 430 in the guideway, outwardly focused permanent magnet arrays 202 on the bogie, and propulsion coils 442, 208. Motion in the travel direction induces voltages within the guideway propulsion coils 442 in the guideway and coils 208 on the vehicle bogie. In both cases, the coils are connected in laterally opposite pairs such that the motion-induced voltages within the coils tend to oppose when the vehicle bogie is on the center plane. This results in no current flow within the coils.

[0047] When the vehicle bogie is biased toward one side of the guideway the voltages increase in the coils on that side and decrease in the coils on the opposite side. This results in a forward current in the coils on the close side and a back current in the coils on the far side. The close side experiences repulsion while the far side experiences attraction. This tends to bring the bogie back toward the center plane. The lack of currents when the bogie is at the center plane results in very low magnetic drag at that position. Because there are laterally constraining forces high and low, the bogie is resistant to rolling. The underhanging vehicle 160 (FIG. 3A) can be damped in its swinging motion with the resulting reaction forces taken up by the bogie and transmitted to the guideway without mechanical contact. Both the upper and lower centering elements in this configuration can contribute to propulsion.

[0048] As shown in FIG. 7B, an exemplary embodiment 720 includes the PMR components and the upper lateral centering elements similar to the exemplary embodiment 710 described above and a modified EDR subsystem. As with the exemplary embodiment 710, the upper lateral centering elements may function as the primary motor in the exemplary embodiment 720. The exemplary embodiment 720 may include lower centering elements having an EDR arrangement that uses a stack of planar conductive elements 290 or a so-called ladder track instead of coils. The stack of planar conductive elements 290 is a passive electrical conductor array. The PMR components, such as guideway propulsion magnet unit 430, of the guideway are focused inward onto this conductor array. As the vehicle bogie moves, voltages are induced within the conductors. Because the guideway magnets, such as the guideway propulsion magnet unit 430, are arranged so that their lateral fluxes are oppositely directed there is a steep gradient in the lateral flux density with lateral position, with lateral flux density tending to zero at the center plane. The induced voltages are strongly dependent on the lateral flux components so at center plane minimum voltages occur.

[0049] As in the previous embodiment the voltages give rise to currents within the conductors and the interaction between these currents and components of the magnetic flux field tend to push the conductor stack (and thus the bogie) back toward the center plane. Because there are laterally constraining forces high and low the bogie is resistant to rolling and the underhanging vehicle 160 (FIG. 3A) can be damped in its swinging motion. The resulting reaction forces taken up by the bogie may be transmitted to the guideway without mechanical contact. The advantages that the exemplary embodiment 720 has are simpler construction of the conductor array compared to the motor coils, and more powerful centering force for the same magnetic array size. In fact, the exemplary embodiment 720 produces the strongest centering forces for a given size of centering element and it produces those strong centering forces near the pivot point where they are maximally effective at controlling lateral displacement of the vehicle.

[0050] As shown in FIG. 7C, an exemplary embodiment 730 includes several permanent magnet components and upper lateral centering elements in a similar manner to the exemplary embodiment 710. The lower centering elements in this embodiment 730 are also the same as the upper centering elements, including the guideway propulsion coils 442 and a permanent magnet component 202 for flux generation. This exemplary embodiment 730 has the advantage of additional propulsion power from motor coils with guideway-sourced power. Also, significantly, this embodiment 730 uses much less magnet mass in the guideway, which may lead to substantial cost reductions in construction.

[0051] Referring now to FIGS. 7D-7F, more exemplary embodiments are depicted. As shown, bogie segments of these embodiments do not include clamping magnets 206 (FIG. 2) for providing vertical clamping forces. Instead, the exemplary embodiments 740, 750, 760, include two EDR centering subsystems. The upper subsystem comprises a linear motor with bogie propulsion magnet arrays 202, a guideway located drive module 449 and guideway propulsion coils 442. Motion in the travel direction induces voltages within the guideway propulsion coils 442. The coils are connected in laterally opposite pairs such that the motion-induced voltages within the coils tend to oppose when the bogie is on the center plane. This results in no current flow within the coils. When the bogie is biased toward one side of the guideway the voltages increase in the coils on that side and decrease in the coils on the opposite side. This results in a forward current in the coils on the close side and a back current in the coils on the far side. The close side experiences repulsion while the far side experiences attraction. This tends to bring the bogie back toward the center plane. The lack of currents when the bogie is at the center plane results in very low magnetic drag at that position.

[0052] The lower EDR centering subsystem comprises a pair of EDR components, such as guideway based planar conductor stacks 290 as shown. The same magnets 202 that provide the flux for the motor and centering in the upper subsystem provide flux for the lower subsystem. In this case, the magnets are above the conductors but overlap by a small fraction of the conductor height. The transverse flux of the magnet arrays induces currents to flow within the guideway
based planar conductor stacks 290. The magnitude of the currents varies with the flux density and with the degree of overlap between the magnets and the conductors. When the magnets are closer to one side, the flux density, and thus the induced current, is greater. When the overlap is greater, the induced current is also greater. The pattern of conductive pathways within the stacks is such that the induced currents flow through vertically oriented paths and are concentrated in the upper and lower edges of the stacks. The interaction of the longitudinal components of the magnetic fields and the electrical currents through the vertical conductors causes forces that tend to push the conductors away from the magnets. Since the magnitude of the force is dependent on the magnitude of the electrical currents, the closer the magnets are to the conductors the larger the repulsion force between them. The electrical currents are dependent on the proximity between the magnets and the conductors, and on the magnitude of the flux density at the conductor (which also increases with decreasing distance). Thus, this may produce a laterally stable arrangement.

The intersection of the transverse components of the magnetic fields and the concentrated currents in the upper edges of the conductor stacks create forces that tend to resist the vertical overlap of magnets and conductors, in effect pushing the magnets back up out of the space between the conductor stacks. In the described embodiments, the lift generated by the motion of the bogie reduces or eliminates the requirement for the direct magnetic repulsion from the homopolar permanent magnet arrays.

Switch for the Networked Guideway System

Generally, the guideway 120 in the networked guideway transit system 100 includes a divergent zone where the two sides of the guideway are spaced progressively farther apart. As described above, a switch is used, at the divergent zone, to cause the vehicle bogie to follow one side or the other of the diverging guideway.

In some embodiments, the switch (the switch zones of the guideway) may include electromagnets so that the magnetic force can be altered to direct the vehicle bogie to either path. In such embodiments, even in the event that no power was supplied to the system and the electromagnets failed to energize, the dead zone would be significantly short and would not cause a complete loss of lift. Instead, the vehicle bogie would travel this section with four of five segments in full PMR levitation, but without benefit of the lateral guidance provided by the electromagnetic arrays. Without the active electromagnets, the path of the active bogie would be determined by the passive EDR centering components and inertia.

An exemplary embodiment, a new electromagnet array may be added in the switch, located above the bogie lifting magnet unit (primary PMR component for lifting). The two vertically opposite attracting guideway arrays exert lateral forces that combine in the same direction and act to bring the PMR components in the vehicle bogie on the first side into proper vertical alignment.

It is noted that the vehicle bogie is not pushed to the outer wall of the guideway but rather to a position where the PMR components in the vehicle bogie and the electromagnet array (in the switch) in an attraction mode are vertically aligned. As a result, the switch causes one side of the bogie to tend to follow the side of the guideway with the dual attraction arrangement. In such cases, another side (second side) of the vehicle bogie is still experiencing lift and lateral forces that push the vehicle bogie off from the center. The switch also includes a electromagnet array operated in a repulsion mode, which allows the second side of the vehicle bogie to experience a vertical clamping and a lateral push, at least while the vehicle bogie and the electromagnet array are in proximity. However, as the sides of the guideway diverge and the guideway arrays are spaced farther apart, the leading edge of the vehicle bogie tracks one side with the electromagnet array operated in the attraction mode and moves away from the other side with the electromagnet array operated in the repulsion mode. At some point the divergence becomes large enough that there is space enough for two complete sets of guideway magnet arrays. At this point, the orientation of all magnets in the modular guideway block is returned to a repulsion mode.

The switch will now be described in more detail in conjunction with FIGS. 8A-8C showing cross sections of a switch portion of the guideway in accordance with an embodiment of the present invention. In FIGS. 8A-8C, each cross section view depicts a portion of the guideway at three different points 810, 820, 830 during a switching operation, for example, a switch portion 810 immediately before divergence, a switch portion 820 during divergence and a switch portion 830 immediately after divergence.

As shown, in the first switch portion 810, the bogie segment is laterally trapped by upper centering/propulsion elements 420, 202 and lower centering/propulsion elements 430, 208. The lift is still provided by guideway permanent magnet arrays 420 at both sides acting on bogie magnet arrays 204. Propulsion, if it is active, is provided by the upper and lower centering/propulsion elements.

In the second switch portion 820, the bogie segment is transiting a portion of the guideway 120 where the outer walls of the guideway have diverged, leaving a wider than normal space in the interior. The permanent magnet lifting arrays in the guideway are replaced with vertically polarized track switching homopolar electromagnetic arrays 725, 726 within this portion. The electromagnetic arrays 725, 726 within this portion are energized by power sources within the guideway electronics module 449 in either of two directions. That is, the electromagnetic arrays of the two sides are energized with opposite polarity. On a first side of the guideway, the electromagnetic arrays 725 are energized with the same polarity as the polarity of the bogie lift magnets 204 so that there is attraction between those elements, both vertical and lateral. Because there is attraction both upward and downward from the upper and lower electromagnet arrays, the net vertical force can be minimized. The lateral attraction forces are summed, creating a strong net lateral attraction for the bogie lift magnets. This tends to pull the attracted side of the bogie segment into alignment with the electromagnet arrays on the first side.

In the second switch portion 820, on a second side of the guideway the electromagnetic arrays 726 are energized with the opposite polarity as the bogie permanent magnets 204. As a result, there is repulsion between the electromagnets and PMR components on the bogie, for example the bogie lifting magnet unit (PMR component) 204, the bogie clamping magnet unit (PMR component) 204, etc. Such repulsion causes the bogie magnets to be moved laterally out from between the electromagnetic arrays on the second side. The net result of the pulling in on the first side 725 and the pushing out on the second side 726 is to cause the bogie
segment to track toward the side with the attracting electromagnet arrays. Since the polarity of the electromagnet arrays can be reversed by simply reversing the electrical current through the electromagnets, the direction of bogie movement can be switched by choosing the direction of current. It is noted that the force attracting the bogie segment forces a vertical alignment of the bogie lifting magnet unit 204 with the active guideway electromagnets. Also, throughout the transit, the lateral repulsion (EDR) elements are still active on the attraction side of the guideway, further preventing the collision of the bogie segment with the wall of the modular guideway block. Preferably, there may be one bogie segment out of five within the divergent track section at any time so the remaining bogie segments continue to provide lift and stability for the whole bogie. The short length of divergent track also makes it mechanically improbable for the bogie to dive downward through the bottom of the guideway.

[0062] As shown in the third switch portion 830, the bogie segment has transited the divergent section of guideway and is engaged with a fully functional modular guideway block of the typical construction. When the front segment of the bogie has transited the divergent section the bogie is well captured at both ends and is very stable. The guideway has become two separate fully functional guideways free to follow divergent paths.

[0063] Referring now to FIGS. 9A-9C, cross sections of a switch portion of the guideway including a bogie segment nested in a modular block are depicted in accordance with another embodiment of the present invention. In the first switch portion 910, the bogie segment is still laterally trapped by upper centering/propulsion elements 420, 202 and lower centering/propulsion elements 430, 208. The lift is still provided by PMR components, such as the guideway lifting magnet unit 420 at both sides acting on the PMR components, such as the bogie lifting magnet unit 204, in the bogie segment.

[0064] In the second switch portion 920, the bogie segment is transiting a portion of guideway 120 where the outer walls of the guideway have diverged, leaving a wider than normal space in the interior of the guideway. As discussed above, the guideway lifting magnet units in the guideway are replaced with vertically polarized track switching homopolar electromagnetic arrays 725, 726 within this portion. These electromagnetic arrays are energized by power sources within the guideway electronics module 449 in either of two directions. The electromagnetic arrays of the two sides are energized with opposite polarity. If one side of the electromagnetic arrays 725 is energized with the same polarity as the polarity of the bogie lift magnets 204 then it provides attraction toward both the primary bogie lift magnets 204 and the bogie clamping magnets 206. Such attraction is both vertical and lateral. Because there is attraction both upward and downward from the upper and lower electromagnet arrays the net vertical force is minimized. But the lateral attraction forces are summed creating a strong net lateral attraction for the onboard lift magnets and onboard clamping magnets. This tends to pull the attracted side of the bogie segment into alignment with the electromagnet arrays on that side. If the other side of electromagnetic arrays 726 is energized with the opposite polarity as the polarity of the bogie lift magnets 204 then it provides repulsion toward both the primary bogie lift magnets 204 and the bogie clamping magnets 206. This repulsion causes the bogie segment to be moved laterally out from between the electromagnetic arrays on that side. The result of the pulling in (attraction) on one side 725 and the pushing out (repulsion) on the other side 726 is to cause the bogie segment to track toward the side with the attracting electromagnet arrays.

[0065] As shown in the third switch portion 930, the bogie segment has transited the divergent zone of the guideway and while exiting the divergent zone, the bogie segment is engaged with a modular guideway block 932 of the desired path. When the front segment of the bogie has transited the divergent zone, the bogie is well captured at both ends and is very stable.

[0066] A failsafe behavior of the switch and the networked guideway system will be discussed in greater detail below. In case when the switch is a symmetric divergent zone, with each side curving away at the same rate and at laterally adjacent locations, then the electromagnets there would be energized to direct a vehicle bogie to either curve. If an asymmetric divergent zone is used where one side continues straight ahead while the other curves away, then energizing the electromagnets is only required in order to follow the curving side. Thus, even if a power or control fails, a vehicle bogie entering this divergent zone would continue to follow the straight path, which would then be the default path (the inertial path).

[0067] At the location where the full divergence is achieved and the single guideway becomes two guideways, the exiting path, which was straight until that point, bends away but with full support of lifting and centering components. The continuation path also has full lifting and centering components beyond the point of full divergence. In this arrangement, there is only one place where magnetic lateral pull is required, i.e., at the start of the continuation path. In other locations the vehicle bogie is guided by passive repulsion forces and inertia or, in the case of very low speed operation, auxiliary rollers or skids.

[0068] As discussed in detailed above, the network guide-way system includes the permanent magnet repulsion (PMR) components, consisting of static field magnetic sources with poles arranged so that their fields oppose each other and developing repulsion forces. Lateral accelerations of various magnitudes will be utilized on various parts of the network guideway system as the vehicle bogie and the vehicle move through. It is advantageous to execute the divergence in as short a travel distance as possible in order to minimize the fraction of the vehicle bogie that is over the divergence at any time. The lateral acceleration on each individual bogie segment is a function of the radii of curvature of the guideway segment and the velocity of the bogie/vehicle.

[0069] It is contemplated that the spread between left and right levitation magnets is minimized to reduce the required lateral separation. In one embodiment, the separation is controlled to occur in a track length equivalent to one segment of the set of five bogie segments. In this embodiment, the excessive lateral accelerations would allow the underhanging vehicle to swing laterally. In such a position the underhanging vehicle does not immediately experience the lateral accelerations of the vehicle bogie but instead swings slightly to accommodate the rapid movement of the vehicle bogie first one way then back to centerline. It is important to note that the highest lateral accelerations are imposed on only one segment of the vehicle bogie at a time, so the magnitude of the force required executing the maneuver is much reduced. Once the front bogie segment has traversed the divergent zone where it is engaged by one side only of the guideway, the behavior of
the electromagnets is less critical to the execution of the operation. At the point where the leading edge of the vehicle bogie has re-engaged a full complement of passive centering and levitation components, the electromagnets could cease function and the operation would still succeed, though at less than optimal performance. In fact, after the first moments of lateral acceleration on its leading edge a vehicle bogie moving at speed will cross the divergent zone to re-engage the full guideway beyond.

As discussed previously, the self-centering behavior of the attractive magnet arrangements may preclude the need for lateral position sensing for good operation under most circumstances. Note that in the circumstance of extreme travel velocities (for example, upwards of 100 mph (160 kph)) extreme lateral accelerations on the bogie segments may require additional direct electromagnetic attraction during the initial curvature. In that case, position sensing may be required to prevent the vehicle bogie from contacting the guideway wall.

The opposite operation of divergence is convergence, where two paths merge into one. This operation is accomplished by similar means, although in general it is more easily performed than the divergence operation. If the electromagnetic arrays of the switch are replaced with permanent magnet arrays arranged to be in vertically attracting positions and the whole configuration is turned around with respect to the travel direction, then a vehicle bogie approaching this apparatus will abruptly enter a zone where its front segment is magnetically captured by one side and the other is left hanging. As the two paths converge the front bogie segment will eventually ride over both sets of attracting magnet arrays and be laterally captured between the usual passive EDR centering components. At that point the magnet orientations revert to repulsion, the extra arrays are eliminated and the two guideways have merged into one. It is noted that this configuration may be implemented with no active components at all. As will be appreciated, it is important to keep the single sided track sections as short as possible in the travel direction.

In a particular situation, a converging zone can act as a latch if only one side of its magnetic arrays is in attraction mode while the other side is left in repulsion. As a vehicle bogie traverses this switch in the convergence direction it will function much as the standard convergence zone. But if a vehicle bogie traverses this switch in the convergence direction it will always follow one path, the path with the attractive magnets. This type of switch may be useful in special situations, for instance parking vehicles in holding bays alongside a low speed through path.

While illustrative embodiments have been illustrated and described, it will be appreciated that various changes can be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A switch apparatus for directing a vehicle bogie in the networked guideway transit system at a divergent portion of a guideway, the switch comprising:
   an electromagnet component for directing a vehicle bogie to a desired direction in the guideway;
   a guideway levitation component for lifting the vehicle attached to the vehicle bogie; and
   an electrodynamic repulsion component for passively centering the vehicle bogie.

2. The switch apparatus of claim 1, wherein the vehicle bogie is directed to the desired direction by the polarity of the electromagnet component.

3. The switch apparatus of claim 2, wherein the polarity of the electromagnet component is changed by reversing the electrical current through the electromagnet component.

4. The switch apparatus of claim 3, wherein the electromagnet component includes a first electromagnet array and second electromagnet arrays which are vertically polarized homopolar electromagnetic arrays.

5. The switch apparatus of claim 4, wherein the first electromagnet arrays and second electromagnet arrays are arranged laterally opposite to each other.

6. The switch apparatus of claim 4, wherein the first electromagnet arrays are energized in the direction that attracts a permanent magnet component of the vehicle bogie.

7. The switch apparatus of claim 6, wherein the second electromagnet arrays are energized in the direction that repels the permanent magnet component of the vehicle bogie.

8. The switch apparatus of claim 1, wherein the divergent portion is a portion of the guideway where the guideway begins to split into two separate guideways.

9. A networked guideway transit system that utilizes permanent magnets levitation and electrodynamic repulsion, the networked guideway system comprising:
   a vehicle bogie that comprises a set of bogie segments, each bogie segment including a bogie levitation component for providing lifting forces and a bogie propulsion component for providing propulsion forces on the vehicle bogie, wherein the vehicle bogie supports a vehicle in the networked guideway transit system; and
   a guideway that comprises a first portion and a second portion, each portion including a set of modular guideway blocks,
   wherein each modular guideway block in the first portion includes a guideway levitation component for lifting the vehicle, a guideway propulsion component for moving the vehicle bogie, and a electrodynamic repulsion component for centering the vehicle bogie and each modular guideway block in the second portion includes an electromagnet component for directing the vehicle bogie, a guideway levitation component for lifting the vehicle, and an electrodynamic repulsion component for centering the vehicle bogie.

10. The system of claim 9, wherein the polarity of the electromagnet component is reversed based on the desired direction of the vehicle bogie.

11. The system of claim 10, wherein the polarity of the electromagnet component is reversed by changing the electrical current through the electromagnet component.

12. The system of claim 9, wherein the bogie levitation component includes a first permanent magnet for providing forces for lifting the vehicle and a second permanent magnet for providing forces for clamping the vehicle.

13. The system of claim 9, wherein the set of bogie segments is nested in the set of modular guideway blocks.

14. The system of claim 9, wherein the second portion is a divergent portion of the guideway where the two sides of the guideway are spaced progressively apart.

15. The system of claim 9, wherein the first portion is a non-divergent portion of the guideway.

16. The system of claim 9, wherein the electrodynamic repulsion component includes guideway propulsion coils and
the bogie propulsion magnet component is positioned at the center with the guideway propulsion coils.

17. The system of claim 9, wherein the bogie levitation component includes a first permanent magnet component and a second permanent magnet component placed in a linear arrangement, the first permanent magnet component providing forces for lifting the vehicle and a second permanent magnet providing forces for clamping the vehicle.

18. A method for implementing a switch for directing a vehicle bogie in the networked guideway transit system at a divergent portion of a guideway, wherein the switch comprises an electromagnet component for directing a vehicle bogie to a desired direction in the guideway, the electromagnet component comprising a first electromagnet arrays and second electromagnet arrays, a guideway levitation component for lifting the vehicle attached to the vehicle bogie and an electromagnetic repulsion component for passively centering the vehicle bogie, the method comprising:

- determining a desired direction for the vehicle bogie;
- determining the first electromagnet arrays that corresponds to the desired direction;
- energizing the first electromagnet arrays in the direction that attracts permanent magnet components of the vehicle bogie; and
- energizing the second electromagnet arrays in the direction that repels the permanent magnet component of the vehicle bogie.

19. The method of claim 18, wherein the first electromagnet arrays are energized with the same polarity as the permanent magnet components of the vehicle bogie while the second electromagnet arrays are energized with the opposite polarity as the permanent magnet components of the vehicle bogie.

20. The method of claim 19, wherein the polarity of the first electromagnet arrays and the polarity of the second electromagnet arrays is changed by reversing the electrical current through the electromagnet component.

21. The method of claim 18, wherein the first electromagnet arrays and second electromagnet arrays are arranged in laterally opposite to each other.

22. A method for conveying a vehicle bogie along either of two guideway paths that converge to a single path within a networked guideway transit system, wherein the guideways include guideway levitation components for lifting the vehicle attached to the vehicle bogie, electrodynamic repulsion components for passively centering the vehicle bogie and electromagnet guidance components for directing a vehicle bogie along its incoming pathway until the two pathways merge to one, the electromagnet guidance components comprising first electromagnet arrays and second electromagnet arrays, the method comprising:

- detecting the vehicle bogie approaching the convergent portion of a guideway; and
- energizing the first electromagnet arrays in the direction that attracts the permanent magnet component of the vehicle bogie and energizing the second electromagnet arrays in the direction that repels the permanent magnet component of the vehicle bogie.

23. The method of claim 22, wherein the first electromagnet arrays and the second electromagnet arrays are replaced with permanent magnet arrays with the same polarity as the permanent magnet components of the vehicle bogie.

24. The method of claim 22, further comprising:

- detecting the vehicle bogie moving in a backward direction;
- determining a pathway for the vehicle bogie to follow; and
- energizing the first electromagnet arrays in the direction that attracts the permanent magnet component of the vehicle bogie and energizing the second electromagnet arrays in the direction that repels the permanent magnet component of the vehicle bogie,

wherein the first electromagnet arrays corresponds to the intended guideway path.

25. The method of claim 23, wherein the first permanent magnet array has the same polarity as the permanent magnet components of the vehicle bogie and the second permanent magnet array has the opposite polarity as the permanent magnet components of the vehicle bogie such that the vehicle bogie moving in the backward direction is to follow the determined pathway.

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