

[54] **TRANSPORTATION SYSTEM EMPLOYING AN ELECTROMAGNETICALLY SUSPENDED, GUIDED AND PROPELLED VEHICLE**

[75] Inventors: **Richard D. Thornton**, Concord;  
**Henry H. Kolm**, Wayland, both of Mass.

[73] Assignee: **Massachusetts Institute of Technology**, Cambridge, Mass.

[22] Filed: **July 23, 1971**

[21] Appl. No.: **165,616**

[52] U.S. Cl. .... **104/148 SS, 191/2, 318/135, 335/216**

[51] Int. Cl. .... **B61b 13/08**

[58] Field of Search ..... **104/148 LM, 148 MS, 104/148 SS, 130; 191/2; 318/135, 227; 310/12, 13**

[56] **References Cited**  
**UNITED STATES PATENTS**

|           |         |                         |            |
|-----------|---------|-------------------------|------------|
| 3,158,765 | 11/1964 | Polgreen .....          | 310/12     |
| 3,470,828 | 10/1969 | Powell, Jr. et al. .... | 104/148 SS |
| 3,611,944 | 10/1971 | Reder .....             | 104/148 LM |
| 3,622,818 | 11/1971 | Payen .....             | 318/135    |
| 3,624,472 | 11/1971 | Graham .....            | 318/227    |
| 3,513,338 | 5/1970  | Poloujadoff .....       | 104/148 LM |
| 3,472,176 | 10/1969 | Trent .....             | 104/130    |
| 3,508,496 | 4/1970  | Larson .....            | 104/130    |

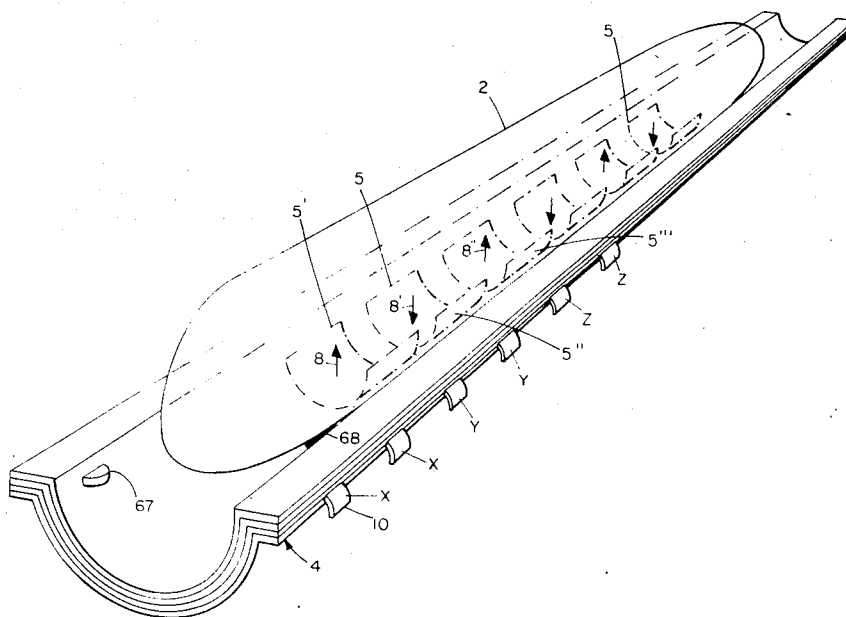
*Primary Examiner*—Gerald M. Forlenza  
*Assistant Examiner*—George H. Libman  
*Attorney*—Thomas Cooch et al.

[57] **ABSTRACT**

A system that includes an elongate cylindrical vehicle

operable to travel along a similarly-shaped, trough-like guide-way. At stations along the guideway, the vehicle is supported by wheels, but between stations it levitates at about 25 centimeters above the inside guideway surface. Levitation of the moving vehicle is effected by interaction between magnetic dipole fields provided by superconducting coils or permanent magnets disposed over substantially the whole lower surface area of the vehicle and a pair of spaced conducting strips located on the guideway inner surface and oriented parallel to the longitudinal axis of the guideway throughout its length. The vehicle is free to rotate or pivot about its longitudinal axis and this, coupled with the very resilient support over its entire length, permits it to travel at 200 kilometers per hour and beyond with minimum discomfort to passengers being transported. The magnet dipole fields must be of the order of 1,000 to 3,000 gauss at a distance of 25 centimeters from the vehicle to give the support necessary to maintain the 25 centimeter clearance. The necessary propelling force is supplied by a polyphase winding which is disposed in the lower portion of the guideway between the conducting strips; the winding produces a traveling-wave magnetic field that interacts with the magnetic dipole fields. Between stations synchronous operation is accomplished by employing a.c. power input with a cycloconverter, i.e., an a-c to a-c converter, to reduce the input frequency to an appropriate ratio. Acceleration and deceleration of the vehicle is accomplished by varying the frequency of the cycloconverter to provide synchronous interaction between the magnetic field of the winding and the magnetic dipole fields of the superconducting coils as the vehicle accelerates. Provision is made for switching vehicles, and a novel method of guideway fabrication is disclosed.

**29 Claims, 27 Drawing Figures**



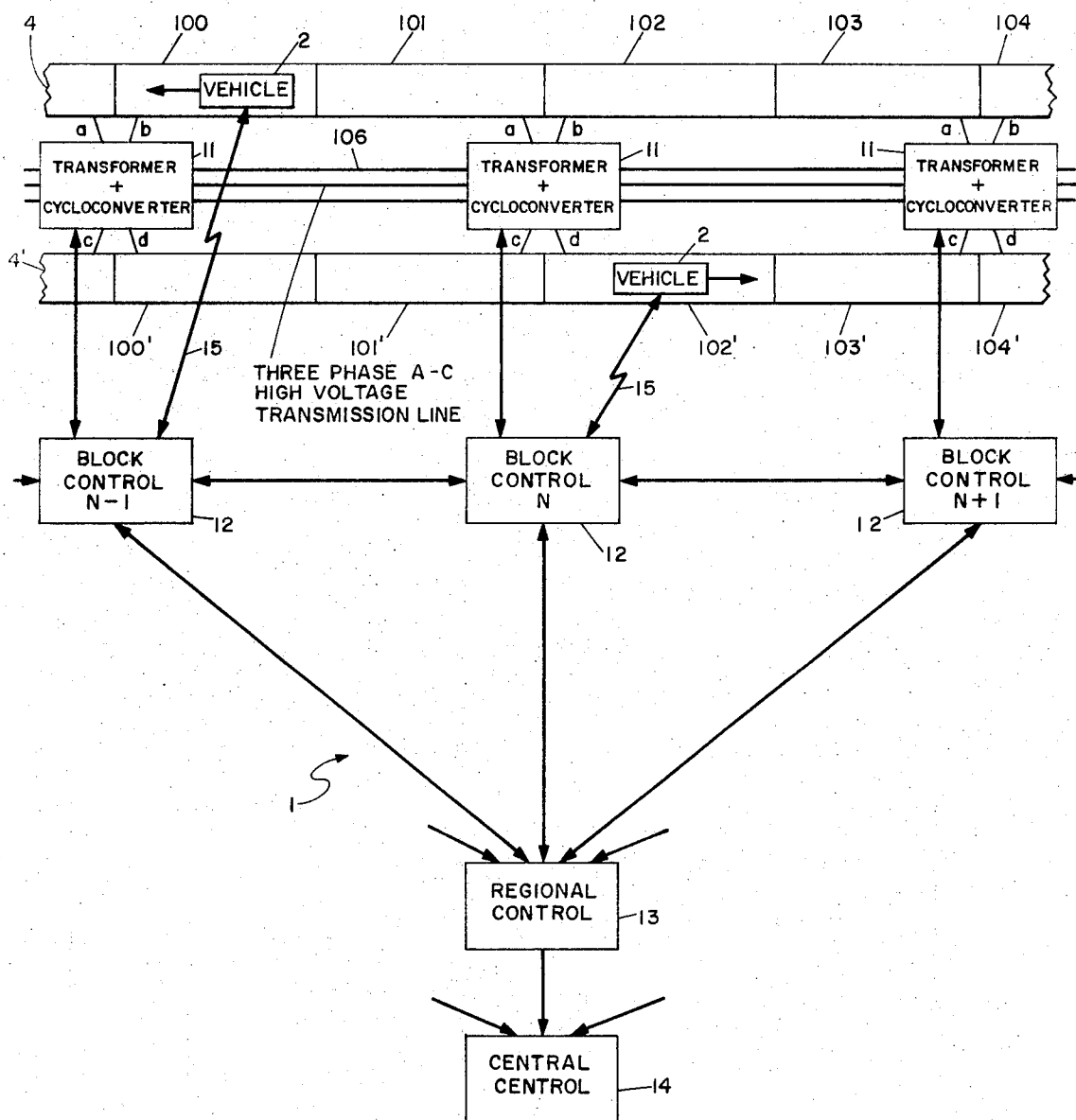
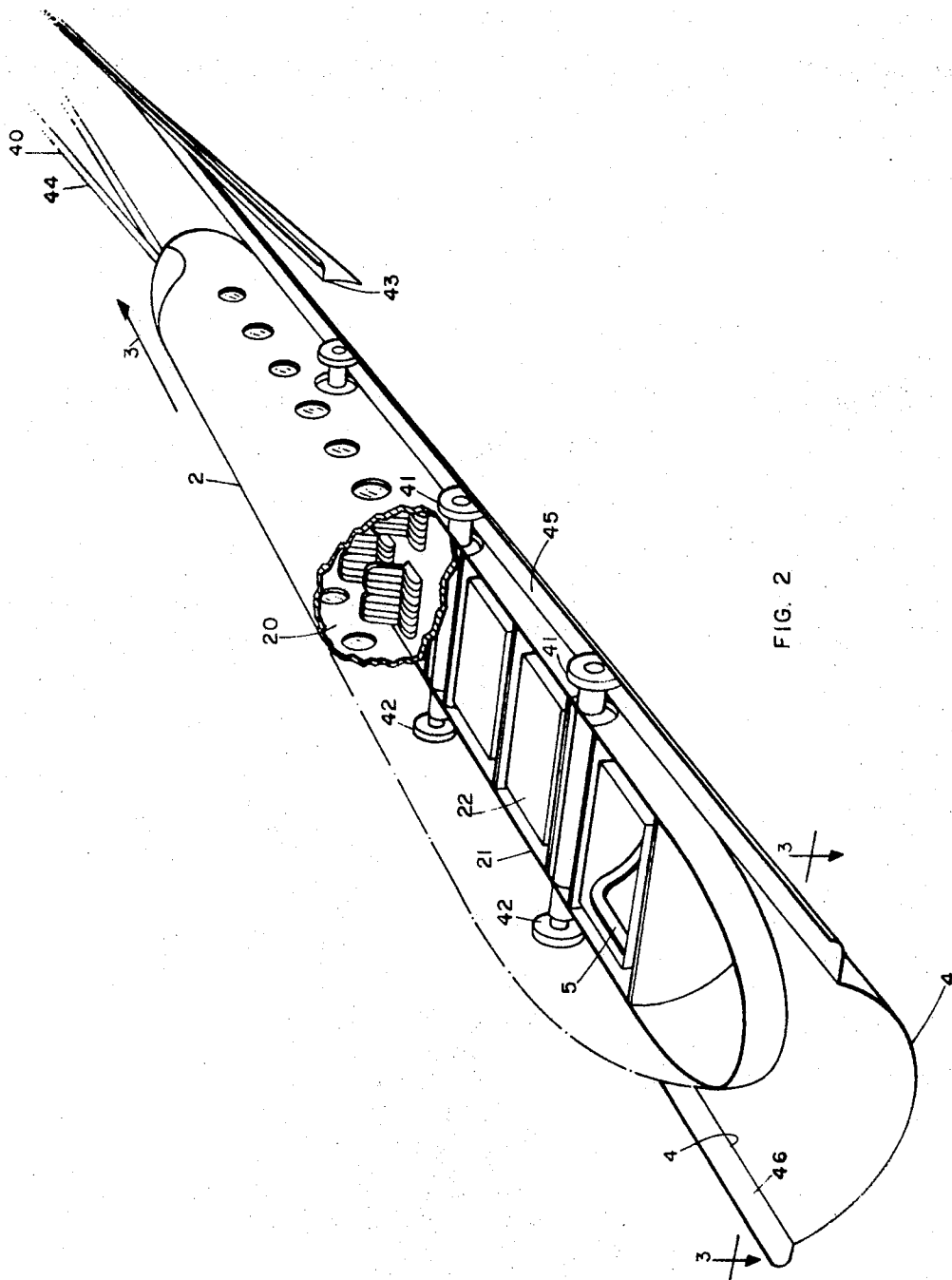


FIG. 1

INVENTORS:  
 RICHARD D. THORNTON  
 HENRY H. KOLM  
 BY *Robert Shaw*  
 ATTORNEY



INVENTORS:

RICHARD D. THORNTON

HENRY H. KOLM

BY

*Robert Shaw*  
ATTORNEY

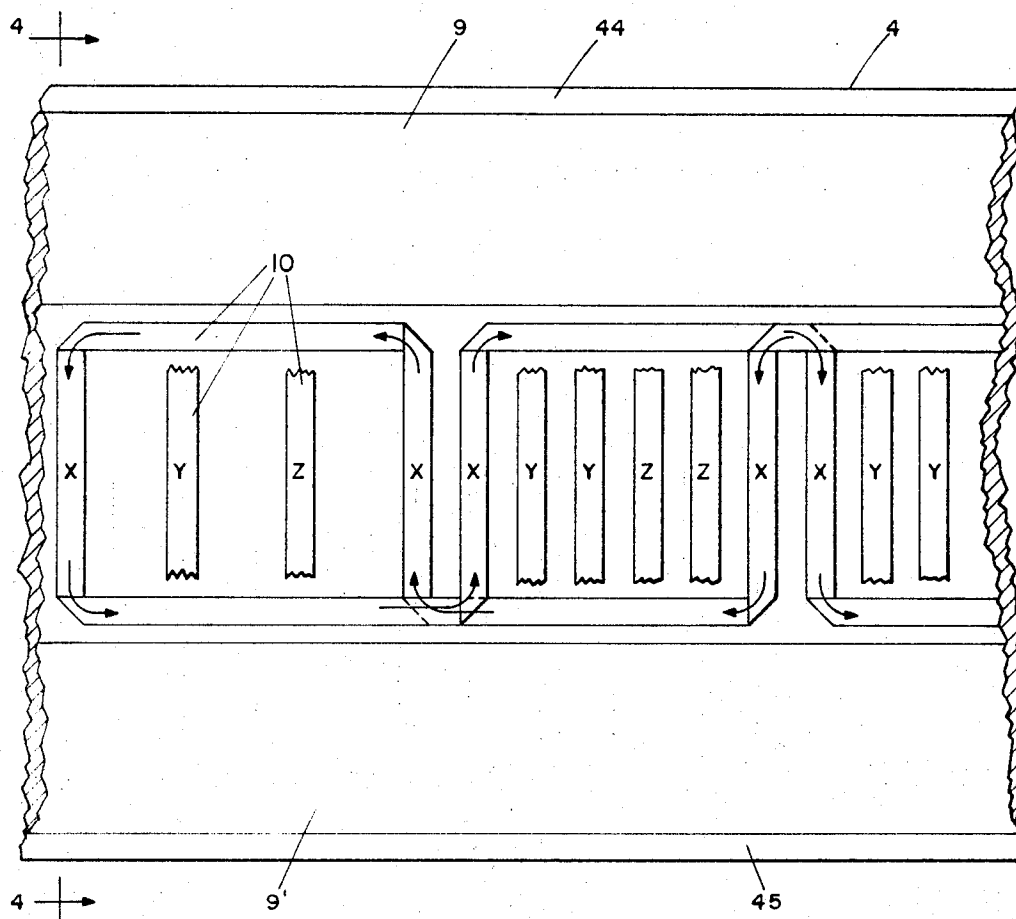


FIG. 3

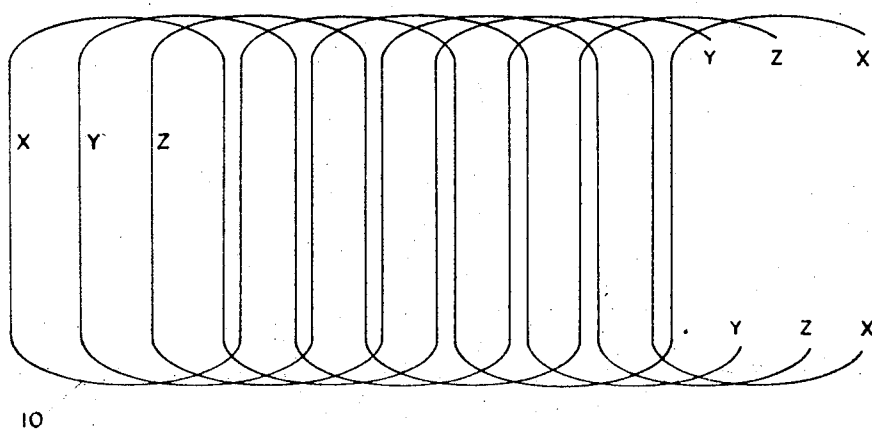


FIG. 6

INVENTORS:  
RICHARD D. THORNTON  
HENRY H. KOLM

BY *Robert H. Kan*  
ATTORNEY

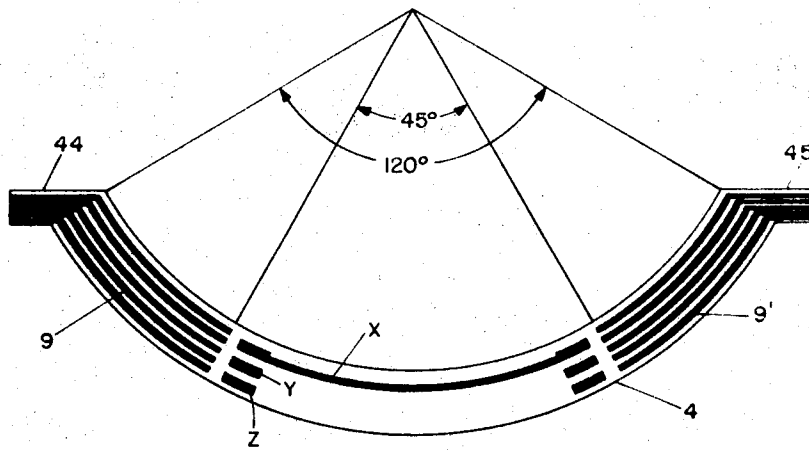


FIG. 4

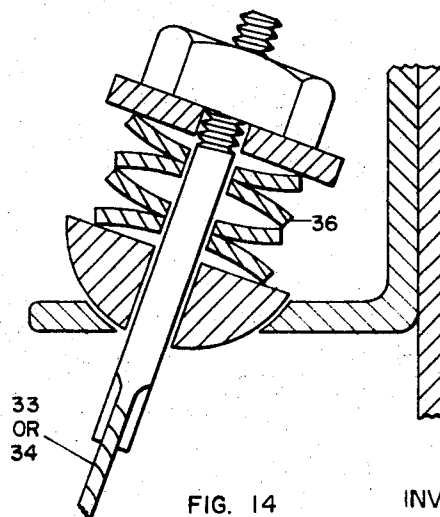


FIG. 14

INVENTORS:  
 RICHARD D. THORNTON  
 HENRY H. KOLM  
 BY *Robert Shaw*  
 ATTORNEY

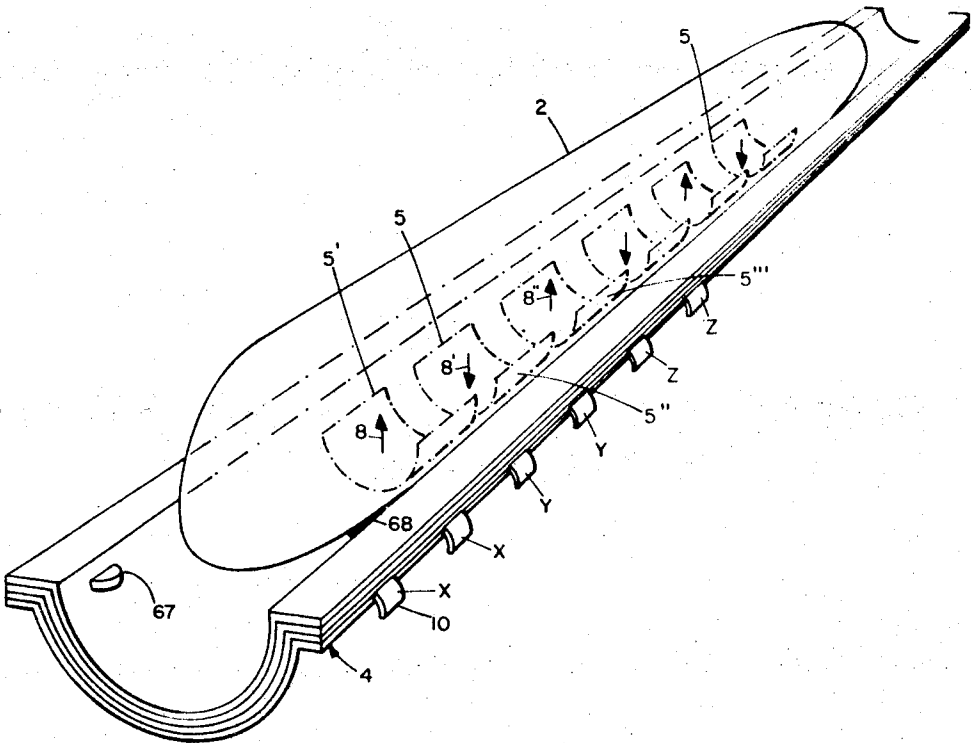


FIG. 5

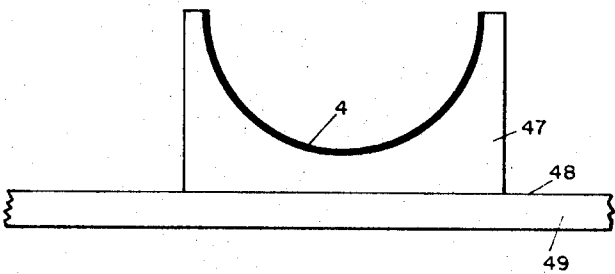


FIG. 22

INVENTORS:  
RICHARD D. THORNTON  
HENRY H. KOLM

BY *Robert H. Kram*  
ATTORNEY

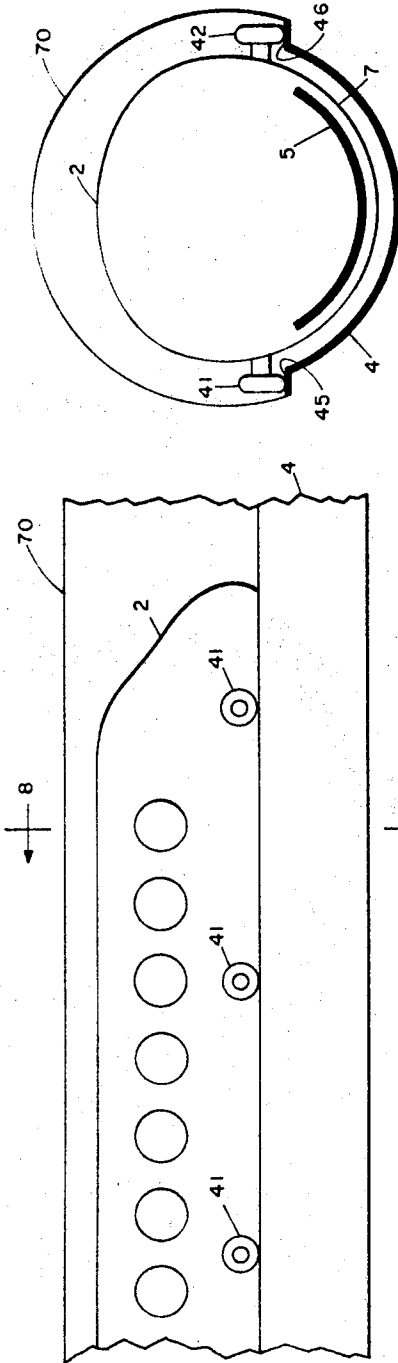


FIG. 8

FIG. 7

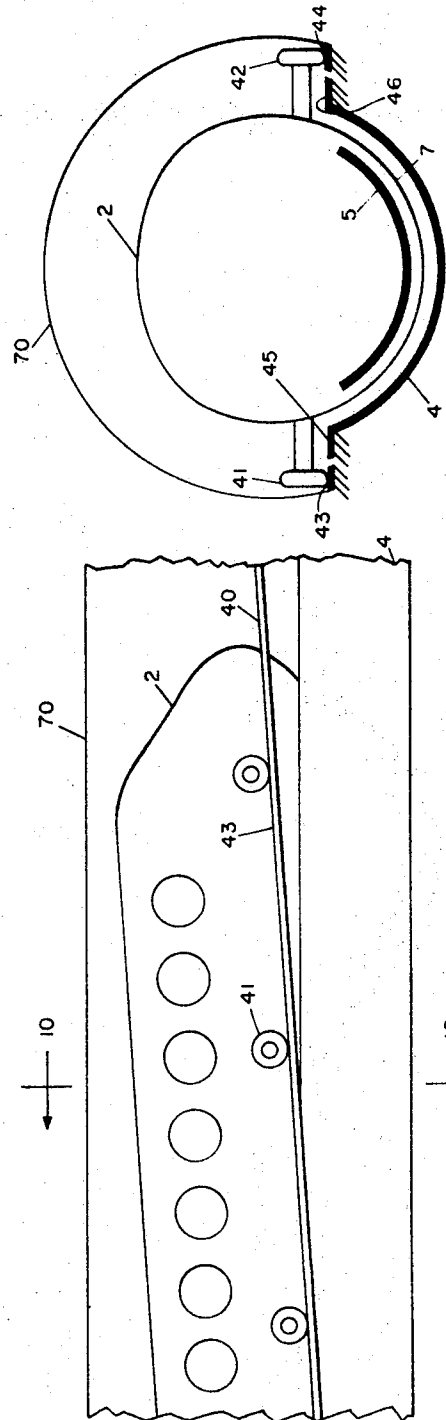


FIG. 10

FIG. 9

INVENTORS:

RICHARD D. THORNTON  
HENRY H. KOLM

BY

*Robert Shaw*  
ATTORNEY

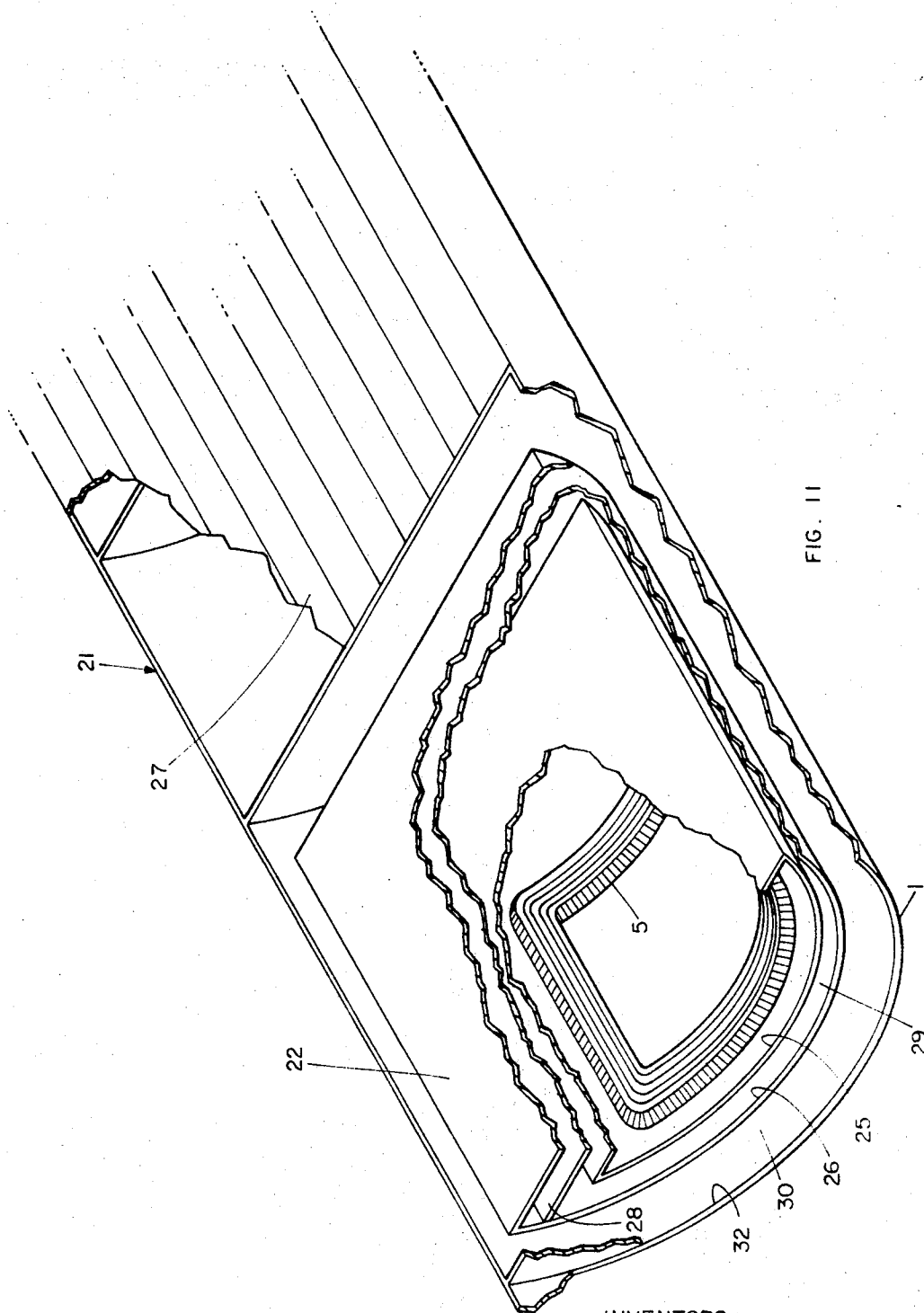


FIG. 11

INVENTORS:  
RICHARD D. THORNTON  
HENRY H. KOLM

BY *Robert L. Shaw*  
ATTORNEY

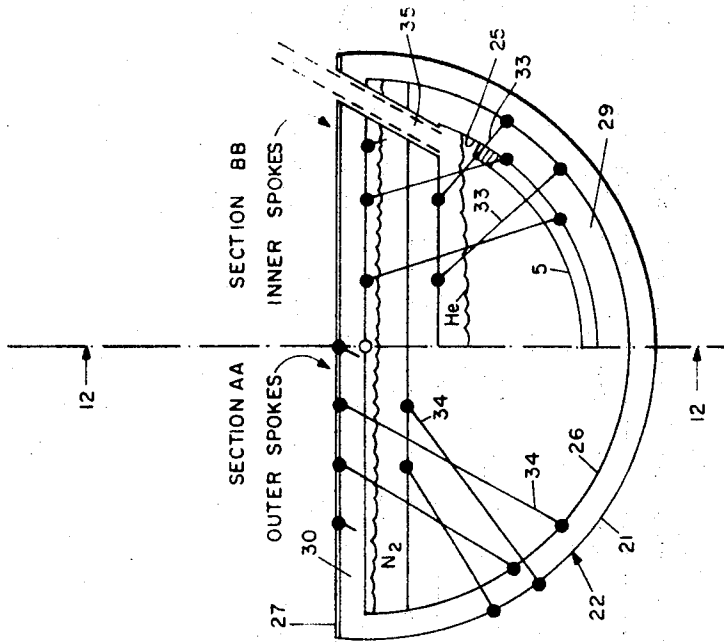


FIG. 13

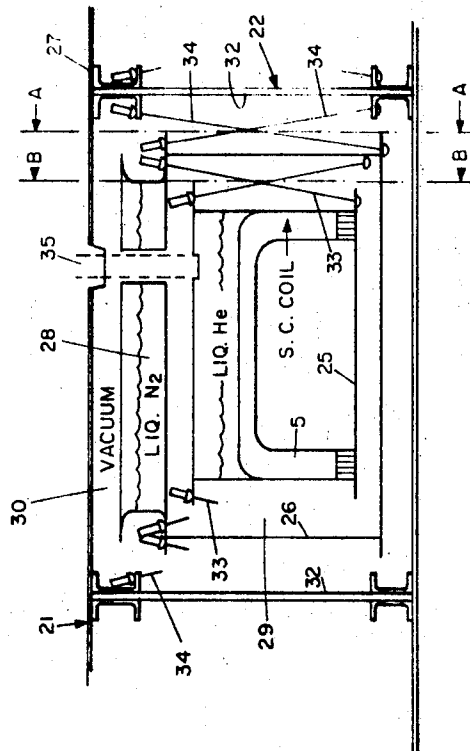


FIG. 12

INVENTORS:

RICHARD D. THORNTON  
HENRY H. KOLM

BY *Robert S. Law*  
ATTORNEY

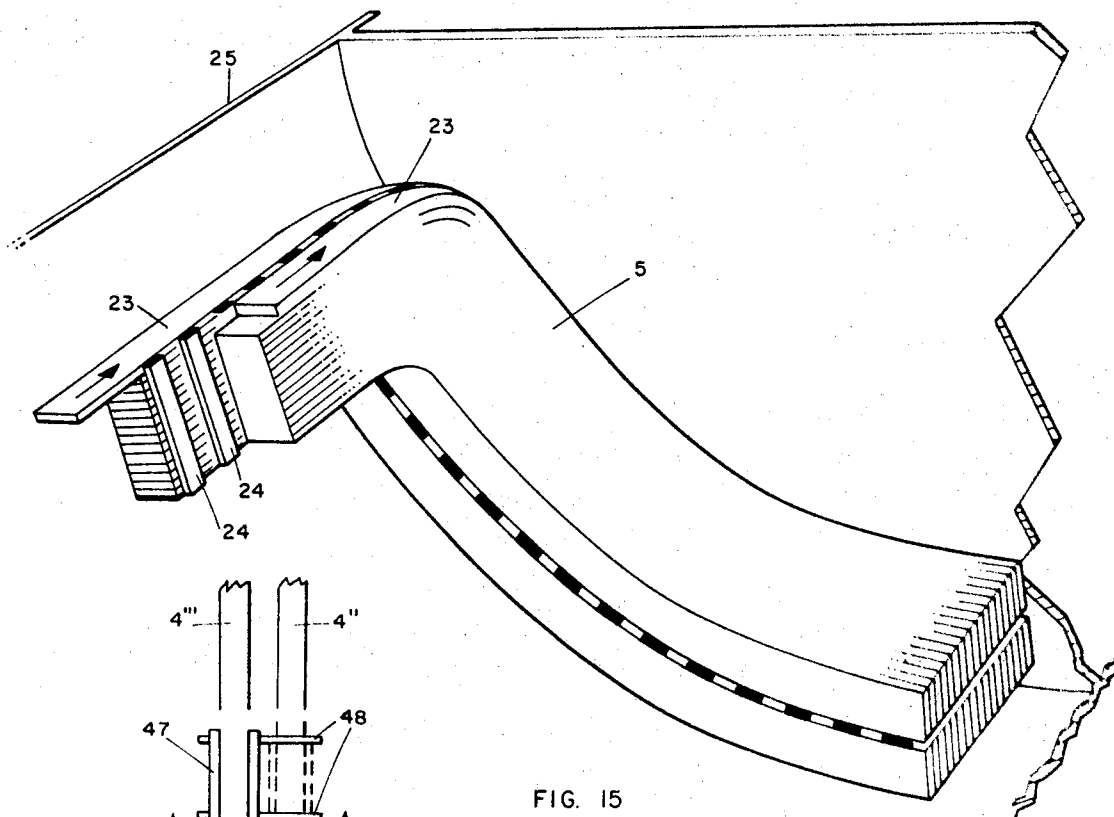


FIG. 15

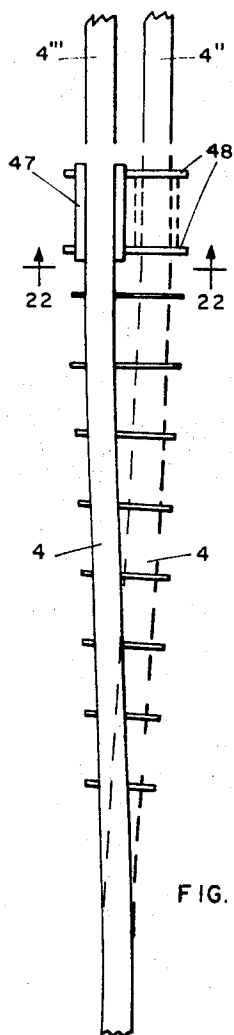


FIG. 21

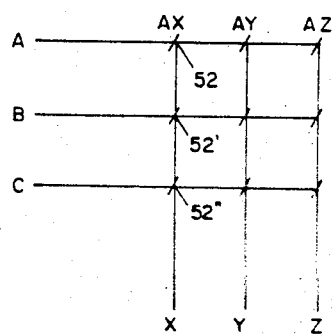


FIG. 17

INVENTORS:  
RICHARD D. THORNTON  
HENRY H. KOLM

BY *Robert Shaw*  
ATTORNEY

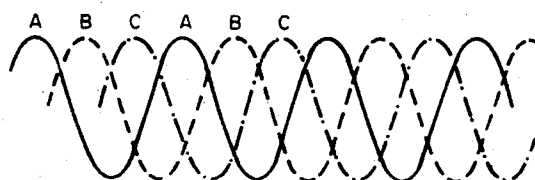


FIG. 16A

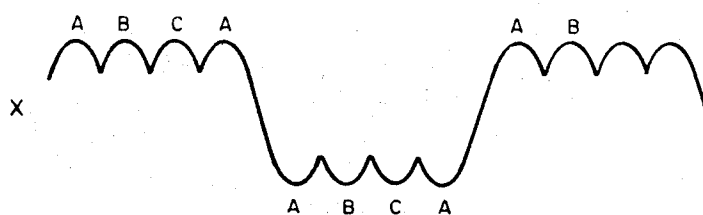


FIG. 16B

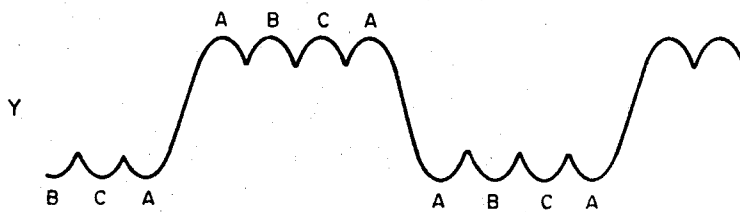


FIG. 16C

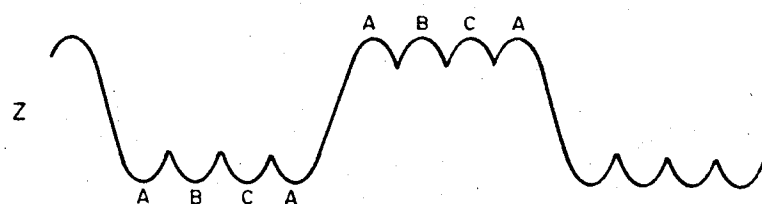


FIG. 16D

INVENTORS:

RICHARD D. THORNTON

HENRY H. KOLM

BY

*Robert Shaw*  
ATTORNEY

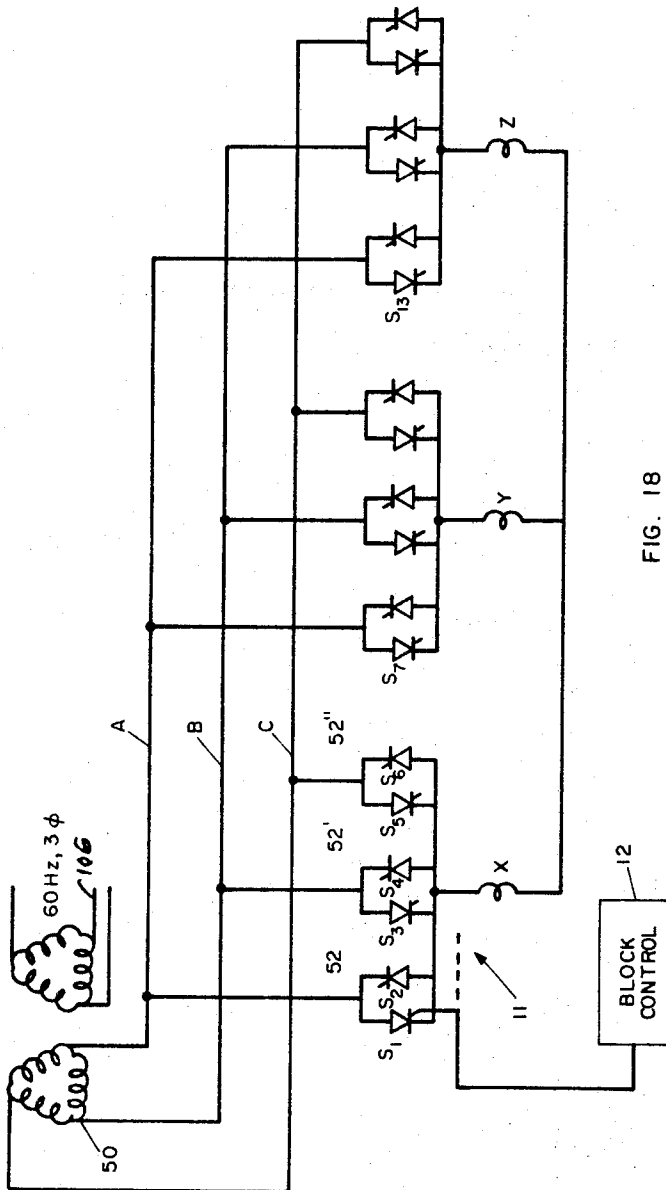


FIG. 18

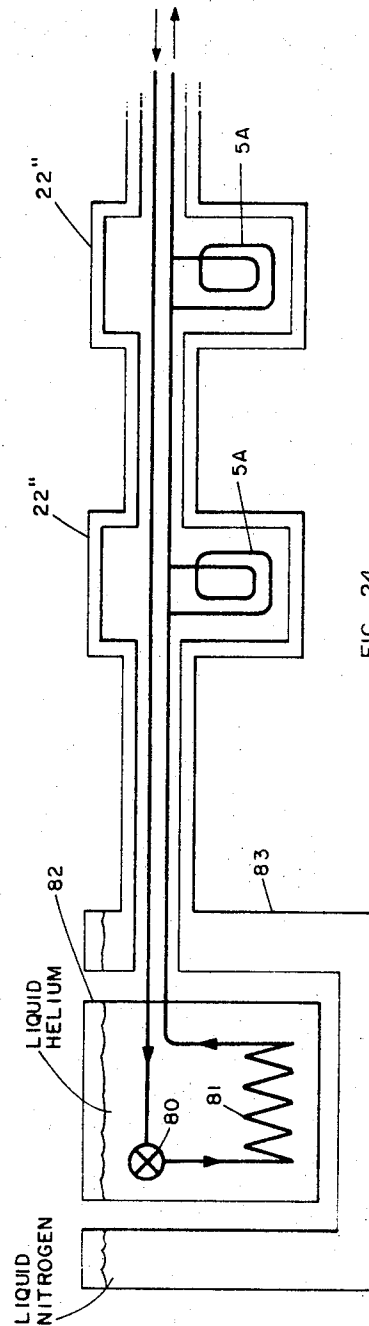


FIG. 24

INVENTORS:  
 RICHARD D. THORNTON  
 HENRY H. KOLM  
 BY *Robert Sloan*  
 ATTORNEY

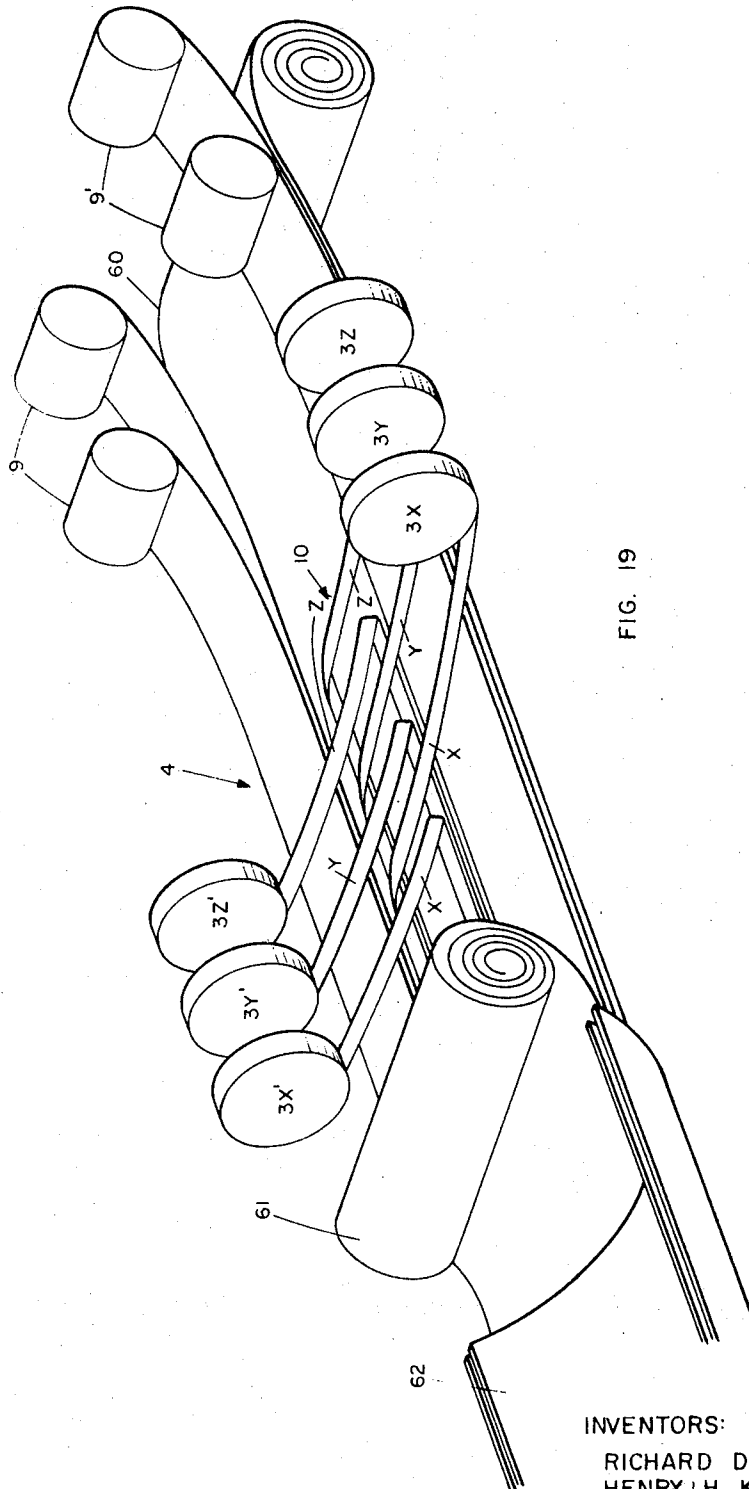


FIG. 19

INVENTORS:  
RICHARD D. THORNTON  
HENRY H. KOLM

BY *Robert Shaw*  
ATTORNEY

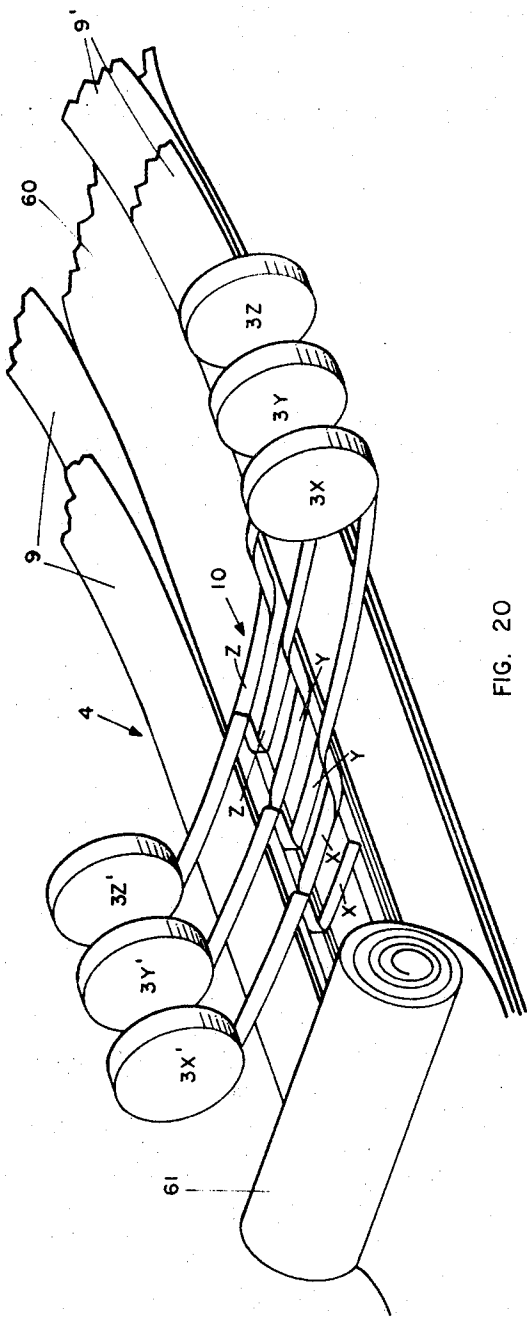


FIG. 20

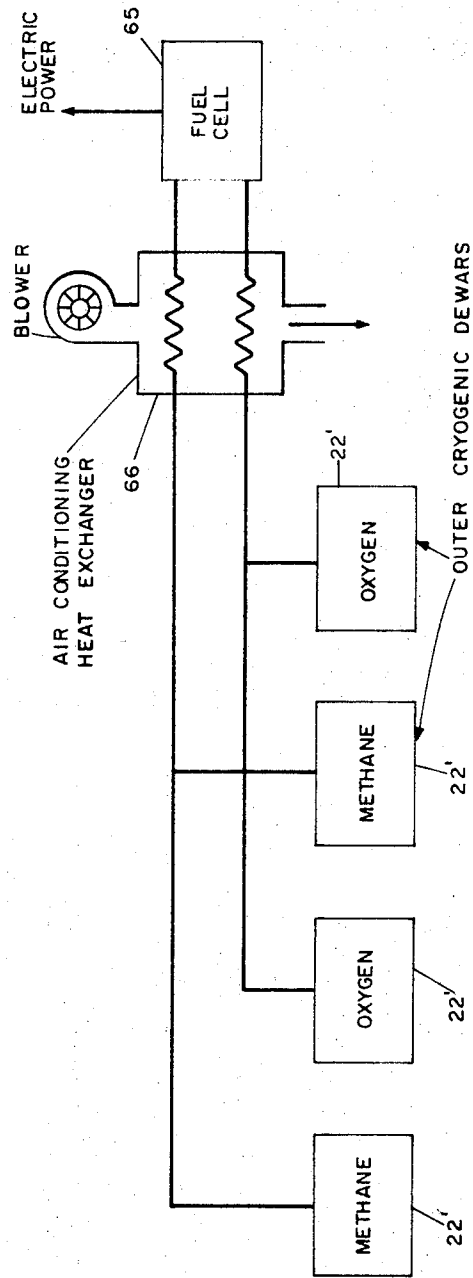


FIG. 23

INVENTORS:  
RICHARD D. THORNTON  
HENRY H. KOLM

BY *Robert Shaw*  
ATTORNEY

# TRANSPORTATION SYSTEM EMPLOYING AN ELECTROMAGNETICALLY SUSPENDED, GUIDED AND PROPELLED VEHICLE

The present invention relates to a transportation system and, particularly, to a system employing electromagnetic levitation of a vehicle in a guideway and electromagnetic propulsion of the vehicle along the guideway; the term "magneplane" is used herein to denote such a vehicle.

It has become increasingly apparent in the last few years that railway transportation of some sort, above and beyond that now in use, will be necessary to replace and/or supplement automobile and airplane transportation. It is also quite apparent, however, that existing systems and proposed modifications and replacement of such systems, heretofore made, do not and will not satisfy needs, particularly at speeds above about 200 kilometers per hour and into the supersonic speed range. Thus, for example, conventional wheeled railway trains are not capable of speeds significantly higher than those available today. The limitation is imposed by track alignment tolerances which can be achieved and maintained, by the finite ratio of sprung-to-unsprung weight of vehicles, by stability, and by the strength and wear resistance of materials. Furthermore, none of the alternatives proposed thus far have succeeded in solving all of the problems involved in achieving train speeds comparable to those of jet aircraft. Guided air-cushion vehicles are inefficient, noisy, and difficult to propel without a prohibitive penalty of weight and pollution. Magnetically suspended vehicles proposed previously must operate at track clearances which are too small to permit significantly higher speeds than those speeds now available and/or leave the propulsion problem unsolved; on board electric propulsion using wayside power is unlikely because of the problem of picking up large amounts of electric power at high speeds, while track-based propulsion systems designed previously are too expensive and require track clearances too small to permit high speeds. The present state of the art can be summarized by stating that even if air cushion or magnetic suspension systems proposed previously can be refined sufficiently to permit jet aircraft speeds of the order of a thousand kilometers per hour, propulsion would have to be accomplished by an on-board combustion engine burning on-board fuel. This entails a prohibitive penalty of weight, noise and pollution, and precludes the possibility of enclosed guideway tunnels and partial evacuation.

Accordingly, it is a principal object of the present invention to eliminate the above-mentioned shortcomings of all previously proposed systems by creating a combined electromagnetic vehicle suspension and propulsion system, one capable of operating resiliently at guideway clearances of the order of 25 centimeters and of permitting the vehicle to seek the correct bank angle at a given speed and guideway curvature.

A further object is to accomplish the foregoing at reasonable capital and operating costs, at good power efficiency, and without imposing unrealistic requirements on guideway alignment or configuration.

The stress concentration involved in supporting and guiding conventional trains is responsible for a large fraction of their high construction and maintenance costs. Thus, still another object of the present invention is to provide a train system that offers an additional and

very fundamental advantage over existing and proposed systems in that the weight and acceleration forces upon the vehicle are distributed uniformly over the entire guideway structure occupied by the vehicle.

Still another object is to provide a system having a guideway in the form of a laminated aluminum shell structure of adequate rigidity to be set directly in a bed of sand, as is common practice in laying pipelines, one in which the guideway can be fabricated continuously in position at the site as a flat lamination of aluminum sheets and then formed to have a cylindrical cross dimension bonded to achieve rigidity, as it is laid.

A still further object is to provide a system in which the propelled vehicle is capable of jet aircraft speeds in open or enclosed, atmospheric or partially evacuated guideways, and creates no pollution or noise and yet permits train separations sufficiently small to handle the passenger density and operating schedule required for economical operation competitive with air and train travel.

A still further object is to provide novel acceleration, deceleration, and speed control in such system by a novel electric power scheme.

Yet another object is to provide novel means for switching vehicles from one guideway to another.

These and still further objects are discussed in greater detail hereinafter and are particularly delineated in the appended claims.

The foregoing objects are attained in an electromagnetic transportation system that includes a vehicle having a substantially cylindrical lower surface and carrying a plurality of permanent magnet or superconducting coils distributed over a substantial portion of that lower surface. The magnets or superconducting coils are positioned within the vehicle adjacent said lower surface and have a contour similar to the contour of that surface; in the case of superconducting coils, means is provided for maintaining the superconducting coils at a superconducting temperature. Individual magnets or coils have sufficient area and are operable, when charged, to generate a magnetic dipole field of 1,000 to 3,000 gauss 25 centimeters from the lower surface of the vehicle, alternate adjacent magnets or coils being energized so as to produce magnetic fields oriented alternately upward and downward. A trough-like cylindrically-shaped guideway surrounding approximately the lower one-third of the circumference of the vehicle supports, guides and propels the vehicle. The guideway contains both active, current-carrying conductors and passive conductors. The passive conductors form two spaced continuous surfaces along the length of the guideway exposed to the magnetic field on the vehicle so as to support the vehicle when the vehicle is moving at a speed above a predetermined minimum of about 35 kilometers per hour, at a clearance of approximately 25 centimeters, by interaction between the magnetic dipoles of the vehicle and the eddy currents they induce in the passive conductors. The current-carrying, active conductors, located in the space between the passive conductors, are shaped to form a series of over-lapping current loops or windings longitudinally along the guideway. The over-lapping loops substantially conform to the cylindrically-shaped surface of the guideway and generate, when energized, a traveling magnetic field which moves along the guideway in the axial or longitudinal direction and propels the vehicle at synchronous speeds by interaction with

the magnetic dipoles of the vehicle magnets or coils. A source of multiphase alternating current is connected to energize the active conductors in correct sequence to produce the traveling wave field. The system contains control means operable to connect the current source to any particular active conductor upon the basis of information transmitted from the vehicle. The moving vehicle is thus supported resiliently above the inner surface of the guideway at a clearance of about 25 centimeters from the guideway and is free to rotate or pivot about the vehicle longitudinal axis so as to establish the correct bank angle when negotiating turns, the guideway being banked at only approximately the correct angle in turns. The center of electromagnetic lift of the vehicle is located above its center of gravity to insure stability.

The invention is hereinafter described upon reference to the accompanying drawing, in which:

FIG. 1 is a schematic diagram, partially in block diagram form, that shows a two-guideway electromagnetic transportation system;

FIG. 2 shows one of the guideways of FIG. 1 and a vehicle, partially cut away, adapted to be propelled along the guideway, the figure being further intended to show one scheme by which vehicles are switched for loading and unloading;

FIG. 3 is a view, partially cut away and on an enlarged scale, taken upon the line 3—3 in FIG. 2 looking in the direction of the arrows, particularly to show active and passive electrical conductors in the guideway;

FIG. 4 is a view on a reduced scale, taken upon the line 4—4 in FIG. 3 looking in the direction of the arrows, and is intended to show an end view of the active and passive electrical conductors of FIG. 3, the interstices between conductors being exaggerated and shown as voids in FIG. 4 but being filled with insulating re-enforcement and bonding material in actual apparatus;

FIG. 5 is an isometric view in schematic form of vehicle like the vehicle in FIG. 2 and is primarily intended to show a plurality of superconducting coils positioned along the whole lower portion of the vehicle, a similar arrangement of permanent magnets also being possible;

FIG. 6 is a schematic representation of a three-phase guideway winding;

FIG. 7 is a partial side view showing a vehicle and a guideway like those shown in FIG. 2 but including a guideway shell over the vehicle;

FIG. 8 is a view taken upon the line 8—8 in FIG. 7 looking in the direction of the arrows, slightly enlarged, particularly to show wheels on the vehicle and two tracks, one on either side of the guideway, upon which the wheels can run;

FIG. 9 is a partial side view like FIG. 7 and is particularly intended to show with greater clarity the switching arrangement shown in FIG. 2;

FIG. 10 is a view taken upon the line 10—10 in FIG. 9 looking in the direction of the arrows, slightly enlarged, and is like FIG. 8, except that two tracks for the wheels are shown on each side of the guideway;

FIG. 11 is an isometric view of a part of the lower portion of the vehicle shown in FIG. 2 and is intended to show details of superconducting coils and related apparatus in that portion;

FIG. 12 is a schematic-type representation of a view taken upon the line 12—12 in FIG. 13 looking in the direction of the arrows and shows details of the super-

conducting coils and related cryogenic apparatus in the vehicle;

FIG. 13 is a view the left-hand part of which is taken upon the line A—A in FIG. 12 looking in the direction of the arrows and the right-hand part of which is a view taken upon the line B—B in FIG. 12 looking in the direction of the arrows, the left-hand view being intended to show a plurality of outer spokes in the cryogenic apparatus and the right-hand view being intended to show a plurality of inner spokes in that apparatus;

FIG. 14 is an enlarged side view of one of the spokes in FIGS. 12 and 13;

FIG. 15 is an isometric view, on an enlarged scale, of one of the superconducting coils shown in other of the figures;

FIG. 16A is the waveform of three-phase 60 Hz electric energy for powering the active conductor through a cycloconverter and transformer combination;

FIGS. 16B, 16C and 16D show 20 Hz output waveforms from the cycloconverter respectively to the X, Y, and Z phases of the active conductor;

FIG. 17 shows in schematic form a matrix switching arrangement for the cycloconverter to convert the 60Hz energy of FIG. 16A to the 20 Hz energy of FIGS. 16B—D;

FIG. 18 shows in greater detail an SCR switching arrangement for the cycloconverter;

FIG. 19 is an isometric view of a proposed scheme for forming the guideway in situ;

FIG. 20 is a view similar to FIG. 19 showing continuing fabrication of the guideway and is one fold later than the position of FIG. 19;

FIG. 21 shows a guideway switch adapted to allow vehicle switching at full cruising speed;

FIG. 22 is a view, on an enlarged scale, taking up the line 22—22 in FIG. 21, looking in the direction of the arrows;

FIG. 23 is a block-diagram representative of apparatus for providing on-board electric energy for the vehicle; and

FIG. 24 is a block-diagram representative of an alternate way to cool the superconducting coils to liquid helium temperature.

Turning now to the drawing, an electromagnetic transportation system is shown schematically at 1 in FIG. 1. The system comprises vehicles 2 which are supported, guided and propelled by and along guideways 4 and 4', one such vehicle only and one such guideway are shown in the remaining figures. The vehicles 2, as shown in FIG. 8, for example, each has a circular cylindrical lower surface 7 and a plurality of superconducting coils 5 distributed axially the length thereof, as shown in FIGS. 2 and 5, the superconducting coils 5 being positioned within the vehicle adjacent the lower surface 7 and having a contour similar to that of said surface, as shown. (It is recognized that suspension can be effected by use of either permanent magnets or superconducting coils, but present technology favors the latter.) The superconducting coils 5 are maintained at a superconducting temperature in a manner later discussed; individual coils 5 have sufficient area and are energized with sufficient persistent supercurrent to generate a radial magnetic dipole field having an intensity of 1,000 to 3,000 gauss at a distance outward of approximately 25 centimeters from the lower surface 7 of the vehicle 2. Adjacent coils 5', 5'' etc., as shown in FIG. 5, are energized so as to produce magnetic dipole

fields, represented by the arrows numbered 8, 8', etc. respectively oriented alternately upward and downward. The vehicle 2 can be circular cylindrical throughout, as shown in a number of the figures, or it can be flattened at the top, as also shown. At any rate, the lower third of the vehicle (except for a slight ellipticity which may be used for stability, as later mentioned herein) is circular cylindrical and the superconducting coils describe an arc through most of that lower third. The guideway 4, as shown in FIGS. 8 and 10, is trough-like and is also circular cylindrical in cross-sectional shape, as shown in FIGS. 8 and 10, (except that a slight ellipticity may be used for stability, as also mentioned later) and surrounds approximately the lower one-third of the vehicle circumference. The guideway 4 contains both active, current carrying conductors 10, further designated X, Y and Z, to represent the phases of a multi-phase ac system, and spaced passive conductors 9 and 9' which form a substantially continuous surface along the length of the guideway 4 exposed to the magnetic field of the superconducting coils 5 in the vehicle so as to support the vehicle, when the vehicle is moving at a speed above the predetermined minimum value of about 35 kilometers per hour, at a clearance of approximately 25 centimeters by interaction between the magnetic dipole fields of the vehicle coils and the eddy currents they induce in the passive conductors 9, 9'. The active conductors 10, as shown schematically in FIGS. 3 and 6, are positioned in the space between the passive conductors 9 and 9' and form a series of overlapping current loops along the axis of the guideway 4 (substantially conforming to the cylindrically-shaped surface of the guideway) so as to generate, when energized, an alternating magnetic field which moves along the axis of the guideway and propels the vehicle 2 in the direction of the arrow labeled 3 in FIG. 2 at synchronous speed by interaction with the magnetic dipoles of the vehicle coils 5. A source 11 of multi-phase electric current in FIG. 1 is connected to energize the active conductors 10 in correct sequence, as hereinafter discussed. The system includes control means designated 12 to connect the source 11 of the electric current to any particular active conductor 10, signals to the control means being received from other control means 12, as shown in FIG. 1, or from the vehicles 2, as represented by the arrows 15, or from a regional control 13 or a central control 14, depending upon circumstances.

The vehicle 2, as it moves down the guideway 4, is thereby electromagnetically supported resiliently at a clearance of not less than about 25 centimeters from the guideway 4 and is free to rotate or pivot about its longitudinal axis so as to establish the correct bank angle when negotiating turns. The guideway 4 is banked at only approximately the correct angle at such turns. The center of electromagnetic lift of the vehicle is located above its center of gravity so as to insure stability, and, further electromagnetic or aerodynamic stabilizing means can be provided to prevent or damp undesirable oscillations.

The vehicle 2, as shown in FIG. 2, comprises a passenger or cargo section 20 and, what may be termed, a drive or tractor section 21. The two sections may be separated at stations for loading and unloading and the tractor section can be attached to a new load section, but, for present purposes, they are described as a unit. The superconducting coils 5 are located within dewars 22 within the tractor section; the next few paragraphs

are devoted to a discussion of the tractor section 21 with particular attention being given to the superconducting aspects thereof. The discussion is made with reference, primarily, to FIGS. 11 to 15. It should be here-noted that while FIGS. 12 and 13 represent section views, they are shown nevertheless in single-line form, without any cross-hatching, a form it is believed most conducive to understanding. Furthermore, many details of systems, including means for handling liquid helium and liquid nitrogen, are omitted since such are known to workers in the cryogenic art.

The superconducting vehicle coils, in particular their cryogenic and structural containment, represent one of the most critical engineering problems involved in the construction of the magneplane. It is necessary that these coils be maintained at liquid helium temperature and that the forces which support and guide the vehicle be transmitted from these coils to the vehicle structure without inordinate heat loss, and in such a manner that the forces are distributed uniformly over the vehicle structure. This is accomplished in the present apparatus in the following manner.

A typical vehicle 2 having a length of 40 meters is supported by approximately 12 coils 5, each having a length of 2.0 meters in the longitudinal or axial direction and a developed width of 4 meters. These rectangular coils 5 are wound in the form of "pancakes" on a curved form (see FIG. 15), so that they conform to the shape or contour of lower surface 7 of the vehicle, surrounding about 120° of its circular circumference. Each coil conducts a total of between 100,000 and 300,000 ampere-turns of persistent current, consisting of 100 to 200 turns of superconductor having a current carrying capacity of 1,000-1,500 amperes. Suitable commercially available material is multi-filament niobium-titanium superconductor imbedded in a copper or aluminum matrix having the shape of a flat ribbon, as shown at 23 in FIG. 15. The material is pancake-wound with insulating spacers 24 of a fibrous material impregnated with stage B epoxy, and subsequently heat-cured to form a monolithic, bonded structure.

Each coil 5, is rigidly attached (by clamps, not shown) to the inside of the curved surface of a cylindrical aluminum container 25 having a D-shaped cross section and which also serves to contain a supply of liquid helium. This helium container 25 is in turn surrounded by a correspondingly shaped aluminum container 26 which is maintained at liquid nitrogen temperature by a liquid nitrogen reservoir 28 which is an integral part of its upper, flat surface, as best shown in FIG. 12. This nitrogen-cooled container is, in turn, surrounded by a correspondingly shaped vacuum vessel 32 (the lower structural member of which is the vehicle skin) that is in fact a sector of a circular cylinder 40 meters in length and 4 meters in diameter subdivided by structural bulkheads into 12 compartments, each being shaped so as to surround one of the nitrogen-cooled containers 26. The upper surface of the vessel 32, which is numbered 27, supports the floor of the cabin 20. The container 25 is separated from the container 26 by a two centimeter vacuum space 29 and the container 26 from the vehicle wall by a similar vacuum space 30.

FIGS. 12 and 13 illustrate the means by which the three nesting containers are supported with respect to each other by means of tension spokes which serve to minimize heat conduction. Two sets of tension spokes

are located adjacent each side of each structural bulkhead: an inner set of spokes 33 connects the helium-cooled container 25 to its surrounding nitrogen-cooled container 26, and an outer set of spokes 34 connects said nitrogen-cooled container to its surrounding vacuum barrier which also represents the vehicle skin, by being attached to channels surrounding the structural bulkheads. Each helium-cooled container 25, along with its rigidly connected superconducting coil, is thus connected mechanically to its two neighboring bulkheads. The spokes are slightly inclined with respect to the bulkheads which are perpendicular to the longitudinal axis of the vehicle. In this manner the spokes provide rigid constraint in the axial as well as the transverse direction. The forces which support, guide and propel the vehicle are thus transmitted from the superconducting coils 5 to all of the structural bulkheads. Each compartment 22 is also provided with a sealed service tube or duct 35 through which a mating, coaxial service nozzle can be inserted from outside the vehicle. This service nozzle, or umbilical cord, is used to replenish the liquid helium supply, the liquid nitrogen supply, to evacuate the vacuum spaces between nesting containers, and to adjust the superconducting current if required. The service tube also contains venting lines for the helium and nitrogen reservoirs.

In FIG. 14 there is shown the manner in which each tension spoke 33 or 34 is elastically connected at one of its ends, the other end being connected rigidly. The purpose of this elastic connection is to provide the normally required supporting force at a minimum thermal contact, while providing back-up support at increased thermal contact to absorb transient mechanical overloads, such as might occur during severe braking or when passing a badly mis-aligned section of guideway. As shown, this elastic support is accomplished by using a stack of Belleville washers, tempered steel washers 36 of slightly dished or spherical shape. Alternate washers in this stack are convex upward and downward. Under normal loads, these washers contact their neighbors only along the inner and outer periphery. If an abnormal load is applied however, the washers are flattened elastically and their contact area increases progressively until the entire stack of washers is compressed to minimum height. When the abnormal load is removed, the washers resume their spherical shape.

The vehicle requires auxiliary electrical energy for such things as lighting, control, hydraulic pumps, air-conditioning, etc. The energy may be provided for example by an air-driven turbo-generator on the vehicle or by some conventional electrical generating means on board. It may, however, be supplied by the scheme shown in FIG. 23 where dewars 22', which may be quite similar to the dewars 22, are shown. In the arrangement of FIG. 23, the cryogenic radiation shields, instead of being cooled by liquid nitrogen as before, are cooled by liquid oxygen and liquid methane. The boil-off gases, oxygen and methane, are passed through fuel cell 65 to generate electric power. Alternately these gases could be burned in a heat engine to generate mechanical and electrical power. The boil-off gases from the cryogenic reservoirs can also be passed through a suitable heat exchanger 66 which serves as an air-conditioner for the cabin 20.

There is contained in this and the next few paragraphs an explanation of the electrical propulsion system and control which are mentioned briefly elsewhere

herein. The system 1 in FIG. 1 is a two-lane or dual-guideway system comprising the side-by-side guideways 4 and 4', each being divided into sections numbered 100, 101, 102, 103, 104, 100', 101', 102', 103', 104', respectively. Each contiguous group of four guideway sections constitutes one block, energized by a single power supply unit located at the center of the associated block. For present explanation purposes the block consisting of the four contiguous sections numbered 101, 102, 101' and 102' will be discussed.

A block is typically 1 to 5 kilometers long depending on required vehicle speed, cost considerations, etc. An underground, high voltage transmission system 106 transmits three-phase power under the guideway. There is a transformer 11, as before mentioned, in the center of each block, with four cycloconverters for each transformer, one for each section. (A two-cycloconverter system can be used; it would require an additional semiconductor or mechanical switch so that one cycloconverter could supply either 101', or 102'.) Additionally, each block contains a control system which is the block control 12 and which can include a small, special purpose computer. Each control 12 is in constant communication with: (1) adjacent blocks, (2) all vehicles in its block, and (3) a regional control 13, as indicated. The pilot of the magneplane in any particular block can request: (1) constant speed at the synchronous block speed specified by the regional control 13 (2) acceleration up to synchronous speed, or (3) deceleration and automatic ejection from the system. The block control 12 will only allow deceleration if there is a suitable off-ramp or if emergency conditions exist. For emergency operation the pilot is placed in direct contact with a controller who can change the prevailing vehicle speeds in various parts of the system through the central control 14. The communication indicated between adjacent blocks is used to control motion of vehicles from one block to another, and, if an emergency develops and the link to the regional control 13 should fail, a block that must shut down can also cause adjacent blocks to shut down. The communication between the vehicle 2 and block control 12 can either be by short range radio link or by electromagnetic pickup by wires imbedded in the guideway. Regional control is necessary in a large system because of the complexity of operation that would result if a central control had to communicate with thousands of block controls. The regional control 13 is associated with a station or terminal and acts as a communication buffer between blocks and the central control. Also, the regional control is responsible for acceleration of vehicles and injection into the system with suitable clearance to leading and trailing vehicles. The regional control 13 continually monitors vehicles in its region, and has a communication link to each adjacent region, as shown. Each regional control may be manned to allow an operator to make some of the decisions.

As before mentioned, each power unit 11 includes a transformer and, usually, four cycloconverters. A cycloconverter is a circuit or device which converts an ac power source into a different frequency ac source. Today the most common cycloconverter for high power levels is one which uses SCR's or thyristors to switch the power, as later discussed in connection with FIG. 18. The output frequency can be continuously varied up to about half of the supply frequency. Thus, a multiphase cycloconverter with 60 Hz input power

can produce reasonably good output up to about 30 Hz. For linear motor applications it is necessary to generate a multiphase output which, typically, can be six phase. To achieve smooth multiphase power output at frequencies near one half of the supply frequency it is desirable to use multiphase input power.

In order to illustrate the operation of a cycloconverter, a three-phase to three-phase system is discussed in connection with FIGS. 16 A-D; 17 and 18 for converting 60 Hz to 20Hz. The curves in FIG. 16A show the waveforms for the three input phases A, B, and C at 60 Hz (as from the transformers shown at 50 in FIG. 18) and the curves in FIGS. 16B, 16C, and 16D show respectively three outputs to phases X, Y and Z at 20 Hz. Each output phase is composed of segments of each of the input phases as indicated in the figures. A simplified schematic of a cycloconverter is shown in FIG. 17 with back-to-back SCR's or triacs represented as the simple switches labeled 52, 52', etc. The operation of the nine switches in FIG. 17 is synchronized by the control 12 to obtain the required waveforms, as indicated in FIG. 18 where the switches 52, 52' etc. are shown as back-to-back SCR's, S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>, etc.

A feature of this cycloconverter which makes it particularly simple and reliable is the fact that there is natural commutation of the SCR's without any extra commutation circuitry. For the three-phase to three-phase system shown in FIG. 18 there are 18 SCR's (a six-phase to six-phase system requires 72) but no other high power components are required. Moreover, most of the 18 SCR's are in active use; so the power output can approach 18 times the output capability of a single SCR. For normal deceleration, the cycloconverter can pump power back into the ac power line (i.e., regenerative braking). For emergency braking, a short-circuit can be placed across the propulsion coils 10 to provide dynamic braking at 0.5 g or more.

For variable frequency operation, when the output frequency is not a sub-multiple of the input frequency, the output waveform is not perfectly periodic at the output frequency, but it can be made nearly periodic if the output frequency is less than half the input frequency and if a sufficient number of input phases (typically six) are used.

The guideway 4, according to a preferred embodiment of the instant invention, is constructed of bonded aluminum laminations, as best shown in FIGS. 19, 20, 3 and 4, suitably interleaved with insulation so as to provide both the passive and the active current-carrying conductors and having sufficient rigidity to maintain the required dimensional tolerances without the need for additional re-enforcing structures. FIGS. 19 and 20 are intended to illustrate a method of continuous fabrication of a laminated guideway from aluminum ribbon; interleaving sheets of insulation and bonding material are not shown. The method shown employs hand fabrication but it is adapted to machine fabrication. Turning now to the figures, the bottom surface of the guideway is formed of a fiberglass (or aluminum) strip 60 over which is laid the passive conductors 9 and 9' (only two layers of passive conductors on each side of the guideway are shown in FIGS. 19 and 20) and the active conductors 10, comprising phases X, Y and Z. The phases X, Y and Z are made up of aluminum ribbons from spool pairs 3X — 3X', 3Y — 3Y', and 3Z — 3Z', respectively, as shown, each spool of the pair holding half the amount of ribbon needed for a particu-

lar phase. Each phase, as shown in FIG. 5, has two input terminals. A layer of fiberglass or the like 61 is laid over the foregoing elements to provide a smooth surface for the guideway and one that is electrically neutral or insulated. Induction heated pressure plates 62, of proper contour, shape and curve the laminations. FIG. 20 shows the continuing fabrication of the guideway one fold later than the condition illustrated in FIG. 19 to illustrate the procedure for forming the conductors X, Y and Z.

In a system such as that described above it is necessary that the magneplane leave the high-speed guideway to load and unload passengers and/or cargo and return to the high-speed guideway to resume travel. This can be accomplished in the embodiment of FIGS. 1, 9 and 10 by having a guideway 40 that inclines upward from the guideway 4. In this switching arrangement the vehicle 2 is first slowed from the 200 kilometers per hour speed to say 100 kilometers per hour and at this juncture wheels 41 and 42, which are normally retracted, are extended out to ride on respective outer tracks 43 and 44 at each side of the guideway 4 (and the guideway 40, as well). In this way the magneplane can be made to run up a ramp onto the guideway 40 where again it will levitate by electromagnetic forces until the speed drops to about 35 kilometers per hour. At that low speed the vehicle will again rest on the wheels 41 and 42. The guideway 4 can, in fact, be provided with two side-by-side tracks on either side thereof, i.e., the outer tracks 43 and 44 and inner tracks 45 and 46, to receive the wheels at one of two outwardly extended positions. The inner tracks 45 and 46, as shown, provide for horizontal movement and/or landing of the magneplane and the tracks 43 and 44 provide for vertical changes in the direction of the movement of the vehicle along the guideway to effect switching thereof. The wheels 41 and 42 can be raised or lowered hydraulically and can be braked. A substantial number of wheels may be used on each vehicle to minimize local mechanical stresses, for example one pair built into every second structural bulkhead. Also, a horizontal switching arrangement can be employed, as shown in FIGS. 21 and 22, where the guideway 4 is shown in two alternate positions to align with a guideway 4'' or a guideway 4''', as the case may be. A long flexible portion of the guideway 4 (up to 5 kilometers for high-speed switching), which is supported on a plurality of cradles 47, is made to move from one or the other of the two positions shown by a hydraulic or other force. The cradles 47 each slide on a Teflon surface 48 of a slide 49.

There is in this paragraph a number of statistics and comments, some of which appear elsewhere herein. The vehicle 2 is a passive cylindrical structure carrying a series of super-conducting solenoids of large dipole moment, energized (by known means) and refrigerated for 8 to 10 hours of operation. Its weight is distributed uniformly over the guideway 4 at a clearance of about 25 centimeters. The vehicle is self-banking (free to rotate or pivot about its longitudinal axis) and does not require secondary articulation (the unsprung weight is zero). The guideway is a trough of laminated aluminum surrounding one third of the vehicle circumference, and provides all the mechanical strength and electrical conduction needed. Propulsion coils form an integral part of the laminated structure. It can be set directly in a bed of sand, requiring no additional structural sup-

port. At speeds up to about 500 kilometers per hour it can be operated open; at higher speeds it is expedient to add an upper shell 70 so as to form a partially evacuated tunnel or the shell 70 can act merely as a cover to exclude rain, snow, thrown objects, etc. from the guideway. Alignment tolerance is of the order of 5 centimeters. Propulsion is guideway-based and synchronous. It requires one multiphase transformer and one or more cycloconverters to feed two guideways for both synchronous cruising speed and for acceleration and deceleration. Some estimated specifications follow.

#### Vehicle

length: 40 m (wt of superconductor—5,000 kg)

diameter: 4 m (total wt of cryogenic units—10,000 kg)

gross wt: 50,000 kg

payload: 30,000 kg (200 passengers)

#### Guideway

clearance: 25 cm

material: laminated aluminum

weight 100–150 kg/m (100 lb/ft single track)

electrical power: 1 transformer/km

#### Power

60 Hz, 3 $\phi$  at available transmission line voltage, 5–15 MW input, depending on speed (electrical efficiency 67%)

#### Performance

lift/drag of suspension: 20 (excluding windage loss)

acceleration and deceleration: 0.1 – 0.2g

emergency deceleration: 0.5g by shorting propulsion coils, field in passenger cabin 100 gauss max

The foregoing discussion is primarily concerned with vehicles intended to operate at long distances and speeds at least the order of 200 kilometers per hour. The apparatus described, however, is useful at lower speeds and shorter distances where smaller maglevs can be used. In such smaller vehicle recent developments in permanent magnets (e.g. samarium-cobalt alloys) indicate the possibility of creating the necessary magnetic flux at required distance from the vehicle, which can be less than 25 centimeters for smaller, slower vehicles, and less favorable but still permissible lift-to-weight ratios. In such apparatus, the dipoles 8, 8' etc. in FIG. 5 would be created by permanent magnets.

A few more details, of some interest, are contained in this paragraph. The system described above employs retractable wheels on the vehicle for landing at stations or in emergency situations. An alternate or complementary system might employ wheels 67 at the station (which can be represented by the portion of the guideway shown in FIG. 5) and the vehicle 2 can be supplied with retractable skids 68 in addition, or as an alternate, to the wheels 41 and 42. The cabin floor 7 can be provided with a plurality of superconducting and ferromagnetic sheets arranged so as to reduce the magnetic field in the passenger or cargo cabin 20 to an intensity of less than 100 gauss. In the system described above, the vehicle and the guideway are circular in cross-section. A system may employ vehicles in which the cross-section of each vehicle and/or of the superconducting coils adjacent to its surface 7 and/or the guideway 4 are slightly elliptical so that the clearance between the vehicle coils 5 and the guideway 4 is slightly smaller at the sides of the vehicle than at the center, thereby to raise the center of lift of the suspension. When the vehicle is slightly elliptical its lateral stiffness

is increased over its vertical stiffness. The cryogenic apparatus may be modified to employ a closed loop liquid-helium apparatus as shown schematically in FIG. 24 and as more particularly described in letters U.S. Pat. No. 3,364,687 granted to Kolm, one of the present inventors, on Jan. 23, 1968. The liquid helium at a pressure above its critical point, or "supercritical helium," is cooled by a heat exchanger 81 immersed in a central dewar reservoir 82 containing helium at ordinary pressure. The supercritical helium is then circulated by a pump 80 through all the superconducting coils labeled 5A, which may be made of hollow conductors or thermally connected to suitable tubing, ultimately returning to the central helium reservoir, where it is re-cooled by the heat exchanger 81. The use of a closed circulation loop of this type has several advantages, the most notable being that the individual superconducting coils are not immersed in liquid helium reservoirs, but are merely surrounded by a vacuum barrier and a suitable radiation shield. This radiation shield, designated 22'', can be cooled by liquid nitrogen which is also circulated from a central reservoir 83 through the same connecting lines which conduct the liquid helium, thereby serving to provide radiation shielding for the helium conductors. This arrangement makes it possible to service the vehicle from one single connection.

Further modifications will occur to persons skilled in the art and all are considered to be within the spirit and scope of the invention.

What is claimed is:

1. An electromagnetic transportation system comprising, in combination: a vehicle having a cylindrical lower surface and carrying a plurality of superconducting coils distributed over a substantial portion of the lower surface, said superconducting coils being positioned within the vehicle adjacent said lower surface and having a contour similar to the contour of that surface, means for maintaining the superconducting coils at a superconducting temperature, individual coils having sufficient area and being energized with sufficient persistent supercurrent to generate a magnetic dipole field having an intensity of 1,000 to 3,000 gauss at a distance of approximately 25 centimeters from the lower surface of the vehicle, adjacent coils being energized so as to produce magnetic fields oriented alternately upward and downward; a trough-like, cylindrically-shaped guideway surrounding approximately the lower third of the circumference of the vehicle to support, guide and propel said vehicle, said guideway containing both active, current-carrying conductors and passive conductors forming a substantially continuous surface along the length of the guideway exposed to the magnetic field of the superconducting coils in the vehicle so as to support the vehicle, when the vehicle is moving at a speed above a predetermined minimum value, at a clearance of approximately 25 centimeters by interaction between the magnetic dipoles of the vehicle coils and the eddy currents they induce in the passive conductors, the current-carrying, active conductors being shaped so as to form a series of overlapping current loops strung axially along the guideway and substantially conforming to the cylindrical surface of the guideway so as to generate, when energized, an alternating magnetic field which moves along the axis of the guideway and propels the vehicle at synchronous speed by interaction with the magnetic dipoles of the vehicle coils; a source of multiphase alternating electric

current connected to energize the active conductors in correct sequence; and control means operable to connect the source of electric current to any particular active conductor; the moving vehicle being electromagnetically supported resiliently at a clearance of about 25 centimeters from the guideway and being free to rotate about its longitudinal axis so as to establish the correct bank angle when negotiating turns, the guideway being banked at only approximately the correct angle in turns, the center of electromagnetic lift of the vehicle being located above its center of gravity so as to insure stability.

2. In the electromagnetic transportation system of claim 1 a cycloconverter connected as part of the source of alternating electric current, the cycloconverter being operable to generate frequencies lower than those of the input electric power.

3. In the system of claim 2, speed control means connected to the cycloconverter to control the frequency output thereof and hence the speed of the vehicle for cruising and for acceleration and deceleration of said vehicle.

4. A system as claimed in claim 2 comprising two substantially parallel-oriented guideways each of which is made up of a plurality of serial sections of guideway, four sections at each region of the system constituting a block, the active conductors of each section being electrically insulated from all other sections, a transformer associated with each block, a cycloconverter being connected between the secondary of each transformer and the active conductors of each section, and speed control means connected to control the frequency output of each cycloconverter and hence the speed of a vehicle in any particular section.

5. A system as claimed in claim 4 in which the transformer and cycloconverter units which energize each of the four guideway sections in a block are governed by three control systems: a block control having its primary input by transmission from the vehicle, which serves to energize any of the four guideway sections in the associated block when said section is occupied by a vehicle so as to provide acceleration, deceleration or synchronous propulsion at a desired speed; a regional control derived from several neighboring blocks which serves to over-ride the block control if this is necessary to maintain a predetermined safe vehicle separation; and a central control which monitors operation of the entire system, serves as a backup for the regional control, and which over-rides the block control if this becomes necessary to avoid congestion at any point of the system, or in the event of mechanical failure or accident.

6. An electromagnetic transportation system according to claim 1 in which the guideway is constructed of bonded aluminum laminations, suitably interleaved with insulation so as to provide both the passive and the active current-carrying conductors, and having sufficient mechanical strength and rigidity to support the vehicle and to maintain the required dimensional tolerances without the need for additional re-enforcing structures, and being constructed in such a manner that all exposed surfaces of the guideway are smooth and electrically neutral.

7. An electromagnetic transportation system according to claim 1 in which the vehicle is circular cylindrical and in which the superconducting coils in the vehicle extend over an appreciable fraction of the underside of

the vehicle to distribute the vehicle weight more or less uniformly over the entire guideway beneath the vehicle.

8. An electromagnetic transportation system according to claim 1 in which wheels are provided on the vehicle to support the vehicle when its speed falls below the minimum speed required for electromagnetic levitation, which is approximately 35 kilometers per hour.

9. An electromagnetic system as claimed in claim 1 in which wheels are provided on the guideway at station sections thereof to support the vehicle when its speed falls below the minimum speed required for electromagnetic levitation.

10. An electromagnetic railway system according to claim 1 characterized by the fact that the guideway trough is covered by an upper shell so as to provide a sealed tunnel which can be installed underground and/or partially evacuated to reduce aerodynamic drag at speeds above 500 kilometers per hour.

11. An electromagnetic transportation system according to claim 1 in which said source is a power supply system comprising multi-phase transformers located at suitable intervals along the guideway and in which the control means includes switching elements controlled in part by signals from the vehicle and operable to connect the transformer to the active conductors in a determined sequence, each transformer being capable of energizing any one of four sections in a block of a two-lane guideway system while the section in question is occupied by the vehicle.

12. An electromagnetic transportation system according to claim 11 in which the power supply system operates at a fixed frequency in constant speed cruising sections of the guideway and in which power supply system utilizes controllable switching elements over accelerating and/or decelerating sections of the guideway so as to provide variable speed synchronization at controllable thrust.

13. An electromagnetic transportation system according to claim 1 in which the cross-section of the vehicle and/or of the superconducting coils adjacent to its surface are slightly elliptical so that the clearance between the vehicle coils and the cylindrical guideway trough is slightly smaller at the sides of the vehicle than its center, thereby to raise the center of lift of the suspension and increase its lateral stiffness in relation to its vertical stiffness.

14. An electromagnetic transportation system according to claim 1, characterized by the fact that the guideway is provided with vehicle switching sections to permit a vehicle to be routed to one of several sidings at full cruising speed by elastically deflecting a sufficiently long section of the guideway to permit a smooth transition of the vehicle to one of several alternate sidings.

15. An electromagnetic system as claimed in claim 1 in which the vehicle is provided with a plurality of extendible wheels at each side thereof and in which the guideway is provided with tracks to receive the wheels.

16. An electromagnetic system as claimed in claim 15 in which the wheels are extendible to two positions outward from the vehicle and in which the guideway has two side-by-side tracks on either side thereof to receive the wheels at the respective positions, one of the tracks on each side of the guideway being inclined at an angle to the other two tracks to allow a vertical change in the direction of movement of the vehicle

along the guideway, thereby to effect switching thereof.

17. A system as claimed in claim 16 in which means is provided to extend and retract said wheels and in which means is provided for raising and lowering said wheels when in the extended position.

18. A system as claimed in claim 16 having means for braking the vehicle through interaction between the wheels and the track.

19. A system as claimed in claim 1 in which said superconducting coils are oriented to produce field lines that are primarily normal to the lower surface of the vehicle at said surface.

20. A system as claimed in claim 1 in which the vehicle is provided with skids for emergency stops between stations.

21. A transportation system employing magnetic levitation comprising, in combination, a passive vehicle carrying a series of superconducting coils capable, when energized, of generating magnetic fields of the order of 1,000 to 3,000 gauss at a distance of 25 centimeters from the vehicle lower surface, said coils being disposed substantially over the whole lower surface area of the vehicle, an active guideway in the shape of a trough surrounding about the lower third of the vehicle, said trough containing linear synchronous motor propulsion coils embedded in the middle section and capable of providing enough force for acceleration and cruising of the vehicle, said propulsion coils utilizing the field of the superconducting coils as part of the linear synchronous motor, the portions of the trough on either side of the propulsion coils being constructed of conductive material in which eddy currents are induced by the passage of the energized superconducting coils over the trough, which eddy currents produce through interaction with the field of the superconducting coils a repulsive force that levitates the vehicle and furnishes lateral guidance, a wayside power system comprising multiphase transformers located at approximately 1 to 5 kilometer intervals along the guideway, and electronically switched electric power means to provide acceleration and deceleration of the vehicle, said electronically switched electric power means being connected to effect excitation of the propulsion coils with a variable frequency electric current, said frequency being variable so as to allow smooth acceleration and deceleration of the vehicle, thereby to provide variable speed synchronization at controllable thrust.

22. An electromagnetic transportation system comprising, in combination: a vehicle having a cylindrical lower surface and carrying a plurality of superconducting coils distributed over a substantial portion of that lower surface, said superconducting coils being positioned within the vehicle adjacent said lower surface and having a contour similar to the contour of that surface, means for maintaining the superconducting coils at a superconducting temperature, individual coils having sufficient area and being adapted, when energized with sufficient persistent supercurrent, to generate a magnetic dipole field having an intensity of 1,000 to 3,000 gauss at a distance of approximately 25 centimeters from the lower surface of the vehicle, adjacent coils being energized so as to produce magnetic fields oriented alternately upward and downward; a trough-like, cylindrically-shaped guideway surrounding approximately the lower third of the circumference of the vehicle to support, guide and propel said vehicle, said guideway containing both active, current-carrying con-

ductors and at least one passive conductor distributed therealong, the passive conductor providing substantially continuously electrically conductive means along the length of the guideway exposed to the magnetic field of the superconducting coils in the vehicle so as to support the vehicle, when the vehicle is moving at a speed above a predetermined minimum value, by interaction between the magnetic dipoles of the vehicle coils and the eddy currents they induce in the passive conductor, the current-carrying, active conductors being positioned to form a series of overlapping current loops strung axially along the guideway and substantially conforming to the cylindrical surface of the guideway so as to generate, when energized, a traveling magnetic field which moves along the axis of the guideway and propels the vehicle at synchronous speed by interaction with the magnetic dipoles the vehicle coils; a source of multiphase alternating electric current connected to energize the active conductors in correct sequence; and control means operable to connect the source of electric current to any particular active conductor; the moving vehicle being supported resiliently at a clearance of about twenty-five centimeters from the guideway and being free to rotate about its longitudinal axis so as to establish the correct bank angle when negotiating turns, the guideway being banked at only approximately the correct angle in turns, the center of electromagnetic lift of the vehicle being located above its center of gravity so as to insure stability.

23. An electromagnetic transportation system comprising, in combination: a vehicle having a cylindrical lower surface and carrying a plurality of magnetic means for creating a plurality of radial magnetic dipole fields distributed over a substantial portion of that lower surface, said magnetic means being positioned within the vehicle adjacent said lower surface, the magnetic means having sufficient area to generate a magnetic dipole field having an intensity adequate to levitate the vehicle ten to fifty centimeters above the guideway, adjacent dipole fields so created being oriented alternately upward and downward; a trough-like, cylindrical-shaped guideway surrounding a portion of the lower circumference of the vehicle to support, guide and propel said vehicle, said guideway containing both active, current-carrying conductors and passive conductive means distributed therealong, the passive conductive means providing electrically conductive means along the length of the guideway exposed to the magnetic dipole fields of the magnetic means in the vehicle so as to support the vehicle, when the vehicle is moving at a speed above a predetermined minimum value, by interaction between the magnetic dipoles of the vehicle magnetic means and the eddy currents they induce in the passive conductive means, the current-carrying, active conductors being shaped so as to form a series of overlapping current loops along the axis of the guideway and substantially conforming to the cylindrical-shaped surface of the guideway so as to generate, when energized, a magnetic field which moves along the axis of the guideway and propels the vehicle at synchronous speed by interaction with the magnetic dipoles of the vehicle magnetic means; a source of multiphase alternating electric current connected to energize the active conductors in correct sequence; and control means operable to connect the source of electric current to any particular active conductor; the moving vehicle being thereby supported resiliently

17

above the guideway and being free to pivot about its longitudinal axis so as to establish the correct bank angle when negotiating turns, the guideway being banked at only approximately the correct angle in turns, the center of electromagnetic lift of the vehicle being located above its center of gravity so as to insure stability.

24. A transportation system as claimed in claim 21 in which the superconducting coils and the conductive material at each side of the trough-shaped guideway in an operating system act to provide both levitation and lateral guidance.

25. A transportation system as claimed in claim 24 in which the electronically switched power means comprises one or more cycloconverters electrically connected between each multiphase transformer and the propulsion coils and in which a communication link is provided between the vehicle and the electronically switched power means to effect and maintain synchro-

18

nous electromagnetic interaction between the superconducting field and the field of the propulsion coils.

26. A transportation system as claimed in claim 25 in which the communication link is a short range radio link.

27. A transportation system as claimed in claim 25 in which the communication link comprises conducting means in the guideway and electrically coupled to the electronically switched power means.

28. A transportation system as claimed in claim 21 in which the conductive material is substantially continuously conductive.

29. A transportation system as claimed in claim 21 in which each of the superconducting coils with its liquid helium system is surrounded by a radiation shield, the radiation shields being cooled by liquified gas which also serves to provide on-board auxiliary power.

\* \* \* \* \*

20

25

30

35

40

45

50

55

60

65