2-19-74 XR SR 3,792,665

United States Patent [19]

Nelson

[11] **3,792,665**

[45] **Feb. 19, 1974**

[54] **LINEAR INDUCTION CONTROL SYSTEM**

[75] Inventor: **Roy A. Nelson,** Grand Prairie, Tex.

[73] Assignee: **LTV Aerospace Corporation,** Dallas, Tex.

[22] Filed: **Aug. 16, 1972**

[21] Appl. No.: **281,262**

[52] **U.S. Cl.** ..... **104/148 LM,** 318/135

[51] **Int. Cl.** **B61b 13/12**

[58] **Field of Search.** 104/148 MS, 148 LM, 148 SS; 318/135; 310/12, 13; 246/110, 108, 161

[56] **References Cited**

UNITED STATES PATENTS

3,721,874	3/1973	Pelenc et al.	318/135
3,701,321	10/1972	Lee	104/148 LM
3,407,749	10/1968	Frig	318/135
3,403,634	10/1968	Crowder	310/12
3,548,751	12/1970	Izhelya et al.	104/148 LM
2,794,929	6/1957	Adamski	104/148 LM
3,555,380	1/1971	Hings	318/135
3,712,240	1/1973	Donlon et al.	104/148 LM
3,547,041	12/1970	Izhelya et al.	104/148 LM
573,823	12/1896	Leffler	310/12
2,618,741	11/1952	Jacobs et al.	246/161

FOREIGN PATENTS OR APPLICATIONS

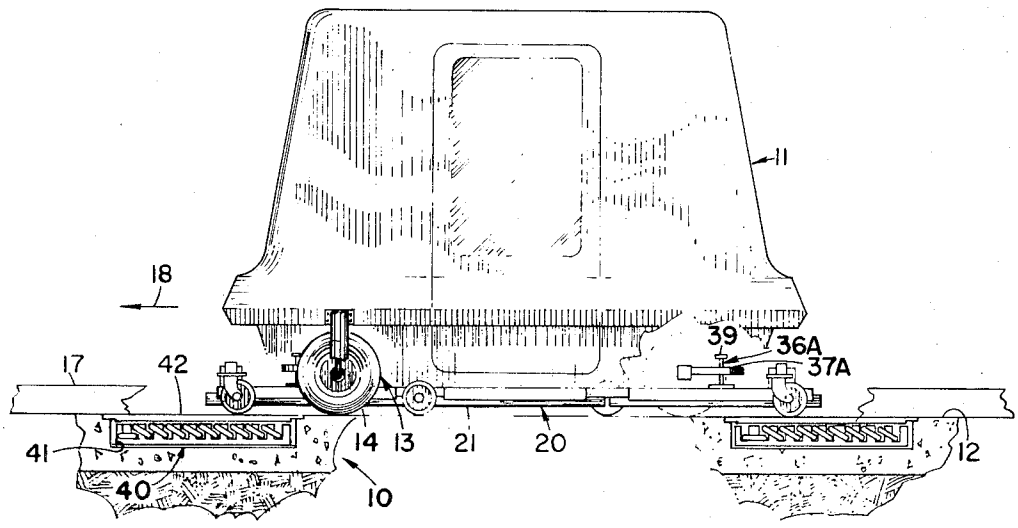
842,090	6/1939	France	310/13
662,682	8/1929	France	104/148 LM

Primary Examiner—Duane A. Reger
Assistant Examiner—Galen L. Barefoot
Attorney, Agent, or Firm—James M. Cate; H. C. Goldwire

[57] **ABSTRACT**

A control system is employed in a linear induction propulsion system of the type having linear induction primary elements which are fixedly mounted at spaced intervals along a guideway and linear induction secondary structures which are carried by respective movable structures driven along the guideway by the propulsion system. Sensing devices are provided for detecting proximity of the linear induction secondary structures to respective ones of the primary elements, and apparatus is provided for conducting electrical power to any of the primary elements which are in alignment with any portion of one of the secondary structures. The control system is operable to regulate the spacing between successive movable structures.

4 Claims, 9 Drawing Figures



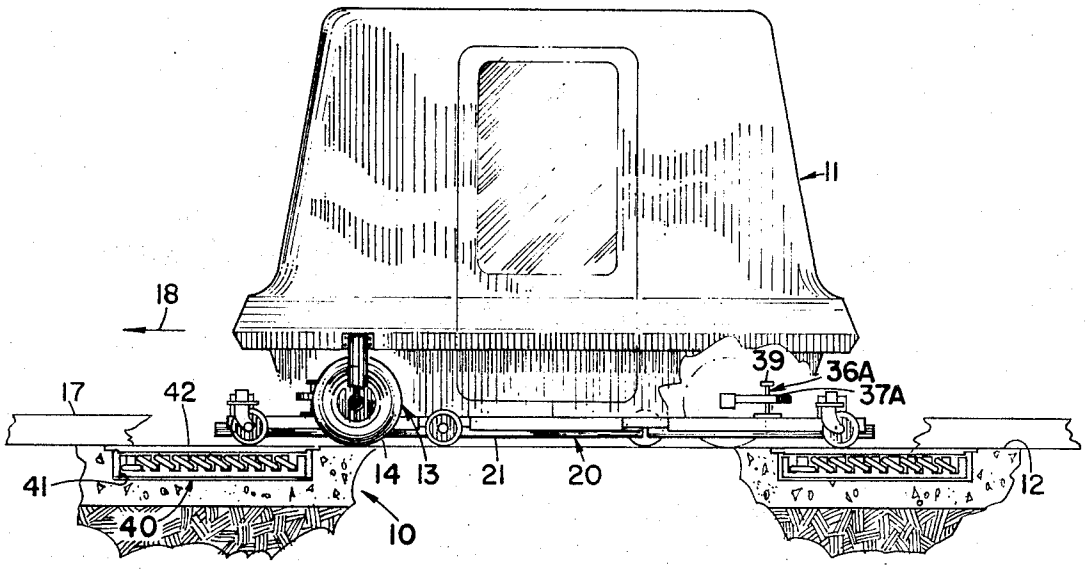

11
18
17
42
39
36A
37A
41
40
14
13
21
20
10
12

FIG 1

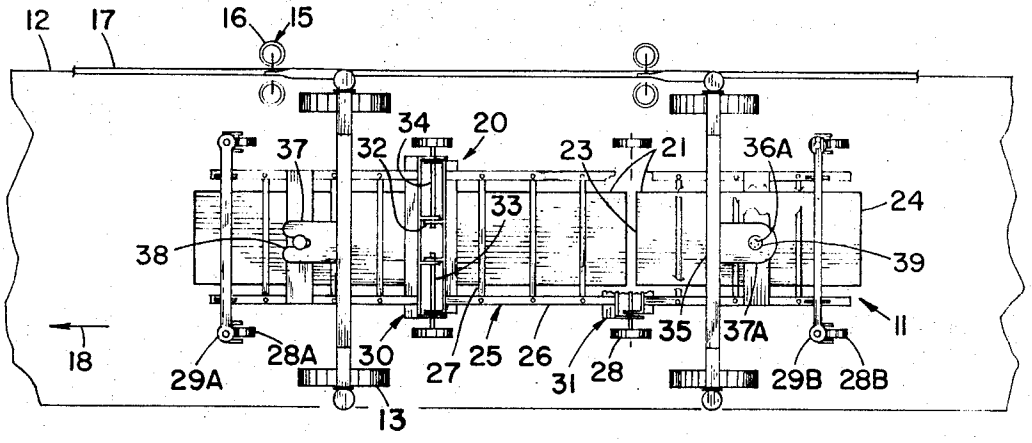

12
17
16
15
34
20
37
32
23
21
36A
24
33
38
39
18
28A
30
27
25
26
31
28
35
37A
11
29A
29B
28B
13

FIG 2

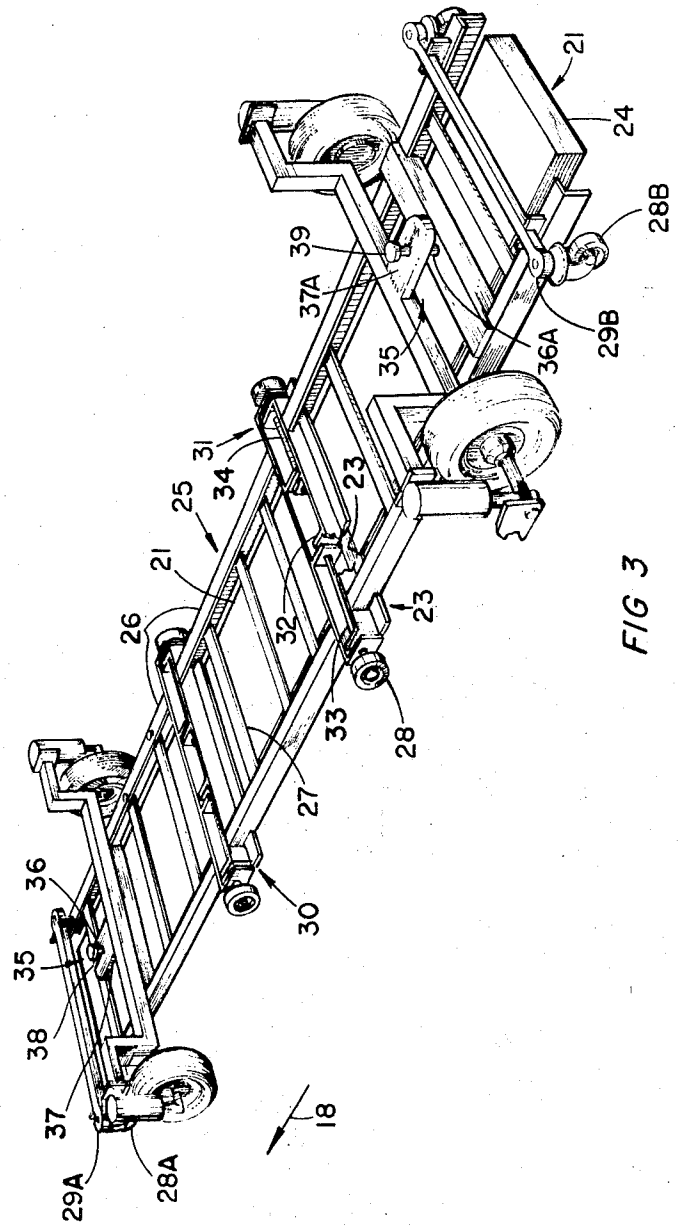

21
24
28B
39
37A
35
36A
29B
31
34
25
23
21
26
32
23
33
28
27
30
36
35
38
37
29A
28A
18

FIG 3

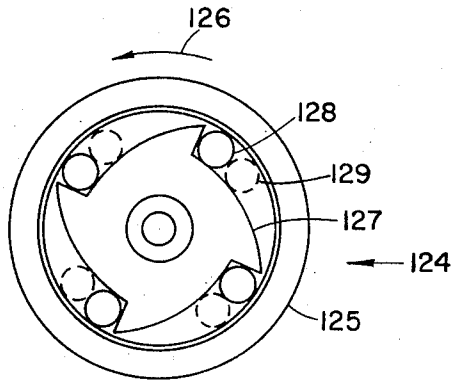


FIG 4

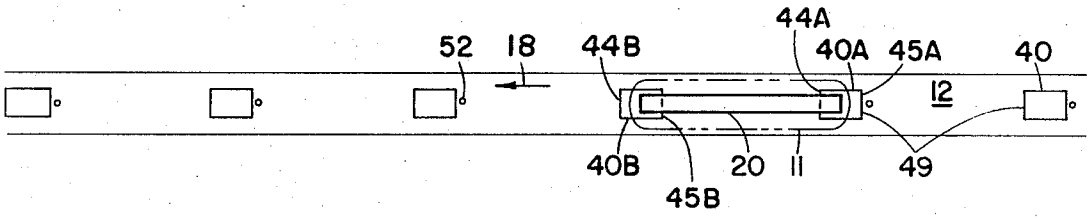


FIG 5

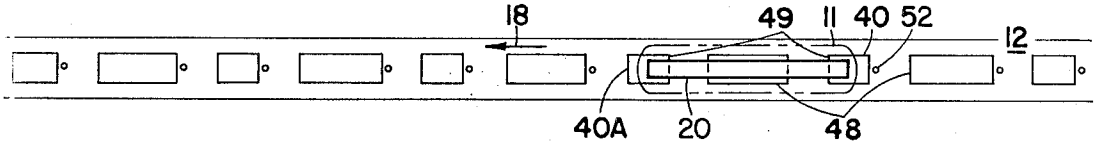


FIG 6

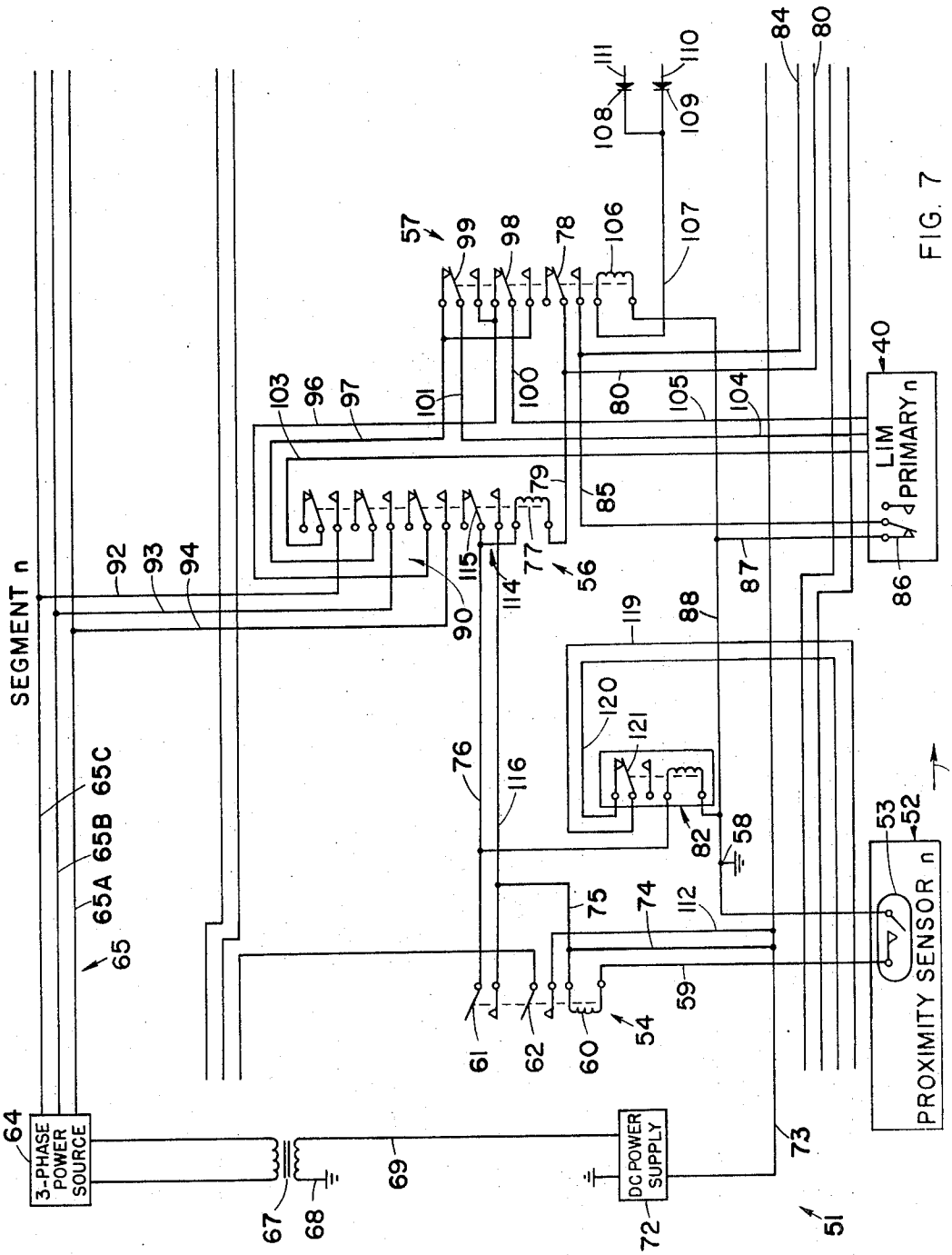

SEGMENT n
3-PHASE POWER SOURCE
DC POWER SUPPLY
LIM PRIMARY n
PROXIMITY SENSOR n
65A 65B 65C
65
64
67
68
69
72
73
51
18
40
52
53
54
56
57
58
59
60
61
62
74
75
76
77
78
79
80
82
84
85
86
87
88
90
92
93
94
96
97
98
99
100
101
103
104
105
106
107
108
109
110
111
112
114
115
116
119
120
121

FIG. 7

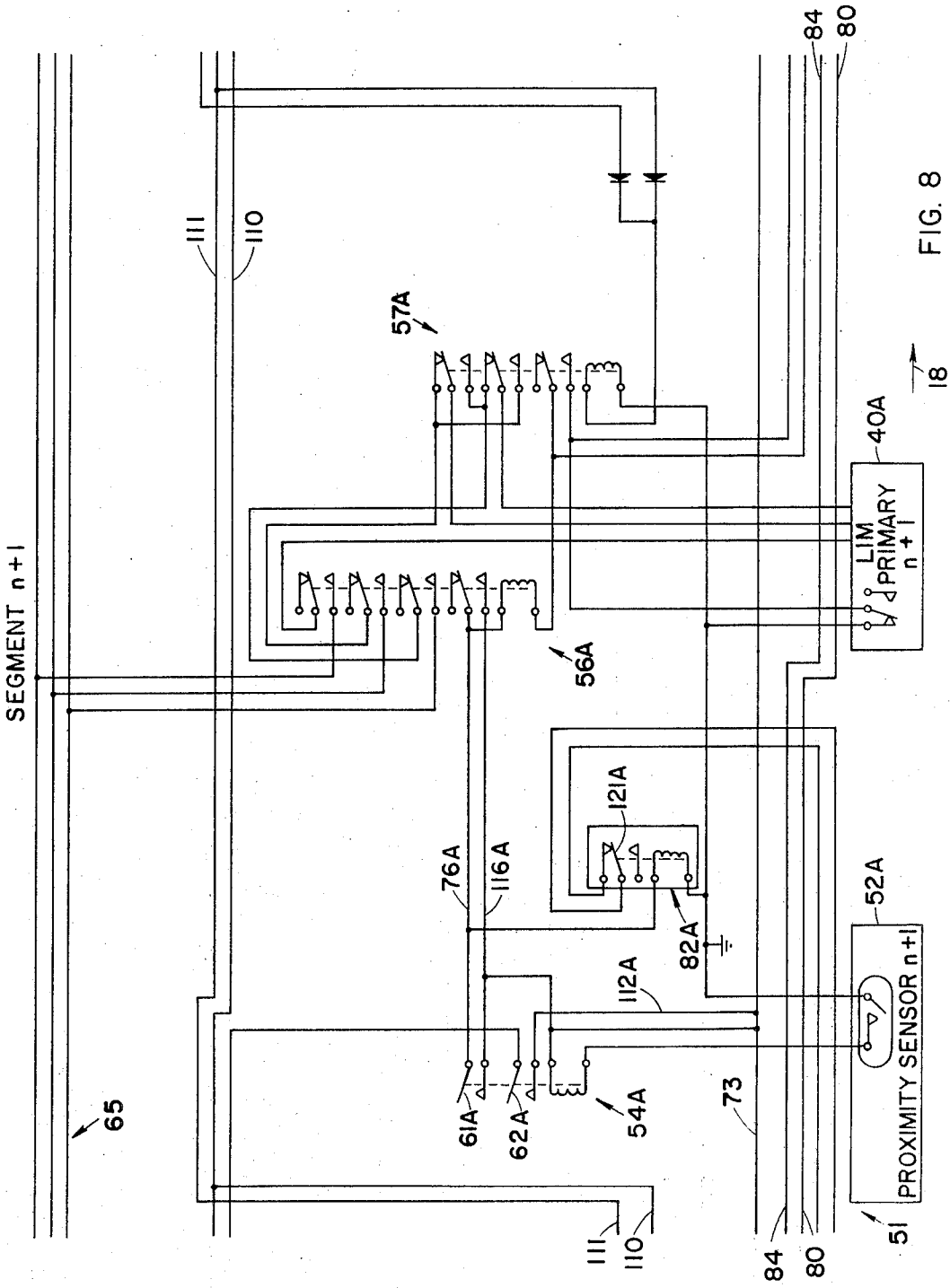

SEGMENT n+1
65
111
110
57A
56A
40A
LIM PRIMARY n+1
18
84
80
121A
76A
116A
82A
112A
52A
PROXIMITY SENSOR n+1
51
61A
62A
54A
73

FIG. 8

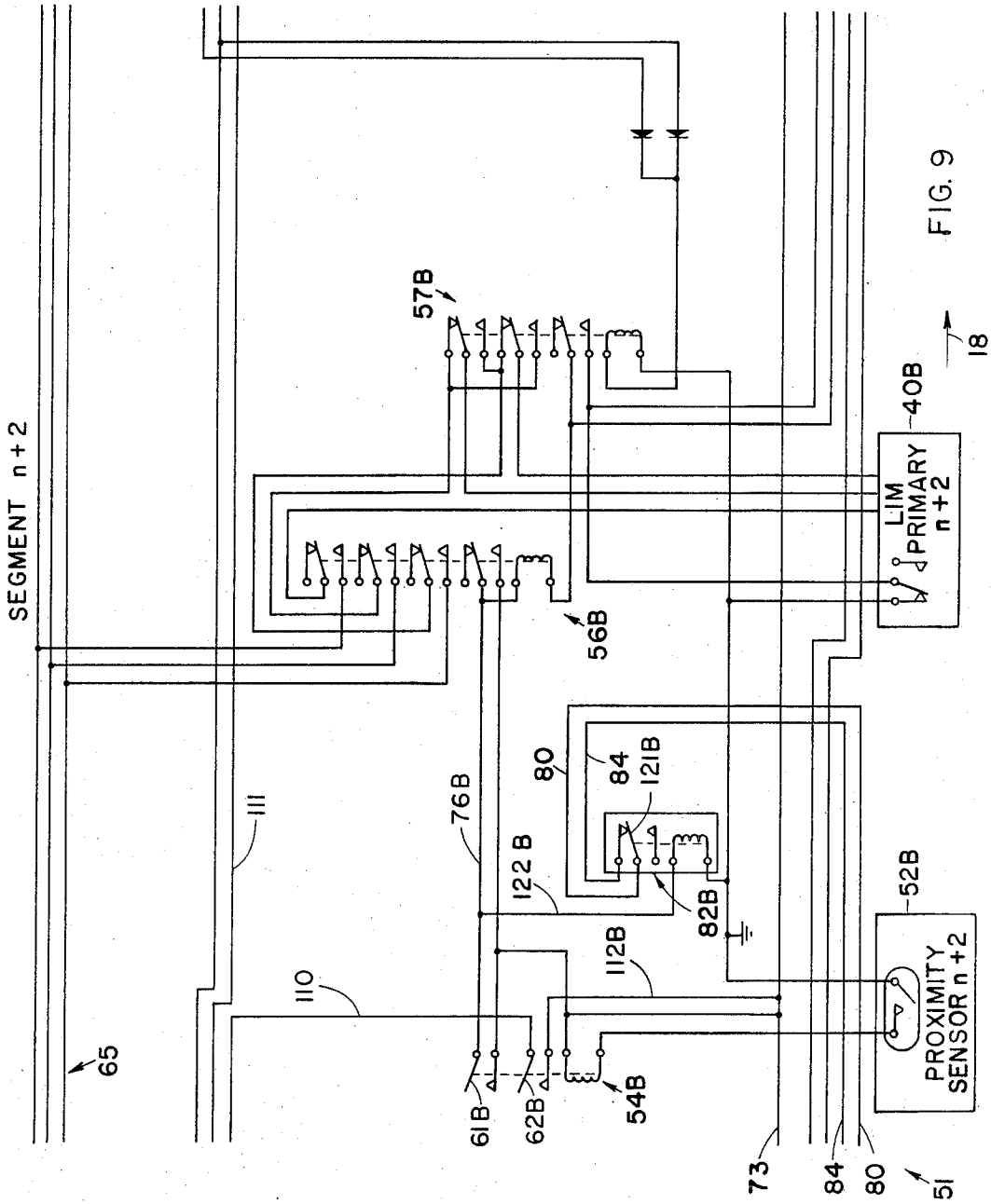

SEGMENT n+2
65
111
110
57B
56B
40B
LIM PRIMARY n+2
18
80
84
121B
76B
122B
82B
112B
52B
PROXIMITY SENSOR n+2
61B
62B
54B
73
84
80
51

FIG. 9

LINEAR INDUCTION CONTROL SYSTEM

This invention relates to linear induction propulsion systems and, more particularly, to a control system for a linear propulsion system having stationary primary elements and movable secondary elements.

Linear induction propulsion systems have been proposed for transportation systems of various types, such as high speed train systems and mass transit systems. A majority of the linear induction propulsion systems proposed for use in public transportation systems have been of the fixed secondary, movable primary type in which vehicles powered by the propulsion systems carry LIM (linear induction motor) primary elements, the primary elements being energized by electrical power conducted to the vehicles from a remote power source. Such an arrangement has been preferred because it has been thought to be more economically feasible than the movable secondary, fixed primary systems wherein the LIM secondaries are carried by the vehicles, primarily because of the elimination, in the former, of the requirement for a multiplicity of primary elements installed at successive intervals along the guideway, track, or roadway along which the LIM powered vehicles travel. Such fixedly mounted, LIM primary elements include coils of relatively high power handling capacity, often of heavy copper wire, and they thus represent a major investment if they must be extended along a large percentage of the length of a guideway. As is known in the art, the secondary elements of fixed secondary LIM systems may be constructed as elongated, vertical rails or strips, often including laminations of ferromagnetic and electrically conductive materials extended along the length of the guideway. Such elongated secondary structures may be constructed less expensively than LIM primary elements which are extended continuously along the length of a guideway.

While the linear induction propulsion systems employing fixed secondaries thus provide some advantages for certain applications, they also suffer from a number of disadvantages when compared with the fixed primary systems. One obvious disadvantage is that, in the fixed secondary systems, motive power for energizing the primaries is conducted to the moving vehicles by means such as electrical brush elements slidably associated with power rails extended along the guideway or track, according to practices well known in the art. Inherent in such sliding contact power supply systems are a number of undesirable features. These include the necessity for protecting bystanders from accidental contact with the power rails or wires while at the same time permitting accessibility thereto by the brushes or other contacting means. Another problem relates to malfunctions which may occur during extremes of weather conditions, e.g., when rain, snow, ice, or blown dust affects contact with the power rails or wires. An undesirably great amount of preventive maintenance of the brush elements, and of the flexible linkage structures which support the brushes in contact with the power rails, is required if failures are to be minimized. Additionally, control signals must be transmitted to the vehicles for regulating the traffic flow and spacing of the vehicles along the guideway is centralized or remote control of traffic flow is desired, as it normally is in high capacity systems.

In contrast, the fixed primary LIM systems avoid many of the difficulties and expenses related to power distribution and traffic control by eliminating the need for the conduction of electrical power and control signals to the vehicles. That is, the LIM primary elements and the required, electrical power distribution systems are fixedly mounted, e.g., within or alongside the guideway or roadway, and may be completely enclosed to prevent accessibility to the public or exposure to extremes of weather. The only necessary relationship between the LIM primary elements and the vehicles is that of the magnetic flux between the primaries and the secondary structures on the vehicles when the primaries and secondaries are in mutually confronting relationship.

Headway control and velocity regulation in continuously circulative, LIM powered systems has, in the past, involved control systems wherein the spacing and velocity of the vehicles is regulated by means of extensive (and expensive) electrical control apparatus. Two general approaches to the problem may be taken. If only very low speed operation is required, relatively unsophisticated and inexpensive control apparatus may be safely employed. If the pole pitch of the LIM primaries is uniform, along the length of the guideway, and the applied AC current is of a constant frequency, the vehicles naturally tend to travel at a uniform velocity and to thus maintain a given initial spacing. Some variation in drag is always encountered, however, which causes a variation in "slippage," or deviation in the velocity of respective vehicles from the constant, syncronous speed to which the vehicles are urged by the LIM primaries, and the vehicles may therefore eventually overtake one another. Collisions at speeds below approximately 5 mph may not be unacceptable if appropriate, spring biased bumpers or the like are provided for the cars. At higher velocities, however, more sophisticated controls are required. Such controls must not only be fail safe with respect to the prevention of collisions between successive vehicles, but also must be operable to accelerate and decelerate the the vehicles at rates of acceleration which do not exceed those acceptable from the standpoint of desired minimum standards of passenger comfort.

With respect to the improvement of standards of safety and reliability for such systems, it is desirable that the control and braking of the vehicles be performed by mechanisms which are not subject to deterioration because of exposure to various weather conditions and to excessive vibration and stress. Therefore, it is believed preferable that control and braking of the vehicle be accomplished by fixed primary elements and associated circuitry mounted along the guideway rather than by sliding power contact means and control apparatus carried by the vehicles. As will be explained in the description to follow, traffic regulation and headway control can be accomplished, in the fixed primary system disclosed herein, by means of control elements contained entirely within sealed facilities fixedly mounted along the guideway.

As has been suggested, the expenses associated with installing extensive, fixed primary, LIM propulsion systems have been a major factor in preventing general use of such systems in the past, in spite of the several advantages, outlined above, which are inherent in such systems. As also suggested above, a major expense in the fixed primary systems has been that of the LIM pri-

mary elements extended along substantial portions of the guideway. In the past, attempts have been made to minimize this expense by spacing the primaries along the guideway rather than extending them continuously along the guideway. This technique has presented further problems, however, in that, in such systems, the vehicles so propelled tend to accelerate and decelerate in an objectionable manner as they pass from one primary to the next because of variances in the total magnetic flux action upon the LIM secondaries carried by the vehicles.

A further economic disadvantage associated with prior, fixed primary LIM systems relates to the excessive power consumption of such systems. Prior art systems often entail the conduction of operating power to a number of the primary elements, although only those which are interacting with the secondaries of adjacent vehicles are performing useful work at a given instance. In contrast, of course, there is no such inefficiency in the fixed secondary systems, since the LIM primary on a vehicle of such a system is continuously operable to magnetically interact with a corresponding, adjacent region of the secondary structure.

It would obviously be a great advance in the art if the advantageous features, outlined above, of fixed primary, linear induction systems could be achieved in a system in which the inefficiencies of present,fixed primary LIM systems, such as excessive power consumption and high initial costs, were minimized.

It is, accordingly, a major object of the present invention to provide a new and improved, linear induction propulsion system having fixed primary induction elements.

Another object is to provide such a propulsion system in which power distribution and traffic control is accomplished by fixedly mounted components, independently of control devices aboard the vehicles.

Yet another object is to provide such a system in which power consumption is reduced greatly from that required in previous, fixed primary systems.

A still further object is to provide such a propulsion system in which the initial cost of the system is minimized by mutual spacing of the primaries along the guideway or track of the system, yet wherein the vehicles receive a substantially constant propulsive force as they progress forwardly, whereby objectional acceleration and deceleration of the vehicles is prevented.

Another major object is to provide a reliable system having the above-cited advantages which is additionally of practicable and economically feasible construction.

In the drawing:

FIG. 1 is a side elevation, partially diagrammatic in form and partially cut away, of a vehicle carrying a LIM secondary structure constructed according to a preferred embodiment of the invention, and showing a portion of a guideway containing two LIM primary elements installed according to the preferred embodiment;

FIG. 2 is a plan view of the secondary structure of FIG. 1 showing the pivotable linkages thereof;

FIG. 3 is a view of the apparatus of FIG. 2 with portions of the framework cut away;

FIG. 4 is a diagrammatic representation of the clutch mechanism employed by the vehicles in the preferred embodiment of the system;

FIG. 5 is a plan view, in diagrammatic form, showing the relative spacing of the LIM primary elements of the preferred embodiment of FIGS. 1–3;

FIG. 6 is a plan view, similar to FIG. 5, showing an alternative embodiment;

FIGS. 7–9 comprise a schematic and block diagram of a preferred embodiment of the traffic control systems of the linear induction propulsion system.

With initial reference to FIG. 1, a linear induction propulsion system 10 constructed according to a preferred embodiment of the invention is employed for propelling a wheeled vehicle 11 along a guideway 12. The propulsion system 10 is suited for use in any transportation system in which movable structures are constrained to travel along a fixed pathway or guideway. To illustrate other, alternative embodiments (not shown), the movable structures 11 may, for example, comprise railway cars, cargo or baggage containers adapted to follow a slideway or chute, or wheeled vehicles; alternatively, vehicles supported by magnetic levitation or by ground-effect air cushion devices or the like may be employed. The guideway followign vehicles 11 of the illustrated system are therefore presented herein or illustrative purposes only.

The exemplary, guideway following vehicle 11 is of the type having steerable wheels 13 suitably provided with resilient rubber tires 14. The vehicle 11 is adapted to automatically follow the guideway 12 by means of internal steering mechanisms (not shown) connected to guidewheel assemblies 15 as shown in FIG. 2. Each guidewheel assembly 15 suitably comprises two, horizontally alighed guidewheels 16 which are mounted to straddle a vertical, upright guide rail 17 extended alongside and parallel to the supporting surface of the guideway 12. The steering mechanism, responsive to horizontal input signals received from the guide wheel assemblies 15, acts to steer the vehicle 11 along the guideway 12 during movement of the vehicle in a first, or forward direction along the guideway as indicated by the arrow 18. Other, analogous guideway systems, for example, have employed U-shaped concrete guideways (not shown) in which vehicles are guided by opposing, centrally facing guide walls extending alongside the roadway. The construction of such guideway systems and guideway following vehicles is generally known, and further description thereof is therefore not considered necessary here. The vehicle 11 will be recognized by those in the art as being of the PRT (personal rapid transit) class for transporting individual or small groups along selected or selectable routes in a controlled manner.

As shown in FIG. 2, a LIM secondary structure 20 is connected to the vehicle 11 for propelling the vehicle along the guideway 12, as will be explained in detail in the description to follow. The LIM secondary structure 20 preferably includes several LIM secondary elements 21 arranged end-to-end in tandem, in a manner also to be described hereinbelow. The secondary elements 21 are suitably for the type supplied by the SACM&G division of the General Electric Company, Nashville, Tenn., under Part No. 153 B 3900 AA. These LIM secondaries 21 are in the general form of a slab of approximately rectangular plan and having a horizontal lower surface which is substantially flat. The secondary elements 21 are mounted in longitudinal alignment with the guideway 12 and each has first and second end portions 23, 24 (FIG. 2) directioned in the first direction,

indicated by arrow 18, and in a second, opposite direction, respectively. The above identified secondaries 21 are formed of multiple, vertical sheets of ferromagnetic material disposed side by side and extending from the first to the second end portions 23, 24 of the secondary elements 21, laticed with transversely extending, horizontally disposed aluminum members inserted through the ferromagnetic sheets. As is known in the art, other constructions and types of secondary elements are available which function in an analogous manner. According to the preferred embodiment of the invention, a supporting framework 25 is provided for carrying the LIM secondary elements 21. With additional reference to FIG. 3, the framework 25 consists of three frame structures 26 bolted to transverse support members 27 which are attached to and extend over the upper side of the LIM secondary elements 21. The frame structures 26 are equipped with wheels 28, suitably of a relatively hard, plastic or rubber material, for supporting the framework 25 and the secondary elements 21 above and in horizontal alignment with the surface of the roadway of the guideway 12. Wheels 28 are provided at the first and second, i.e., the front and rear end portions 23, 24 of each secondary element 21, and eight wheels 28 are thus provided for the illustrated embodiment employing three secondary elements 21. To prevent excessive friction between the wheels 28 in turns, the frontmost and rearmost wheels 28A, B are connected to the respective frame structures 26 by means of respective, rotatable caster supports 29A, 29B. The three frame structures 26 are aligned longitudinally by means of first and second hinge connections 30, 31 positioned adjacent the confronting end portions 23, 24 of the secondaries 21. At each hinge connection 30, 31, vertical, interdigitating tab elements 32 are extended forwardly from the forward ends of the respective frame structures 26 and rearwardly from the rear end portions, and positioned side by side in horizontal alignment. Horizontal, left and right axles 33, 34 are extended transversely of the vehicle 11 through corresponding bores formed through the tab elements 32, and the four, central, framework wheels 28 are coaxially and rotatably mounted on outwardly projecting end portions of the axles 33, 34. The hinged connections 30, 31 permit the secondary structure 20 to bend vertically, at the hinged connections, when the vehicle 11 is traveling over irregular portions of the guideway 12 and when it travels from level sections onto upwardly or downwardly sloped portions of the guideway. This articulated construction of the secondary structure 20 permits the secondary elements 21 to be positioned in close proximity with primary elements (to be described) installed in the guideway 12, yet allows the vehicle 11 to travel safely over guideways having some degree of irregularity. Thus, the expense related to construction of the guideway 12 is reduced, in that precise and level construction thereof is not required. The hinged construction of the secondary structure 20 also permits the effective length of the secondary on each vehicle 11 to be extended to the full length of the vehicle, as shown, or even to somewhat more than the length of the vehicle, which provides further advantages which will become apparent from the description to follow.

Connection between the secondary structure 20 and the vehicle 11 is preferably made by means 35 permitting relative vertical movement between the vehicle 11 and the secondary structure 20 but preventing substantial relative horizontal movement therebetween. In the preferred embodiment, upstanding, vertical posts 36, 36A are welded or otherwise rigidly affixed to front and rear portions of the framework 25. Corresponding openings are formed through respectively adjacent portions 37 of the vehicle 11 in register with the adjacent posts 36, 36A for slidably receiving the respective posts. Preferably, one of the posts 36A is received in a circular bore formed vertically through the vehicle frame portion 37, while the other post 36 is slidably received in a slot 38 formed through the frame portion 37 and extending parallel to the longitudinal axis of the vehicle 12. Forward and rearward forces received by the LIM secondary elements 21 are thus transmitted to the vehicle 11 through the rear post 36A, while the forward post 36 is slidable forwardly and rearwardly within groove 38 and therefore does not transmit such forces to the vehicle, although it does serve to prevent relative movement of the secondary structure 25 transversely of the vehicle 11 and thus keeps the secondary structure in proper alignment with the guideway 12 and with the primary elements 40 to be described. The reason for this arrangement is that, as the flexible framework 25 travels over irregular surfaces and flexes at its hinged connections 30, 31, some variance of its overall length occurs, and compensation therefor is thus provided by the slot 38. Respective caps or bosses 38 are formed on the uppermost portions of the posts 36, 36A for retaining the posts 36 in the frame portion 37. The connecting means 35 thus permits relative vertical movement of the vehicle 11 and the secondary structure 20, yet can transmit forward or rearward driving forces on the vehicle. Accordingly, the vehicle 11 can be provided with a suitable suspension system for providing a relatively soft ride for the vehicle even though the secondary structure 20 is provided with a relatively rigid suspension for resisting the substantial, downwardly directed magnetic forces which are exerted upon the secondary elements 21 during operation.

Referring again primarily to FIGS. 1 and 2, a plurality of linear induction primary elements 40 is also provided, each primary element 40 being fixedly mounted within a corresponding chamber 41 depressed below the upper surface of the guideway 12, each LIM primary element being positioned with its upper surface depressed slightly below the surface of the guideway 12. The primary elements 40 are suitably covered by horizontally disposed sheets 42 of magnetically permeable material mounted contigously with the surface of the guideway 12 for protecting the primary structures, and the circuitry connected to the primary structures, from environmental conditions and vandalism. The LIM primaries 40 are suitably of the type manufactured by the General Electric Company at its Nashville facility under part number 149 C 4200 AG, these primaries having approximately 150 pounds of stall thrust capacity.

Referring now to FIG. 5, the LIM primary elements 40 are mutually spaced along the guideway 12 and have respective first and second, i.e., front and rear end portions 44, 44A, 44B; 45, 45A, 45B directed in the first and second or forward and rearward directions, respectively, along the guideway 12. The direction indicated by arrow 18 again is to be considered the normal direction of travel for the vehicle 12. Each respective first end portion 44B of each primary element 40B is prefer-

ably spaced, by a uniform distance in the first direction along the guideway 12, from the first end portion 44A of a respective, corresponding primary element 40A, each pair 49 of corresponding, mutually spaced primary elements 40B, 40A; 40A, 40 in at least a portion of the guideway 12 being of substantially the same length, for reasons which will become apparent. Each secondary structure 20, in the preferred embodiment, has a total length substantially equal to the uniform distance between the first end portions 44B, 44A of a corresponding primary elements 40B, 40A. In the embodiment of FIG. 5, the corresponding primary elements 40, 40A are successive, and thus comprise a pair 49 of successive elements. Primary element 40A and the next successive primary element 40B comprise a second pair of corresponding primaries, it being thus shown that the secondary structure 20 will pass over the rear portion 45B of the forward primary of any corresponding pair as it passes the rear portion 45A of the rearmost primary of the pair. In an alternate embodiment as shown in FIG. 6, for example, the primary elements 40 of respective pairs 49 of corresponding primary elements are not successive; rather, the frontmost primary element 46 of a first pair 48 is positioned forwardly of the rearmost primary element 40 of a second pair 49. In this example, the primary elements 46 of the first pair 48 are larger and more powerful primary elements than those of the second pair 49 and are suitable for assisting the second pair 49, for example, in powering the vehicle 11 up inclined portions of the guideway 12. In the embodiment shown in FIG. 5, the length of each secondary structure 20 is greater than twice the length of the primary elements 40, 40A; 40A, 40B or pairs of corresponding primaries. Thus, as advantageously permitted by the disclosed system, the primary elements 40 need to be extended along only a small percentage of the total length of the guideway 12 in normal installations. The primaries (40, 40A; 40A, 40B) of respective pairs 49 of corresponding primaries are corresponding in the sense that they both react with a single one of the secondary structures 20 when the front and rear portions of the secondary are positioned in register with the primaries of a respective pair, as will be described with respect to the operation of the system.

With respect now to the circuit diagram of FIGS. 7, 8, and 9, three successive segments [n, ($n+1$), and ($n+2$)] of the control circuit 51 of the propulsion system 10 are shown in FIGS. 7, 8, and 9, respectively. First, second, and third proximity sensors 52, 52A and 52B are positioned immediately forward of first, second and third LIM primaries 40, 40A, and 40B (corresponding to the identically numbered elements of FIG. 5) respectively, in guideway segments n, ($n+1$), and ($n+2$). The proximity sensors 52, 52A, and 52B are spaced forwardly in the guideway from the respective LIM primaries 40, 40A, and 40B by about 4 to 6 inches and comprise sensing means, adjacent each primary element 40, 40A, 40B, for sensing the proximity to the respective, corresponding primary elements 40, 40A, and 40B, of one of the secondary structures 20 (FIG. 1) on one of the vehicles 11. The sensors 52, 52A, 52B are suitably for the ferromagnetic, reed switch type, such as that manufactured under part number 4FRI-6 of the Micro Switch Company, and are operable to close a normally open switch 53 when a mass of ferromagnetic metal, e.g., that of one of the secondary structures 20, passes over the sensor. Alternatively, they may be of the mechanical trip switch type, the inductive coil type, or any other suitable type.

To briefly summarize the control circuit 51, each proximity sensor 52, 52A and 52B is connected in series with the coil of a corresponding, proximity relay (54, 54A, and 54B, respectively) whose function is to actuate a corresponding, power control relay 56, 56A, and 56B, respectively, to supply power successively to LIM primaries 40, 40A, and 40B, respectively if forward progress of the vehicle 11 (FIG. 1) is appropriate. Each segment n , ($n+1$), ($n+2$) of the circuit 51 is connected between a respective one of the power control relays 56, 56A, 56B and a respective LIM primary 40, 40A, 40B for reversing the polarity of power supplied when emergency braking of a vehicle is required.

More specifically, and with respect now to the circuit of the first or "n" th segment illustrated in FIG. 7 the proximity sensor 52 includes a normally open switch 53 connected in series between a grounded point 58 and, via lead 59, to one side of relay coil 60 of the first proximity relay 54. The proximity relay 54, and the corresponding proximity relays 54A, 54B of the other two segments, are suitably of the single throw type, having first and second, normally open switch elements 61 and 62. Relays of the general type typified by Model 8501-C02 manufactured by Square D Company are exemplary of the type employed as proximity sensor relays 54, 54A, 54B, although only two poles are necessary for the illustrated embodiment.

While relay controlled switching elements, e.g., relays 54, 54A, 54B and 56, 56A, 56B, are shown in the drawings, it will be understood by those skilled in the art that solid state switching devices of various types may be substituted therefor if desired, according to practices known in the art.

A power source 64 for suppling 440 -volt,3 -phase power to the system is provided, and 3 -phase voltage therefrom is conducted to segments n, ($n+1$), ($n+2$) through a power cable 65, comprising power bus wires 65A, 65B, and 65C. A voltage reducing transformer 67 has a primary winding connected to the power source 64 and a secondary winding connected, on one side, to a ground 68 and on the other side to a lead 69 which connects to a rectifying, DC power supply circuit 72 for rectifying AC power from the reducing transformer 67. The DC output of DC power supply 72 is conducted through a "power supply conductor" 73 to the several segments of the circuit 51.

Upon actuation of the proximity sensor 52 by an adjacent secondary structure 20 (FIG. 1) passing over the sensor 52, the normally open switch 53 of the sensor 52 is closed, thus completing a circuit from DC supply conductor 73 and lead 74, through the coil 60 of proximity relay 54, through lead 59 and switch 53 to the grounded point 58. This completed circuit loop results in the current flow which actuates the proximity relay 54 to close normally open switch elements 61, 62 thereof. Positive potential is then conducted from DC power supply 72 through DC supply wire 73, successively through leads 74 and 75, through switch element 61 and through lead 76 to the coil 77 of power relay 56. The other side of coil 77 is normally connected to ground, successively through leads 79 and 80, lead 80 being extended to the second succeeding segment ($n+2$) and connected through normally closed contacts of a headway control relay 82B (headway control relays

tion of the first proximity relay 54 because the circuit from the coil 77 of the first power control relay 56 to grounded point 58 is interrupted by the currently "open," third time delay relay 82B. A vehicle 11 passing through the first segment n then tends to decelerate because of the inherent frictional drag derived, for example, from its rotating wheels 13, (FIG. 1), and thus falls back somewhat from the vehicle preceeding it. Thus, spacing of the vehicles 20 along the guideway 12 is controlled as a function of the delay times to which the time delay relays are set. The time relay relays, associated circuitry, and the power control relays 56 thus comprise time responsive switching means operable in response to detection by any respective one of the sensing means of the proximity of one of the secondary structures, for preventing operation of at least one primary element 40 spaced a predetermined distance, or multiplie of circuit segments, in the second direction along the guideway from the respective sensing means actuated by a vehicle during the preselected time period following detection by the respective sensing means of the proximity of a respective secondary structure. Preferably, the time responsive switching means prevents operation of a primary element (40), FIG. 5, spaced in the second direction beyond a second primary element (40A) spaced between the respective sensing means (52B) and the first primary element (40), in order that the first primary element 40 will remain energized until a vehicle 11 powered thereby is completely passed. The proximity sensors 52 thus actuate the proximity relays 54 and the power control relays 56 when the secondary structures 20 of the vehicles enter a zone or region approximately bounded by first and second, parallel planes perpendicular to the guideway 12 and extending through the first and second end portions 44, 45 of the respective adjacent primary element 40, since several inches of spacing between the respective proximity sensors 52 and the respective, corresponding primaries 40 is sufficient to permit actuation of the control means, i.e., the respective proximity relay 54 and power control relay 56, by the time the LIM secondary reaches the area in approximate vertical align-ment with the respective LIM primary 40.

This method of "time responsive" headway control provides the important advantage that the spacing of the vehicles corresponds directly with their velocity. that is, it follows that a given delay time provides a greater spacing for vehicles passing at high velocity than for those traveling at a low velocity. The efficiency of the system is thus greater than one dependent upon a predetermined, minimum headway spacing, in that when the vehicles are traveling at lower velocities at which less headway spacing is required, their spacing is automatically reduced. Such low speed operation may be required, for example in congested areas, approaches to stations, or the like, and the speed of the vehicles is reduced in such areas by the utilization of primary elements 40 having greater pole pitch, or by reducing the frequency of the 3-phase power applied to those primaries. A further advantage of the disclosed method of headway control is that the vehicles are not sharply decelerated by the non-energized LIM primaries, as they are upon the application of positive braking devices, but are gradually decelerated at a comfortable rate. Additionally, the spacing of the vehicles may be easily changed by adjusting the delay period of the time delay relays.

The propulsion system 10 may be modified for adaption to transportation systems of various types. For example, the control circuits 51 may be simplified by the elimination of the headway control mechanism and the reversing relays in systems or portions of a system wherein only very low speeds are required. In such a system, the proximity relays 54A are preferably connected through respective, additional leads (not shown) in parallel with leads 76A, 116A, extended to the respective power control relay 56 preceeding the proximity sensor (52A) for simultaneously energizing two LIM primaries, 40, 40A, to ensure that the LIM primaries remain on until the vehicle has passed.

Permanent magnets (not shown) are preferably employed in portions of the guideway which are inclined downwardly or in guideway sections preceeding station areas, for providing a decelerative force to the vehicles in such sections to maintain proper spacing and to provide a further safeguard for the system in the event of a power failure. Such use of permanent magnets as braking means is generally known in the art.

It should be understood that, in normal operation, control and spacing of the vehicles is accomplished entirely by the action of the time delay relays, the phase sequence reversing apparatus being employed only in case immediate, sharp braking of the vehicles is required. If such emergency braking is required, however, as in the case of a vehicle stalled upon the roadway in front of an approaching vehicle, the reversing relay acts to bring the approaching vehicle to a complete stop. If for example, a vehicle is stalled in segment $(n+2)$, the third proximity sensor 52B will have actuated proximity relay 54B, closing switch element 62B and permitting positive potential to be con-ducted via lead 110 back to the coil 106 of the first reversing relay 57. When an approaching vehicle then enters segment n and actuates the first proximity sensor 52, the first proximity relay 54 and the first power control relay 56 are actuated to conduct power to LIM primary 40, but the first reversing relay 57 causes such power to be reversed in polarity at two of the coils of the primary 40, and to produce a magnetic flux which tends to oppose the forward movement of the vehicle and to strongly decelerate the vehicle, bringing it to a complete stop before it collides with the stalled vehicle. The switch element 78 of the reversing relay 57 closes the circuit to ground through leads 85, 87, and 88, thus conducting current through coil 77 of power control relay 56 in spite of the open switch 121B of the third time delay relay 82B. The reversing means thus comprises a means "overriding any operation of the time responsive switching means 82B, to prevent operation of the respective primary element 40 to which reversed power is applied." The reverse thrust thus exerted would tend to drive the vehicle in reverse if it were not then opposed, and such a condition is preferably prevented by the installation of a ratchet mechanism or the like on one of the wheels of the vehicles for preventing rearward mvoement of the vehicle, Prefer-ably, a mechanism such as the one-way clutch 124 illustrated in FIG. 4 is employed. The clutch is mounted coaxially within a wheel 13 of each vehicle 11, with the vehicle wheel being affixed to an outer, circular, rotatable member 125 which is rotatable in the direction indicated by arrow 126 about a fixed, central element 127. Rotation

82B, 82, and 82A to be described in more detail below) the closed circuit continuing through return lead 84 to lead 85 (FIG. 7) through a normally closed, thermal protection switch 86 mounted on the first LIM primary 40, and finally returning to grounded point 58 through successive leads 87 and 88. Current passing through the coil 77 of the first power relay 56 is operable to close the switch elements 90 of the power control relay 56, which is suitably of the type manufactured by the Square D Company as Class 8536-SDGI. Three switch elements 90 of the power control relay 56 are connected, through wires 92, 93, and 94, to respective, 3-phase power supply conductors 65A, 65B, and 65C; when closed, the switch elements 90 connect wire 92 through wire 103 to one terminal of the first LIM primary 40. The other wires 93, 94 are connected to wires 97 and 96, respectively, which are conducted to the other two terminals of the LIM primary 40 through the reversing relay 57 and subsequently through wires 104 and 105, respectively. The reversing relay 57 is, in its illustrated, normal condition, connected to supply 3-phase power to the first LIM primary 40 in a sense, i.e., phase sequence, which will cause the primary element to react with an adjacent secondary structure 20 (FIG. 1) to urge the secondary structure in a forward direction. If reversing relay 57 is actuated, however, the contacts of the reversing relay 57 are reversed in position, and the relay 57 acts to reverse the polarity of current supplied through leads 104 and 105 and to thus cause the primary element 40 to urge an adjacent secondary structure 20 rearwardly, causing a fairly sharp deceleration of a vehicle 11 associated with the secondary 20.

The reversing relay 57 remains in its normal, non-activated position until current is conducted through its coil 106, from input lead 107 through grounded lead 88. Input lead 107 is connected, through a plurality of rectifying diodes 108, 109 directioned to supply positive potential only to lead 107, to reverse signal leads 110 and 111 which extend, respectively, to the proximity relays 54B of successive preceeding circuit segments beginning with segment $(n+2)$ which is spaced, from segment n, beyond the next adjacent preceeding segment $(n+1)$. Lead 110, for example, extends to proximity relay 54B of segment $(n+2)$ and is connected to the "output" terminal of normally open, switch element 62B. The other side of switch element 62B receives a positive potential through lead 112B connected to the positive supply conductor 73. The other reverse signal lead 111 extends to the next preceeding segment $(n+3)$, not shown in the drawing. The terms "preceeding" and "succeeding" are used in the specification in referring to physical location (in front of, to the rear of) rather than to the order in time.

When reversing relay 57 is actuated, its lowermost switch element 78 closes and completes a circuit to ground 58 through leads 85, 87, and 88 from the coil 77 of power control relay 56.

Referring again to the circuit of segment n and with primary reference to FIG. 7, a latching circuit 114 is provided connected to the fourth (lowermost) terminal 115 of the first power control relay 56 whereby once the relay switches 90 are closed, positive DC current is conducted to the relay coil 77 through leads 116, 117, 75, and 74 from the positive DC supply conductor 73 independently of the position of switches 61, 62 of the proximity relay 54. The purpose of the latching circuit 114 is to keep the power relay 56 closed when switch 53 is opened after the vehicle passes the first proximity sensor 52. The first LIM primary 40 would otherwise be deactivated prematurally, and would not react with an adjacent LIM secondary 20 after the rear end portion of the secondary had passed the first proximity sensor 52.

The latching circuit 114 remains latched until the power control relay 56 is deactivated by the action of the headway control relay 82B of segment $(n+2)$ when the secondary structure 20 trips the proximity sensor 52B, which will now be described.

The normally closed, headway control relay 82 is connected with its coil in series between ground and a lead 118 connected to lead 76 and has leads 119, 120 connected in series with its normally closed switch element 121 and extending rearwardly to the second preceeding segment (not shown). For the purpose of explaining the headway control relay 82, reference is made to the corresponding headway control relay 82B of the third segment $(n+2)$ which has its coil connected between lead 76B between relays 54B and 56B and ground. As will be seen, the third headway control relay 82B controls the operation of the power control relay 56 of the first segment n. The headway control relays 82, 82A, 82B are of the time delay type operable to open respective, associated switch elements 121, 121A, and 121B immediately upon actuation, and to remain open for a predetermined time thereafter. Preferably, the time delay relays 82, 82A, 82B are of the type wherein the delay period may be adjusted at will. An example of such a time delay relay is that manufactured by the Allen Bradley Company under part number 849A-ZAD 24.

In operation, when a vehicle 11 (FIG. 1) passes over the first proximity relay 52, the first proximity sensor 54 is actuated, and, as has been previously described, causes the first power control relay 56 to close its switch elements 90 and conduct 3-phase power to the first LIM primary 40 in a phase sequence which energizes the LIM primary to urge the vehicle 11 in a forward direction, assuming the first reversing relay 57 has not been actuated to reverse the polarity of the supplied power. It will be recalled, however, that acutation of the first power control relay 56 depends upon completion of the circuit (described above) to grounded point 58 from the coil 77 of power control relay 56. The circuit to ground passes through leads 84 and 80 connected through the normally closed switch element 121B of the third time delay relay 82B of segment $(n+2)$. The third time delay relay 82B remains in its closed condition unless it is actuated by a positive potential received through lead 122B from lead 76B from the third proximity relay 54B. Such a potential exists when the third proximity relay 54B has been actuated by a vehicle passing over the third proximity sensor 52B. Because of its time delay function, previously described, the third time delay relay 82B remains open for a selected interval of several seconds after a vehicle has passed segment $(n+2)$. Therefore, if a vehicle passes over the first proximity sensor 52 while another vehicle is adjacent the third proximity sensor 52B, or if another vehicle has passed the third proximity sensor 52B within the delay period during which the third time delay relay 82B remains open after initial actuation, the forst power control relay 56 is not actuated by actua-

thereof in the opposite direction tends to move the bearings **128** into a locked position indicated at **129** and to prevent further rotation. Inasmuch as the use of such mechanisms is generally known, further description thereof is not considered necessary.

The reversing relay **57** of segment n will be actuated by a vehicle in segment $(n + 2)$, through lead **110**, or by a vehicle in segment $(n + 3)$ (not shown) through lead **111**. In LIM systems of higher speeds, however, it may be desirable to provide additional protection by actuating the first reversing relay **57** if a vehicle is spaced forwardly of segment n by an even greater distance. This is accomplished, in an alternative embodiment (not shown), by adding additional leads extending from the proximity relays **54** of those segments ($n + 3$, $n + 4$, etc.) and extending the leads back to the first reversing relay **57** through respective, additional diodes connected in parallel with diodes **108** and **109**. Additional redundancy of the time delay portion of the circuit **51** may also be provided by connecting the time delay relays **82** to the power control relays of additional segments preceeding the one spaced two segments behind. Such additional connection is provided, in an alternative embodiment, by employing time delay relays **82** having additional switch elements, and conducting leads from the additional switch elements to the power control relays three or more segments preceeding (e.g., from relay **82B** to $(n - 1)$, $(n - 2)$, etc.)

With reference now to FIG. **5**, the spacing of the LIM primary elements **40, 40A**, and **40B** of respective, corresponding pairs **49** with their respective first end portions **45** spaced equally along the guideway, and the use of primaries of approximately equal lengths, permits the application of an approximately equal, forwardly directioned, magnetic driving force to the secondaries even though successive ones of the primary elements **40, 40A**, and **40B** are not positioned end to end along the guideway or in close proximity with each other along the guideway, as they have been in some prior systems. Thus, the great expense of purchasing and installing LIM primary elements extended substantially continuously along the guideway is avoided. In the preferred embodiment, illustrated in both FIGS. **5** and **6**, wherein the respective first end portions of the primary elements of respective corresponding pairs **49, 48** are spaced from each other by a distance substantially equal to the length of the secondary structures **20**, the spaced LIM primaries **40** are positioned to provide a substantially constant propelling force to a respective secondary structure **20** as it moves along the guideway **12**. When a secondary structure **20** is centered over two primary elements **40A, 40B** of a respective pair **49** as shown in FIG. **5**, for example, the equivalent of one primary element is reacting with the secondary, since the forward end of the secondary structure is positioned over approximately one half of the secondary **40B** and over one half of the rear secondary **40A**. In the embodiment shown in FIG. **6**, the secondary structure **20** is continuously urged forward by the equivalent of one of the shorter primaries **40, 40A** and additionally, by the equivalent of one of the longer secondaries **46**. The control circuit **51** (FIGS. **7–9**) operates to energize the successive primaries **40, 46, 40A** sequentially, since the respective segments n, $(n + 1)$, $(n + 2)$ of the control circuit **51** are actuated by successive proximity sensors adjacent each of the successive LIM primaries **40, 46, 40A**.

The combination of the above-described spacing of the primary elements relative to the preferred length of the secondary structures and the articulated framework **25** supporting the LIM secondary elements **21** in each secondary structure **20** (FIG. **3**) provides further economic benefits in that secondary structures **20** of considerable length may be employed successfully over a less-than-perfectly constructed guideway, thud permitting the spacing of the LIM primaries **40** to be greater than that required if rigid, single element secondaries are employed. Thus, in the embodiment of FIG. **5**, the primaries **40** are extended along only a small percentage of the guideway, the length of each secondary structure being greater than twice the combined length of the primary elements **40, 40A; 40A, 40B** of pairs **49** of corresponding primaries.

It can thus be seen that the present system provides the advantages inherent in the fixed primary, movable secondary, linear induction propulsion systems while greatly minimizing many of the economic disadvantages of such systems.

The primary elements and their associated control circuitry are safely enclosed beneath the surface of or alongside the guideway, thus preventing deterioration of the control elements from vibration and weather conditions and minimizing the likelihood of vandalism. Moreover, the requirement for slidable electrical brushes and exposed power rails extended alongside the guideway is completely eliminated, along with the attendent safety and maintenance problems of such power supply systems. Economic advantages are thus derived from the elimination of both the initial costs of such systems and the avoidance of continuous maintenance thereof.

Current is conducted to only the LIM primaries adjacent respective ones of the LIM secondaries, and power consumption is therefore minimized. Control of headway and velocity is achieved by control circuitry enclosed safely within or alongisde the guideway, and does not depend upon braking devices or operators aboard the vehicles. Headway can be varied conveniently by a simple adjustment of the time delay relays, and finally, the combination of time-dependent headway control means and distance-related emergency braking means permits close spacing of the vehicles for providing a high rate of passenger flow. This last feature is of great importance in personal rapid transit systems, in that the relatively small vehicles and low speeds of such systems require close spacing of the vehicles if economically practical levels of passenger volume are to be achieved.

While only one embodiment of the invention, together with modifications thereof, has been described in detail herein and shown in the accompanying drawing, it will be evident that various further modifications are possible in the arrangement and construction of its components without departing from the scope of the invention.

What is claimed is:

1. For a transportation system of the type having movable structures adapted to follow a guideway, a plurality of linear induction primary elements fixedly mounted in the guideway, mutually spaced along the guideway, and having respective first and second end portions directioned in first and second directions, respectively, along the guideway, and elongated, linear induction secondary structures connected, respec-

tively, to each of the movable structures, a control system comprising:

a plurality of sensing means, each corresponding to a respective primary element and each comprising means operable for detecting the proximity of one of the secondary structures to the respective primary element; and

control means, operatively associated with the proximity sensing means, for conducting multi-phase electrical power to any of the primary elements when any portion of one of the secondary structures lies within a region approximately bounded by first and second, parallel planes perpendicular to the guideway and extending through the first and second end portions, respectively, of a respective primary element, for urging the respective secondary structure in the first direction, the control means further including time responsive switching means, operable in response to detection by any respective one of the sensing means of the proximity of one of the secondary structures, for preventing operation of at least one primary element spaced a predetermined distance in the second direction along the guideway from the respective sensing means during a preselected time period following detection by the respective sensing means of the proximity of a respective secondary structure.

2. The apparatus of claim **1**, wherein the time responsive switching means comprises means for preventing operation of a first primary element spaced in the second direction along the guideway from a second primary element interposed between the first primary element and the respective sensing means.

3. The apparatus of claim **1**, further comprising reversing means for applying multi-phase electrical power, in a phase sequence causing magnetic forces to be produced opposing movement of the secondaries in the first direction, to a primary element adjacent a respective one of the secondary structures when another respective secondary structure is adjacent at least one sensing means spaced, in the first direction, from the respective primary element, the reversing means comprising means overriding any operation of the time responsive switching means to prevent operation of the respective primary element to which reversed power is applied.

4. The apparatus of claim **3**, wherein the movable structure is provided with means preventing movement thereof along the guideway in the second direction.

* * * * *