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**Lu et al.**

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(54) **MAGNET ARRAYS FOR VEHICLE IDENTIFICATION IN AN INDEPENDENT CART SYSTEM**

(58) **Field of Classification Search**

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(Continued)

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**B65G 43/02** (2006.01)

(Continued)

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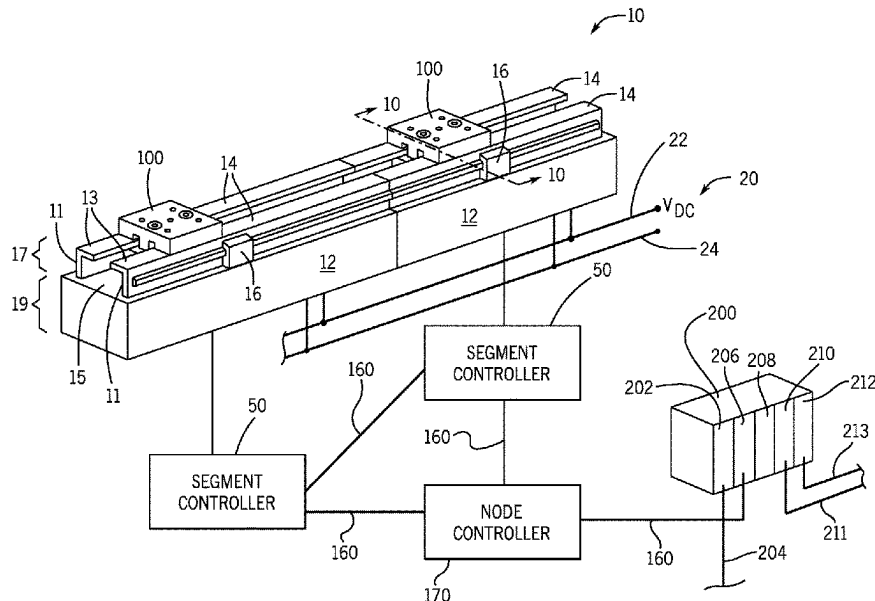
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**ABSTRACT**

An independent cart system includes multiple track segments, multiple movers, multiple position sensors, and a controller. Each track segment includes multiple coils along a length of the track segment and a segment controller operative to selectively energize the coils to generate an electromagnetic field. Each mover includes a magnet array having multiple magnets, where the magnet array generates a magnetic field that interacts with the electromagnetic field generated by the coils to propel the mover along the track segments. The position sensors are spaced apart along the length of each track segment and generate a position feedback signal with a waveform as a function of the magnetic field generated by the magnet array on each mover. The controller is operative to receive the position feedback signal from each position sensor and to determine a unique identifier for each mover as a function of the waveform of the position feedback signal.

**20 Claims, 15 Drawing Sheets**



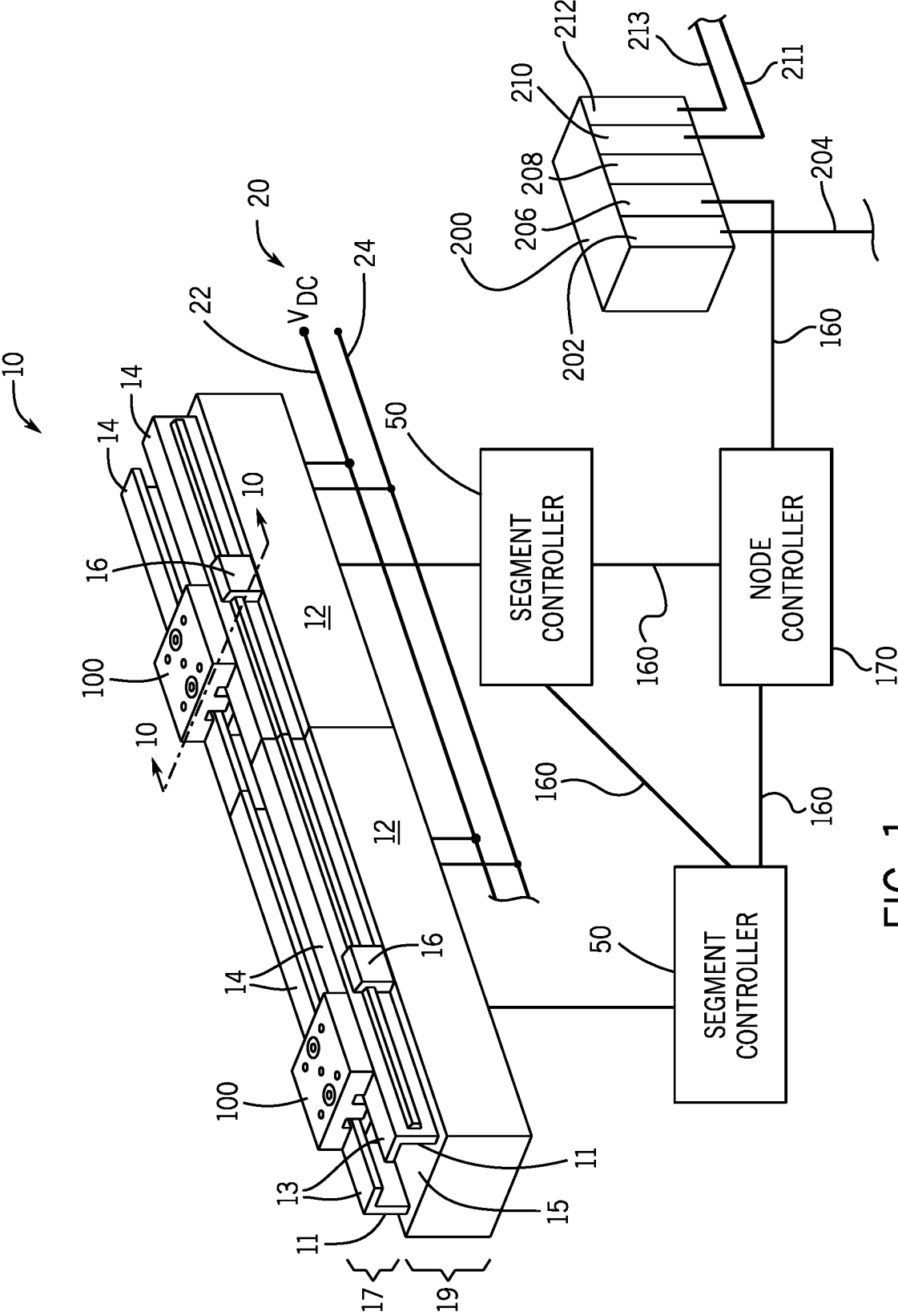
- (51) **Int. Cl.**  
*B65G 43/10* (2006.01)  
*B65G 54/02* (2006.01)  
*H02K 41/03* (2006.01)
- (52) **U.S. Cl.**  
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 (2013.01)
- (58) **Field of Classification Search**  
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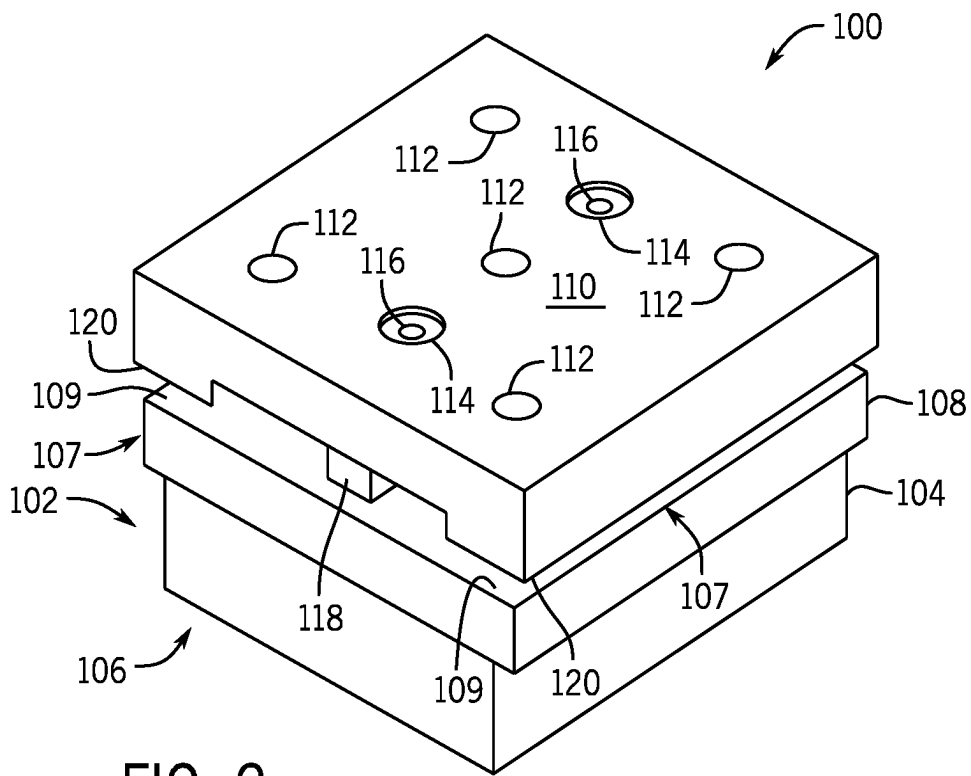


FIG. 2

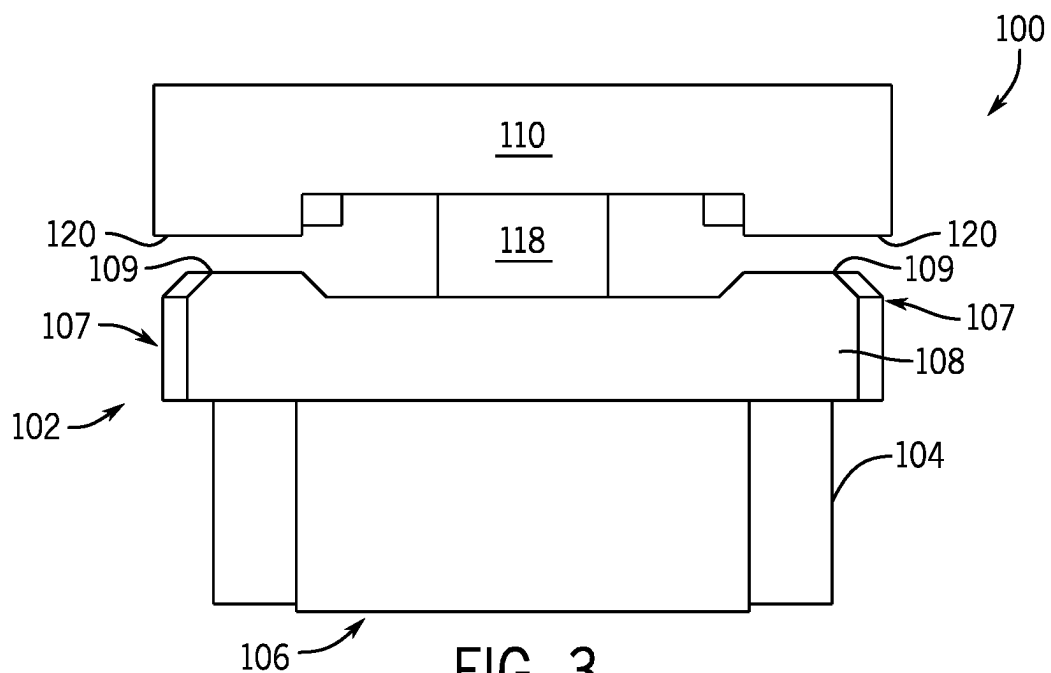
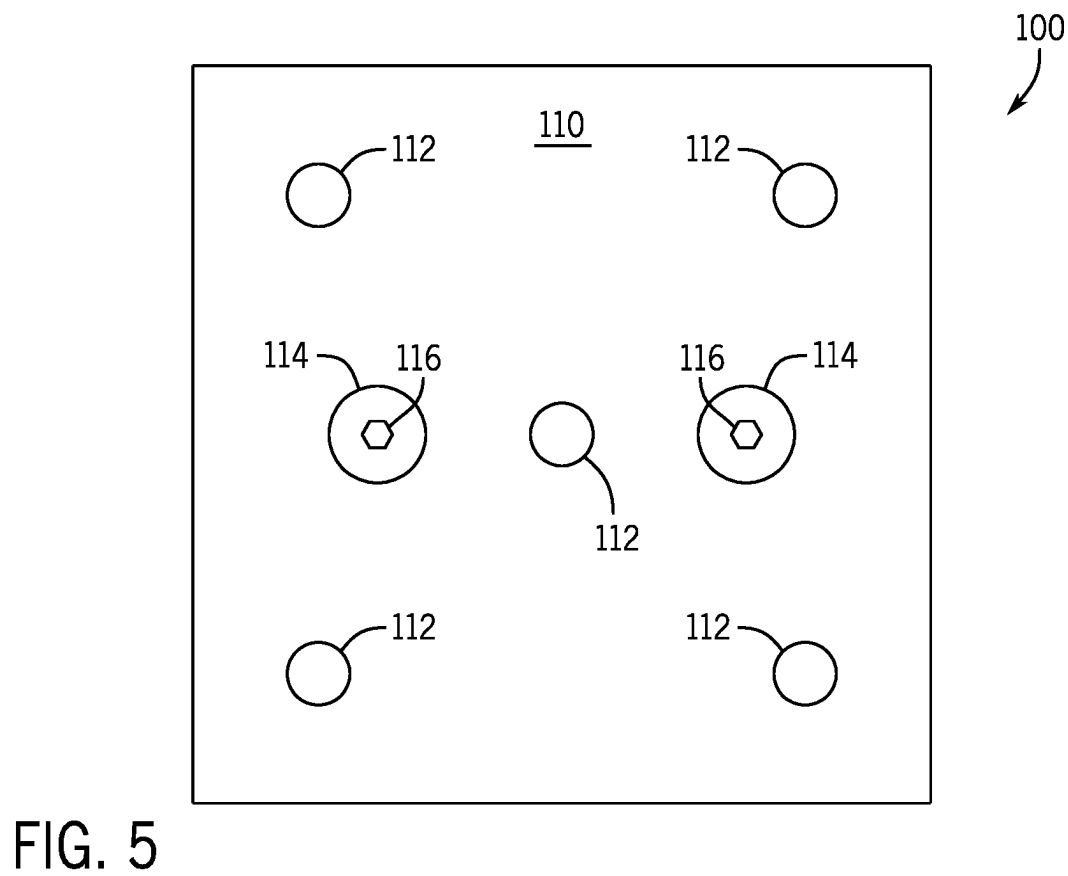
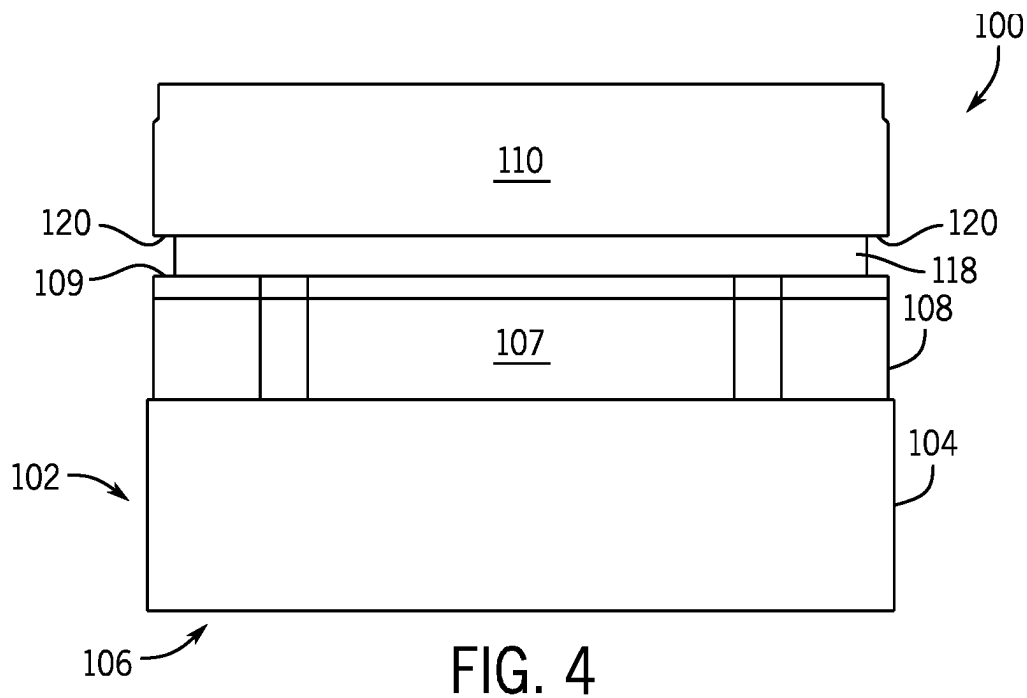


FIG. 3



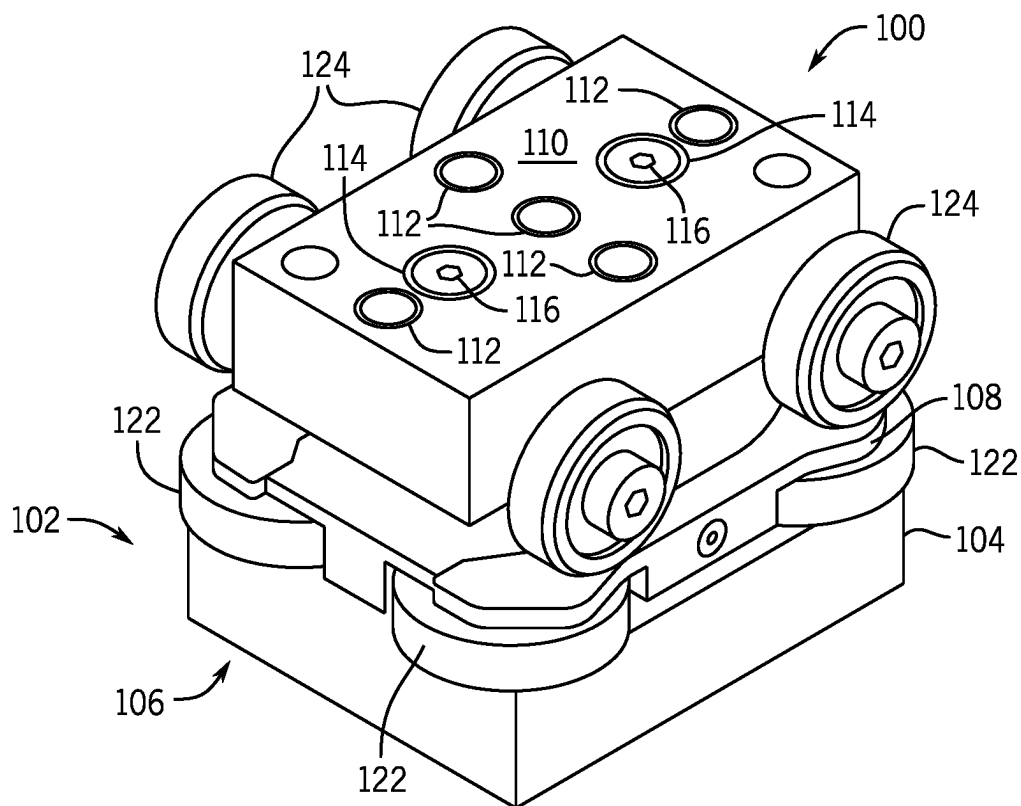


FIG. 6

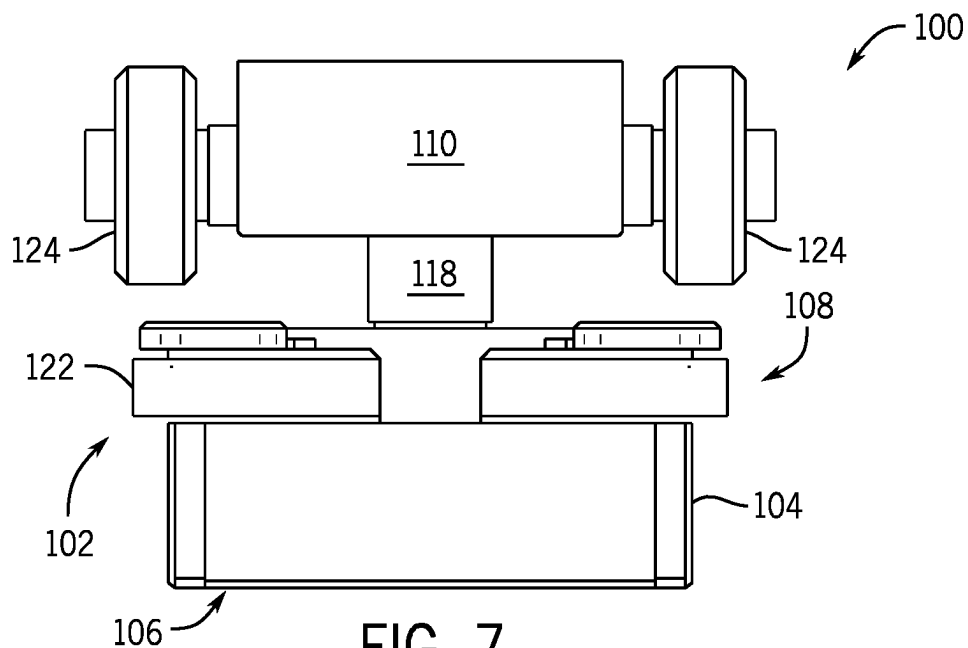


FIG. 7

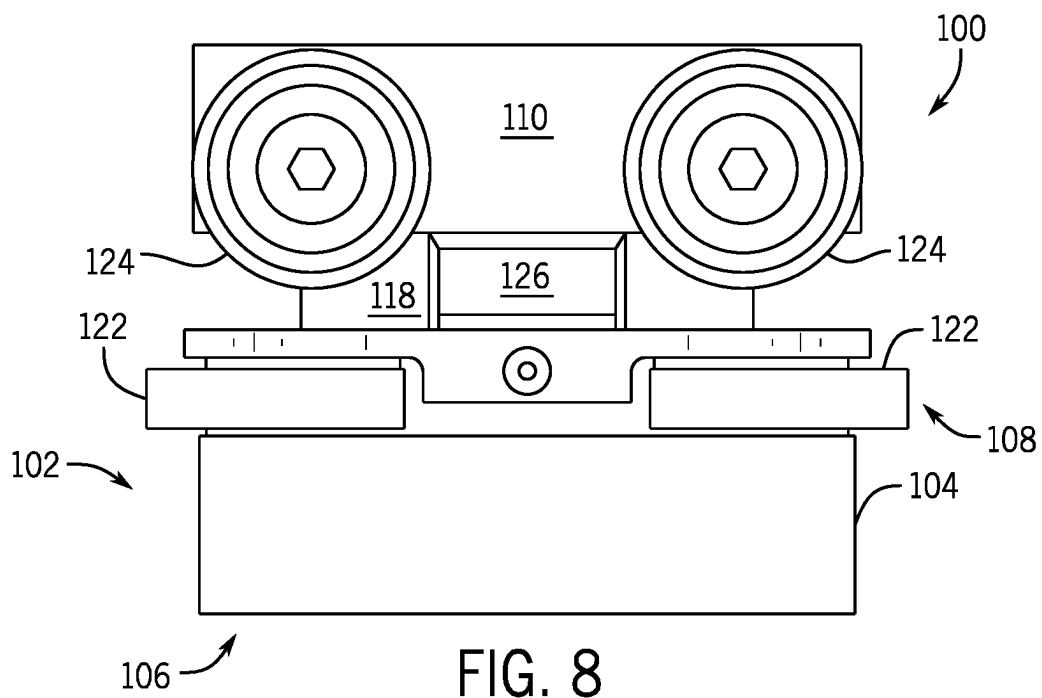


FIG. 8

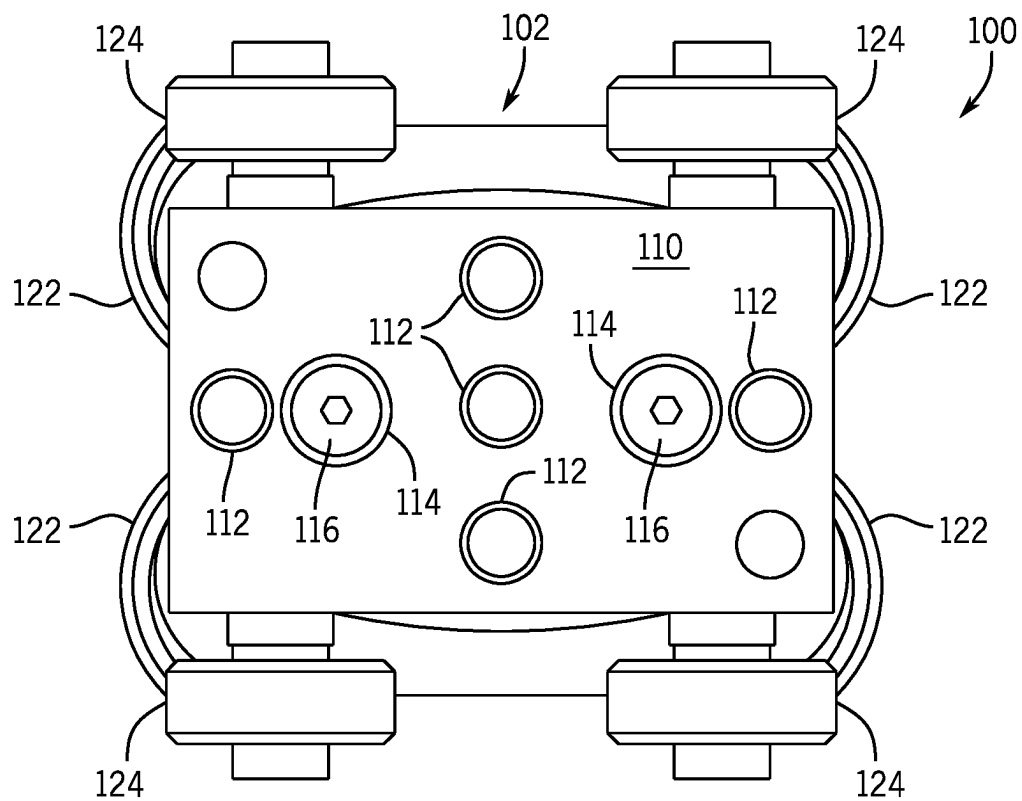
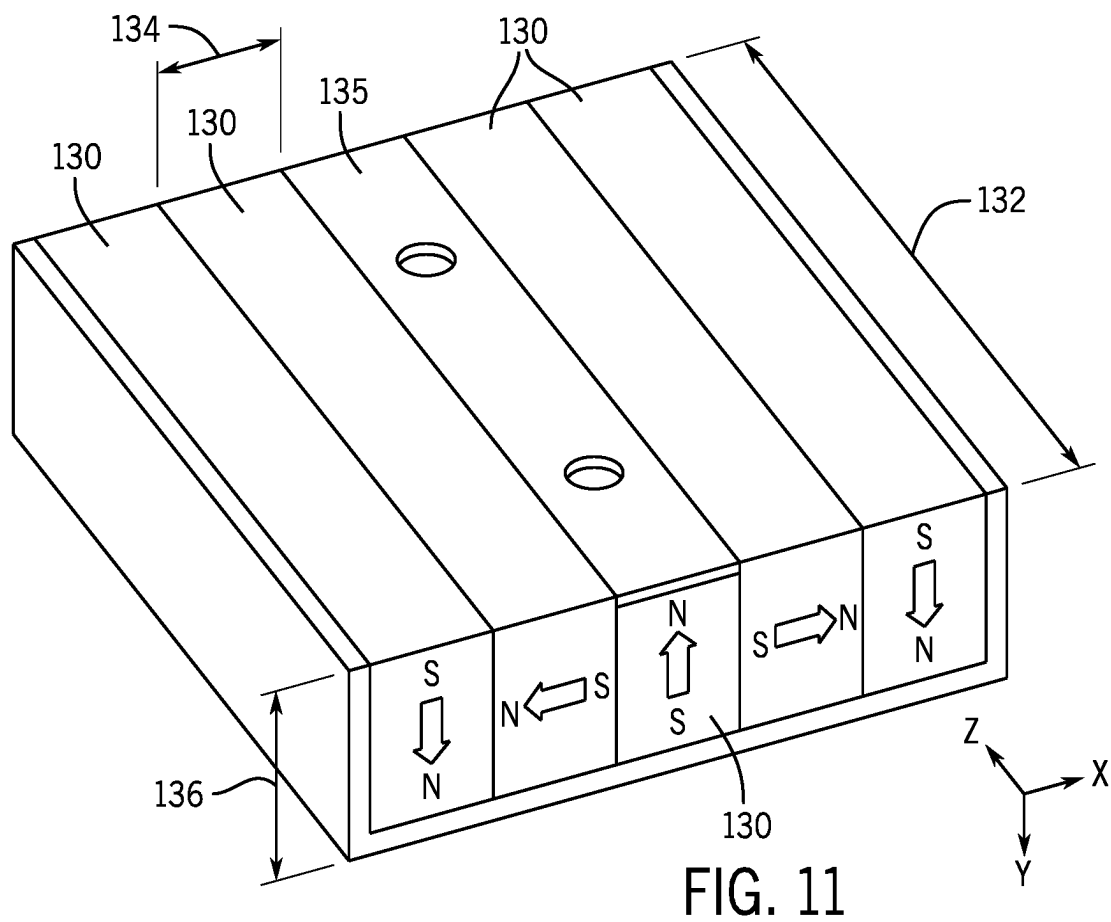
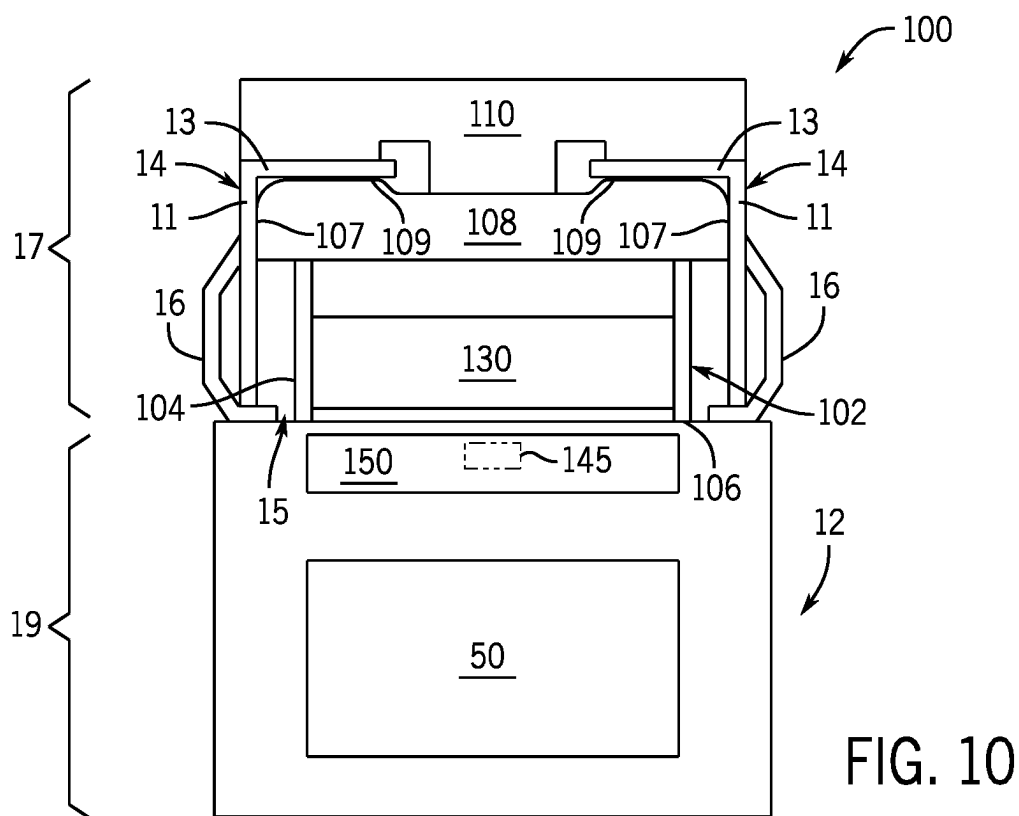


FIG. 9





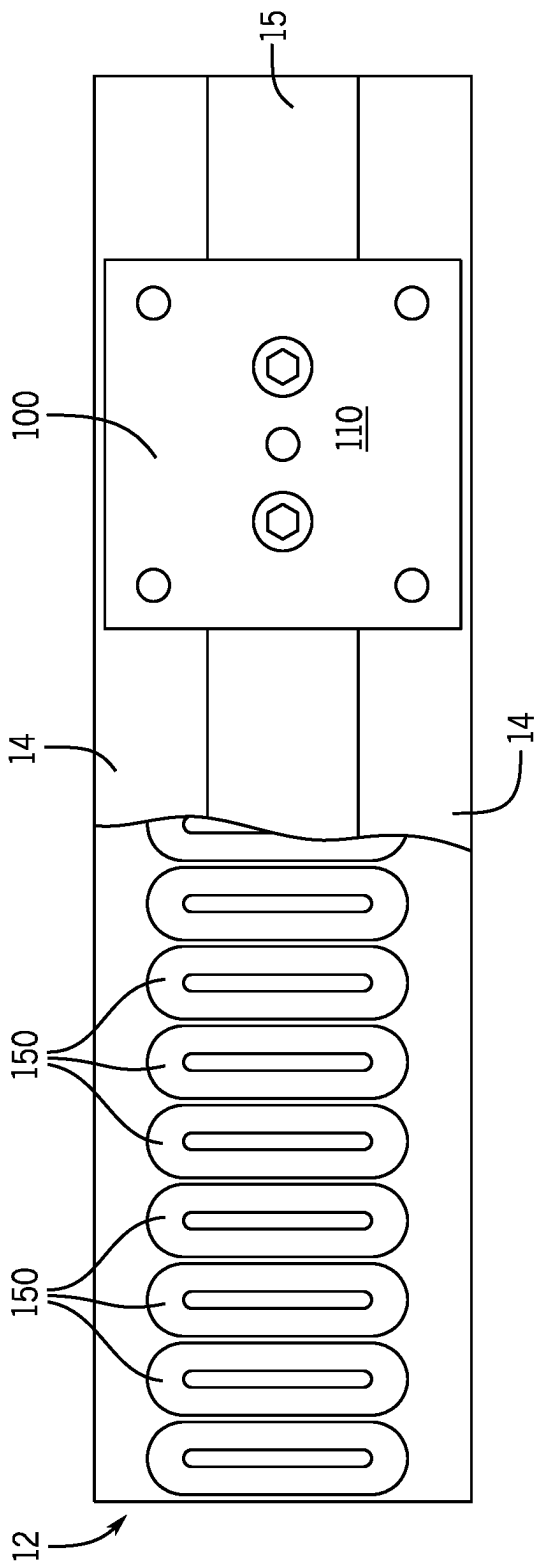
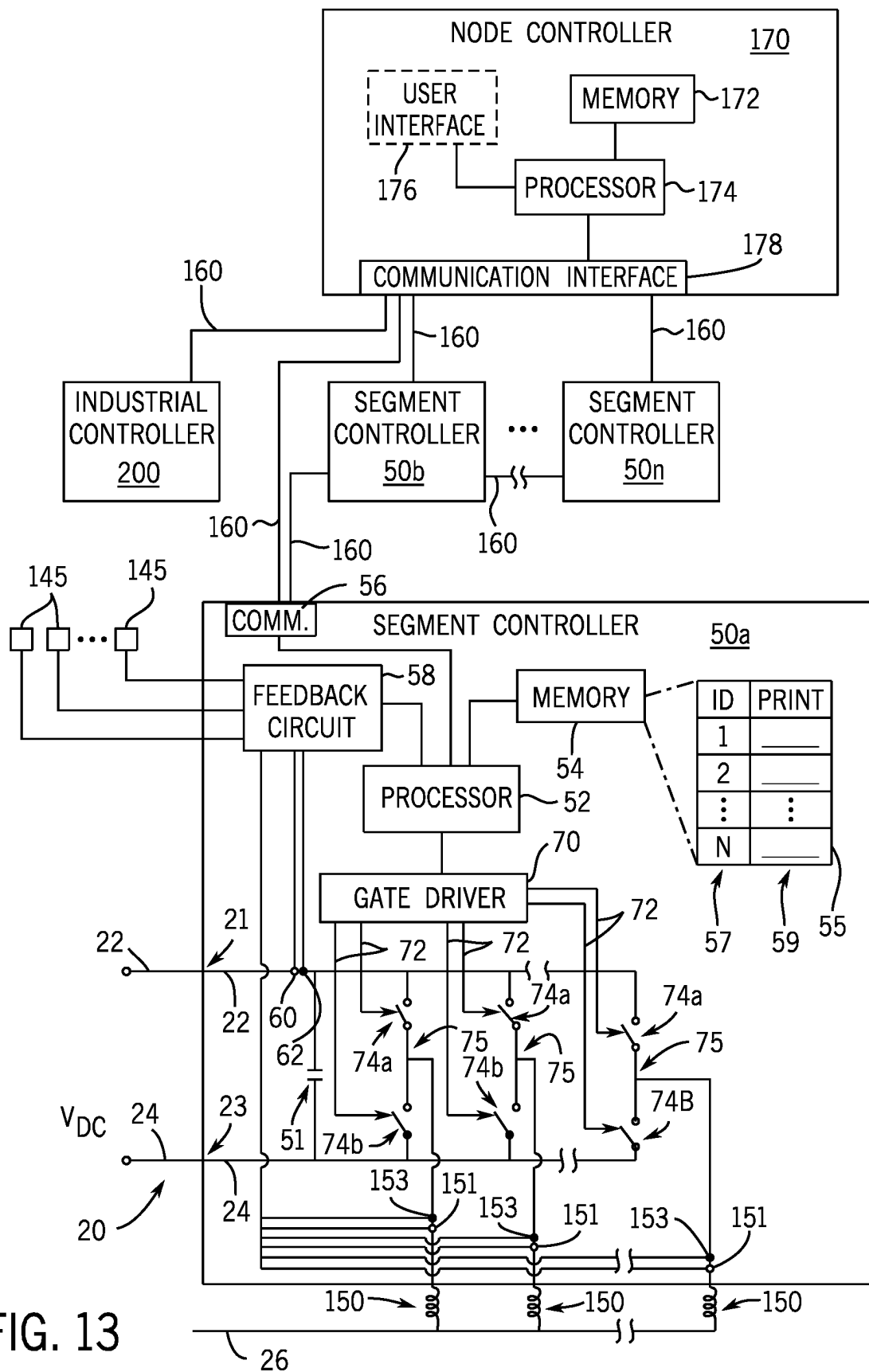


FIG. 12



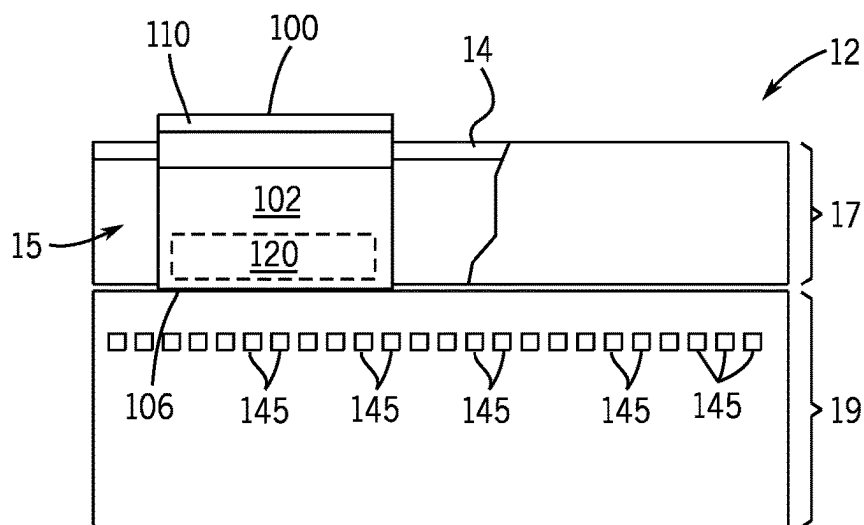


FIG. 14

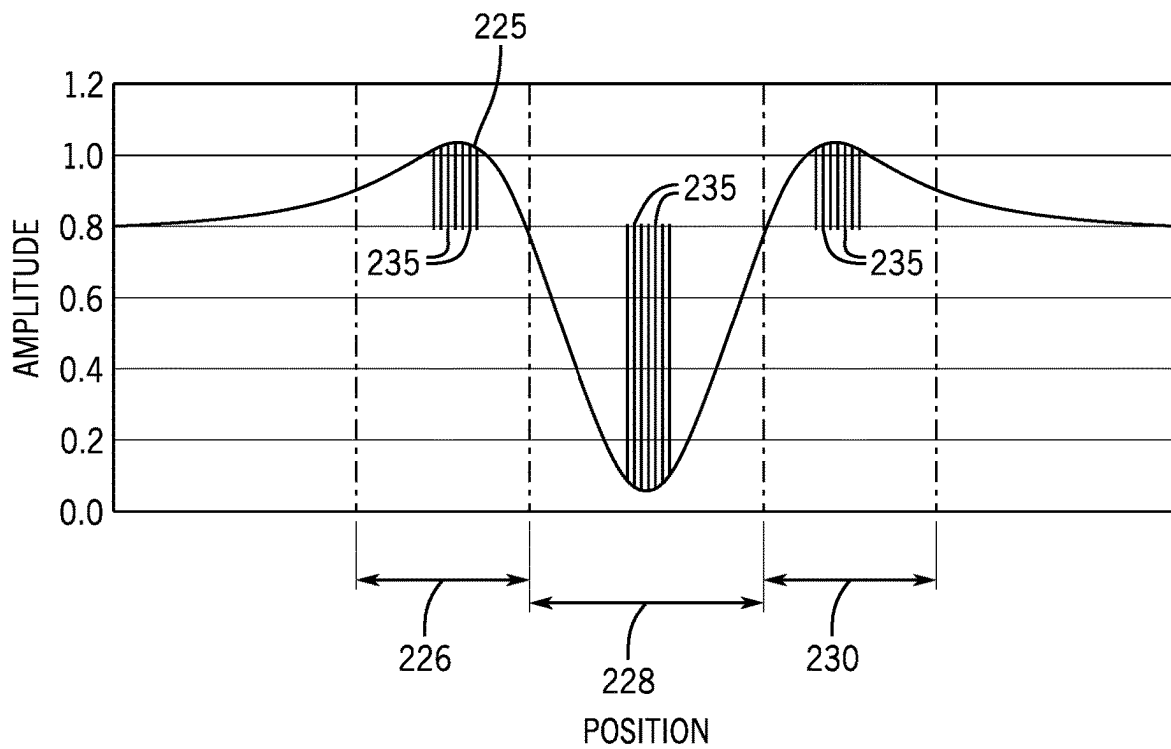
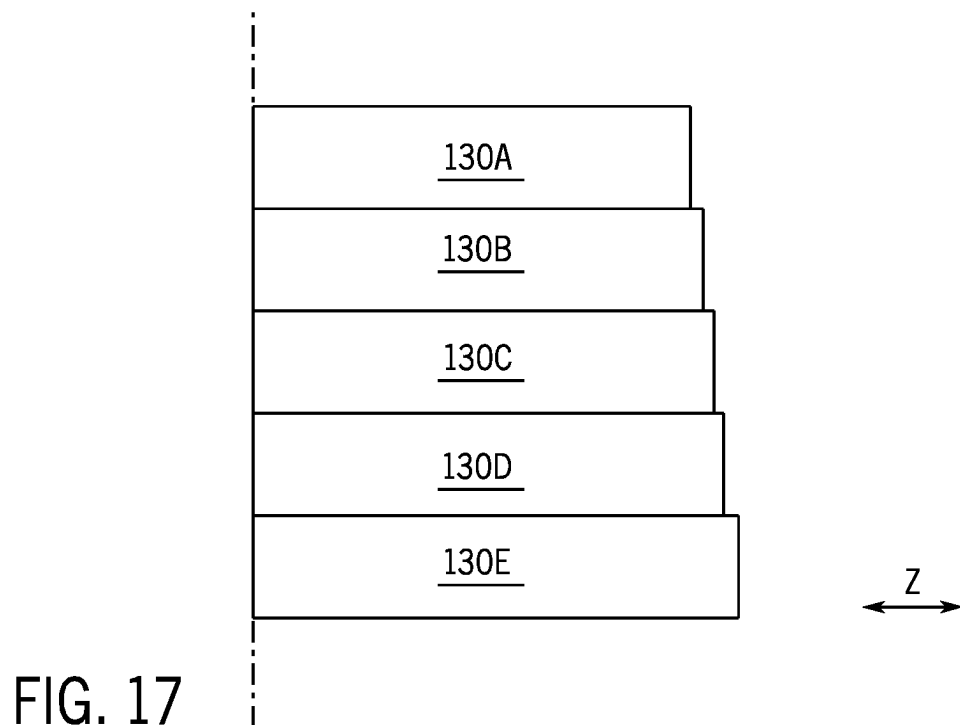
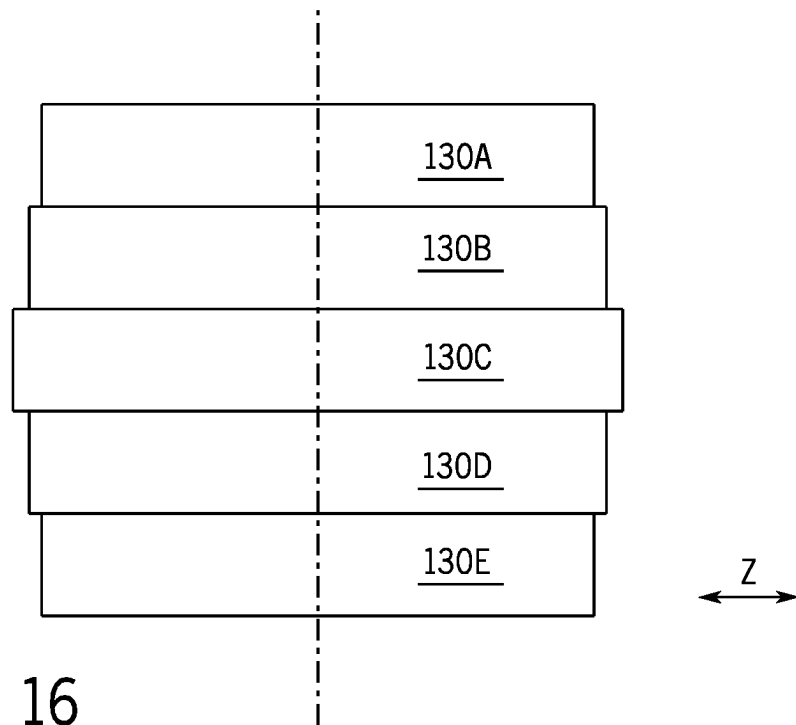


FIG. 15



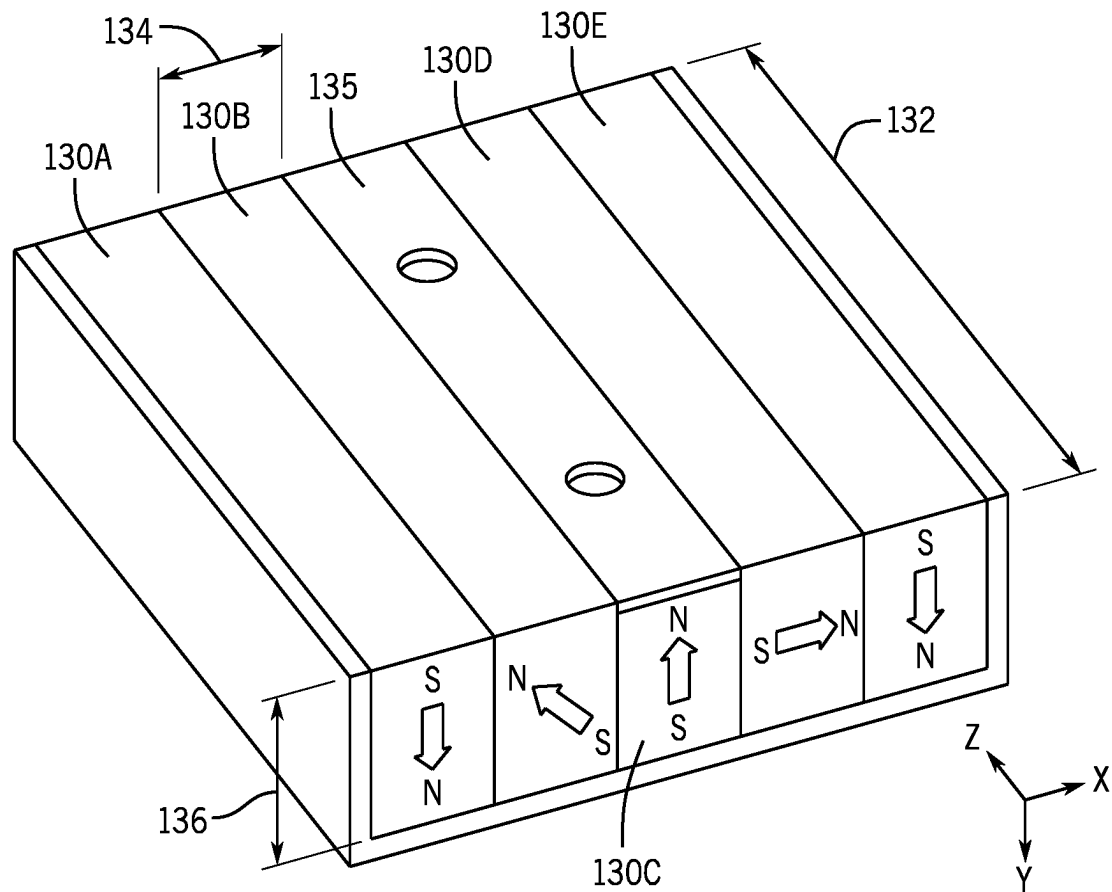


FIG. 18

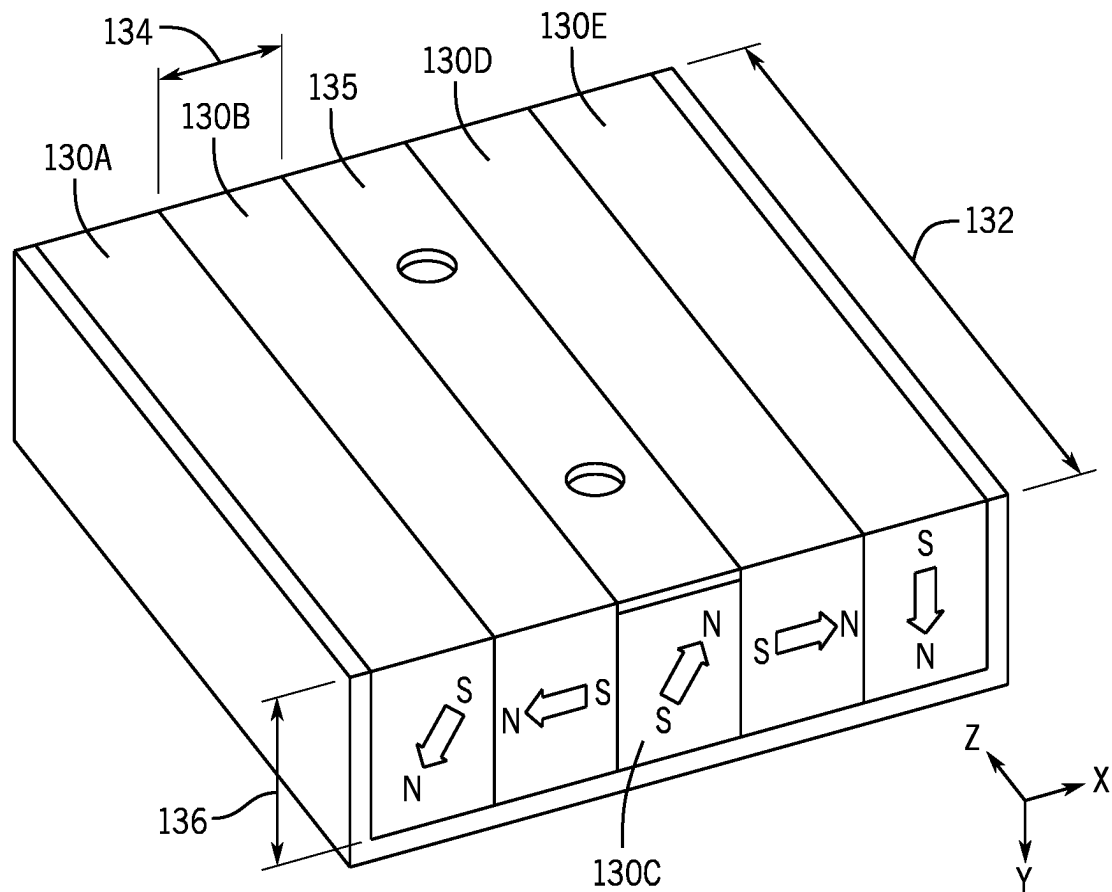


FIG. 19

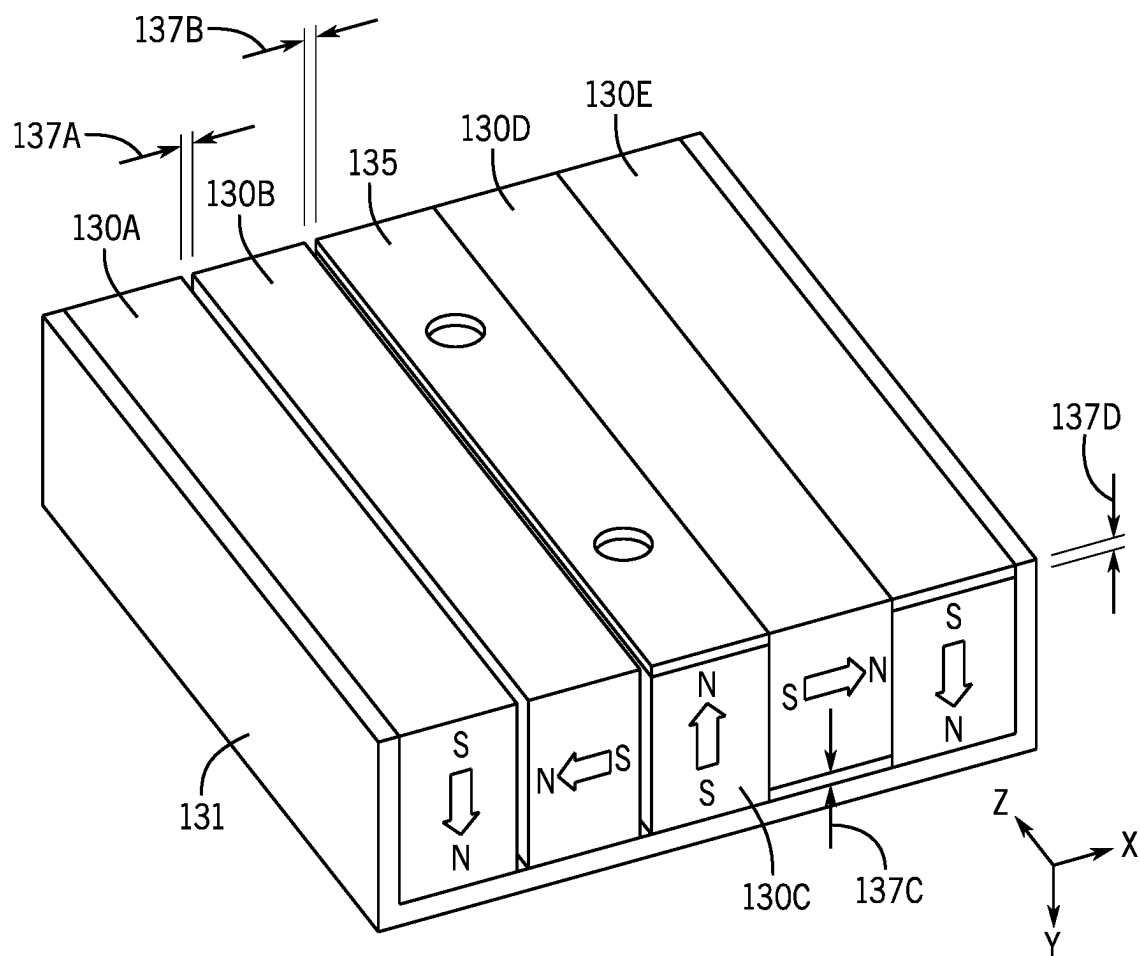


FIG. 20

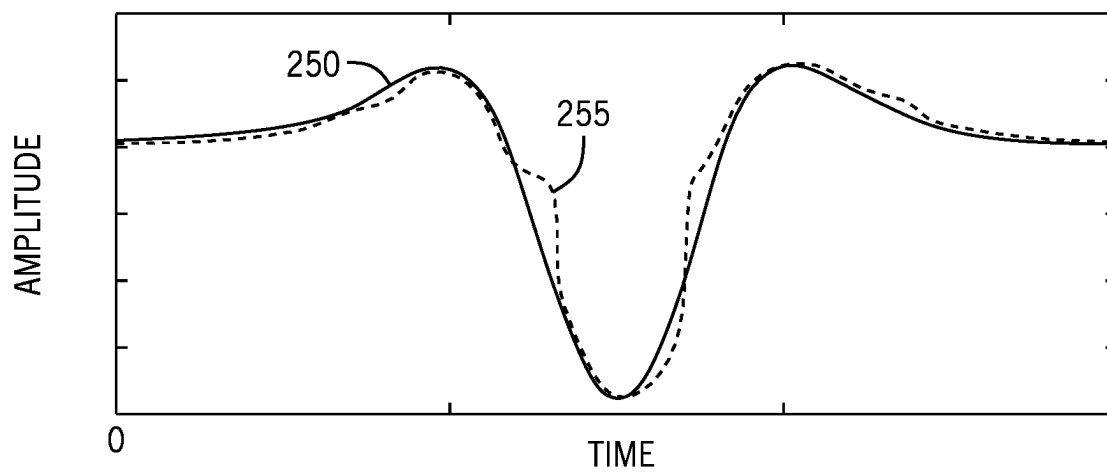
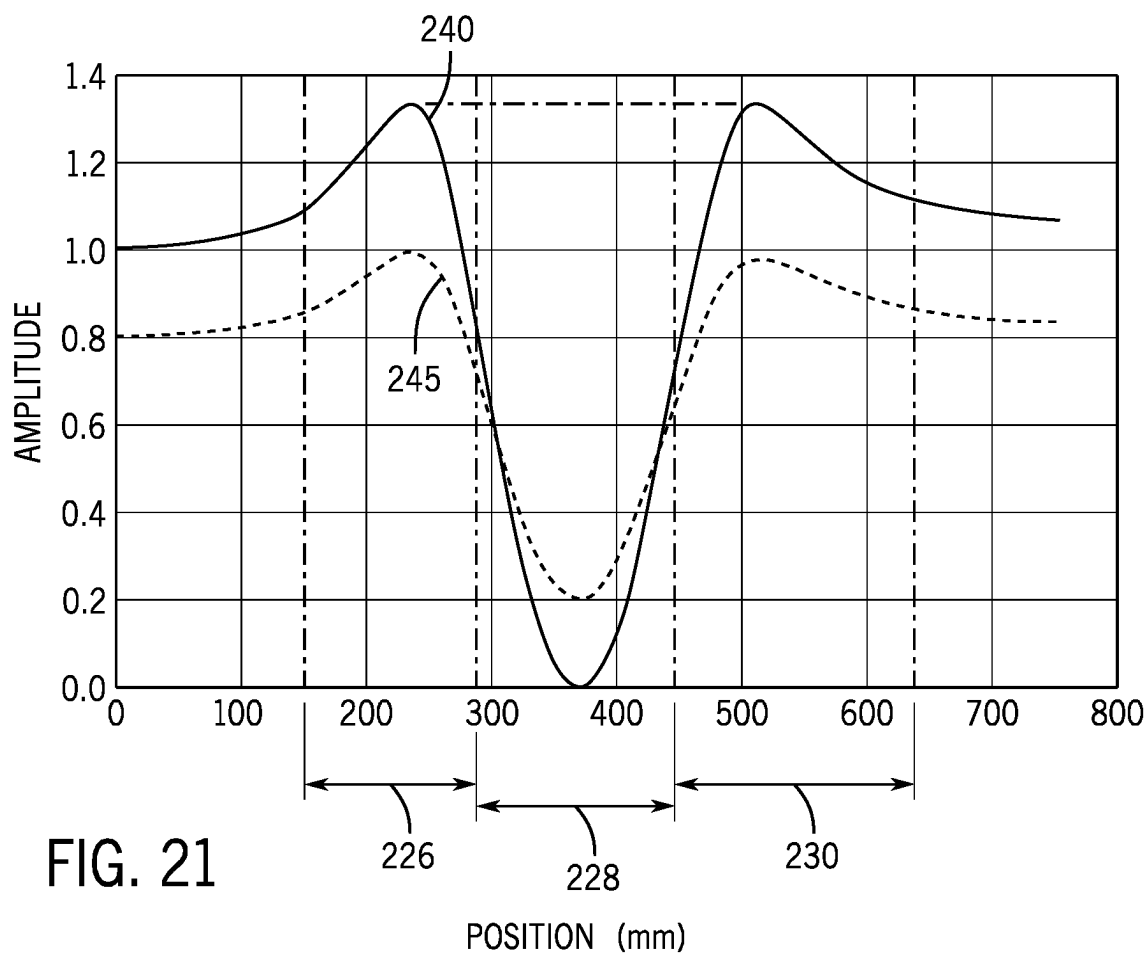


FIG. 22



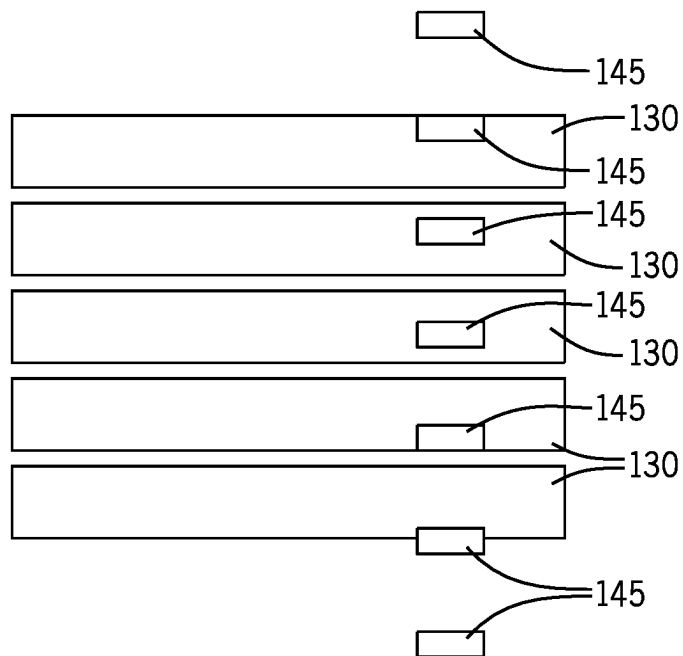


FIG. 23

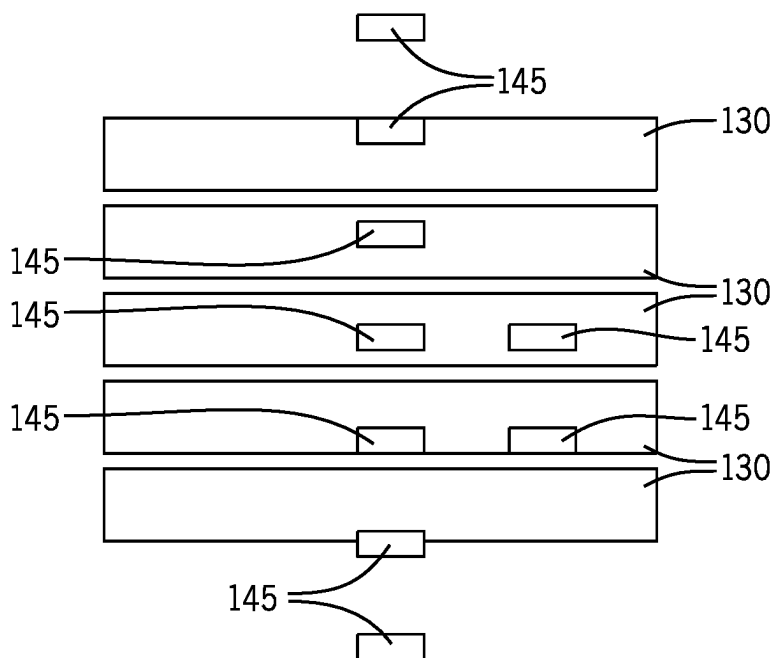


FIG. 24

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## MAGNET ARRAYS FOR VEHICLE IDENTIFICATION IN AN INDEPENDENT CART SYSTEM

### BACKGROUND INFORMATION

The subject matter disclosed herein relates to permanent magnet arrays for vehicles in an independent cart system which are modified to aid in vehicle identification. More specifically, permanent magnet arrays mounted on each vehicle are constructed with variations in the materials, dimensions, alignment, or orientation of the magnets to generate magnetic fields that uniquely identify a vehicle.

Motion control systems utilizing independent cart technology employ a linear drive system embedded within a track and multiple vehicles, also referred to as “movers” or carts, that are propelled along the track via the linear drive system. Movers and linear drive systems can be used in a wide variety of processes (e.g. packaging, manufacturing, and machining) and can provide an advantage over conventional conveyor belt systems with enhanced flexibility, extremely high-speed movement, and mechanical simplicity. The independently controlled movers or carts are each supported on a track for motion along the track. The track is made up of a number of track segments that, in turn, hold individually controllable electric coils. Successive activation of the coils establishes a moving electromagnetic field that interacts with the movers and causes the mover to travel along the track. Sensors may be spaced at fixed positions along the track and/or on the movers to provide information about the position and speed of the movers. Each of the movers may be independently moved and positioned along the track in response to the electromagnetic fields generated by the coils.

The complexity of tracks and the number of movers present on a track in independent cart systems are increasing. The number of options for movers is also increasing. For example, movers may vary in size or function. One mover may travel independently while two other movers may travel in tandem. Different movers may have different fixtures configured to receive different payloads. The independent cart system must have knowledge of each mover, its location along the track, and its configuration to ensure that a properly configured vehicle is delivered to the correct location within the system at the proper time.

While the location of each vehicle may be tracked during operation, when power is cycled, the current location of a vehicle may be lost. While power is off, vehicles may be removed from the track for maintenance or new vehicles inserted into the system. It is, therefore, desirable to identify each vehicle and its present location when a system is powered up.

Historically, a separate identification tag has been provided on each vehicle. The identification tag may be, for example, an RFID tag, a magnet array, or some other identifier requiring a corresponding sensor to detect the identification tag. The identification sensor may be placed at one or more locations to scan vehicles as they travel by the location. However, the separate identification tags create an added expense for the dedicated tag on each mover and for the additional sensors to detect the identification tags.

Thus, it would be desirable to provide an improved system and method for identifying each mover in the independent cart system.

### BRIEF DESCRIPTION

According to one embodiment of the invention, an independent cart system includes multiple track segments, mul-

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multiple movers, multiple position sensors, and a controller. Each track segment includes multiple coils along a length of the track segment and a segment controller operative to selectively energize the coils to generate an electromagnetic field with the coil. Each mover includes a magnet array having multiple magnets, where the magnet array generates a magnetic field that interacts with the electromagnetic field generated by the coils to propel the mover along each of the track segments. The position sensors are spaced apart along the length of each track segment, and each position sensor generates a position feedback signal with a waveform which is a function of the magnetic field generated by the magnet array on each mover. The controller is operative to receive the position feedback signal from each position sensor and to determine a unique identifier for each of the movers as a function of the waveform of the position feedback signal.

According to another embodiment of the invention, an independent cart system includes a first mover and a second mover. The first mover includes a first magnet array, and the second mover includes a second magnet array. The first magnet array generates a first array magnetic field that interacts with an electromagnetic field generated by multiple coils to propel the first mover along a track for the independent cart system. The first magnet array includes multiple first magnets, where each first magnet includes a first length, a first width, and a first height. The first length extends orthogonal to a direction of travel for the first mover and parallel to a surface of the track. The first width extends in the direction of travel, and the first height extends orthogonal to the direction of travel and orthogonal to the surface of the track segment. Each first magnet includes a body of the first magnet and a first magnet magnetic field, where the first magnet magnetic field has a first orientation through the body of the first magnet. The second magnet array generates a second array magnetic field that interacts with the electromagnetic field generated by the coils to propel the second mover along the track for the independent cart system. The second magnet array includes multiple second magnets, where each second magnet corresponds to a first magnet in the first magnet array. Each second magnet includes a second length, a second width, and a second height. The second length extends orthogonal to a direction of travel for the second mover and parallel to the surface of the track. The second width extends in the direction of travel, and the second height extends orthogonal to the direction of travel and orthogonal to the surface of the track segment. Each second magnet includes a body of the second magnet and a second magnet magnetic field, where the second magnet magnetic field has a second orientation through the body of the second magnet. A physical construction of a first magnet differs from a physical construction of a corresponding second magnet such that the first array magnetic field differs from the second array magnetic field.

These and other advantages and features of the invention will become apparent to those skilled in the art from the detailed description and the accompanying drawings. It should be understood, however, that the detailed description and accompanying drawings, while indicating preferred embodiments of the present invention, are given by way of illustration and not of limitation. Many changes and modifications may be made within the scope of the present invention without departing from the spirit thereof, and the invention includes all such modifications.

## BRIEF DESCRIPTION OF THE DRAWINGS

Various exemplary embodiments of the subject matter disclosed herein are illustrated in the accompanying drawings in which like reference numerals represent like parts throughout, and in which:

FIG. 1 is a schematic representation of an exemplary control system for an independent cart system according to one embodiment of the invention;

FIG. 2 is a perspective view of one embodiment of a mover configured to travel along the track of FIG. 1;

FIG. 3 is a front elevational view of the mover of FIG. 2;

FIG. 4 is a side elevational view of the mover of FIG. 2;

FIG. 5 is a top plan view of the mover of FIG. 2;

FIG. 6 is a perspective view of another embodiment of a mover configured to travel along the track of FIG. 1;

FIG. 7 is a front elevational view of the mover of FIG. 6;

FIG. 8 is a side elevational view of the mover of FIG. 6;

FIG. 9 is a top plan view of the mover of FIG. 6;

FIG. 10 is a sectional view of one embodiment of a mover and track segment included in the linear drive system taken at 10-10 of FIG. 1;

FIG. 11 is a perspective view of one embodiment of a magnet array used within the mover of FIG. 10;

FIG. 12 is a partial top cutaway view of the mover and track segment of FIG. 1;

FIG. 13 is a block diagram representation of the exemplary control system of FIG. 1;

FIG. 14 is a partial side cutaway view of the mover and track segment of FIG. 1;

FIG. 15 is a graphical representation of an exemplary position feedback waveform with respect to position;

FIG. 16 is a top plan view of an exemplary magnet array having varying length magnets aligned at the center of each magnet;

FIG. 17 is a top plan view of an exemplary magnet array having varying length magnets aligned at one edge of each magnet;

FIG. 18 is a perspective view of an exemplary magnet array having one magnet with a skewed magnetic field;

FIG. 19 is a perspective view of an exemplary magnet array having two magnets with skewed magnetic fields;

FIG. 20 is a perspective view of an exemplary magnet array having gaps within the magnet array;

FIG. 21 is a graphical representation of an exemplary position feedback waveform taken from a first position feedback sensor compared to a second position feedback sensor, where the second position feedback sensor has both an offset and a gain different than the first position feedback sensor;

FIG. 22 is a graphical representation of a first position feedback waveform for a mover travelling at a uniform speed and sampled at discrete time intervals and a second position feedback waveform for a mover travelling at a non-uniform speed and sampled at the same discrete time intervals;

FIG. 23 is a top plan view of an exemplary magnet array with position sensors aligned off-center with respect to the magnet array; and

FIG. 24 is a top plan view of an exemplary magnet array with position sensors aligned to the center of the magnet array and dedicated identification sensors aligned off-center with respect to the magnet array.

In describing the various embodiments of the invention which are illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, it is not intended that the invention be limited to the specific terms so

selected and it is understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose. For example, the word "connected," "attached," or terms similar thereto are often used. They are not limited to direct connection but include connection through other elements where such connection is recognized as being equivalent by those skilled in the art.

## DETAILED DESCRIPTION

The various features and advantageous details of the subject matter disclosed herein are explained more fully with reference to the non-limiting embodiments described in detail in the following description.

The subject matter disclosed herein describes an improved system and method for identifying each mover in the independent cart system. The present invention utilizes the permanent magnet array, which is part of the linear drive system and already present on each mover, to provide identification for the vehicle. As part of the linear drive system, the permanent magnet array generates a magnetic field which interacts with an electromagnetic field generated by coils spaced along the track. The electromagnetic field is varied such that the electromagnetic field "travels" along the track which, in turn, attracts the magnetic field generated by the permanent magnet to follow the moving electromagnetic field. The interaction between the electromagnetic field and magnetic field drives the movers along the track.

Although each permanent magnet array may nominally be constructed in an identical manner, manufacturing tolerances in the positioning of magnets, in the dimensions of materials, in the orientation or strength of the magnetic field generated by the magnets and the like cause the magnetic field generated by each magnet array to vary slightly. A magnetic field sensor is used to detect these magnetic fields and may be used to characterize individual magnetic fields generated by each magnet array. In some applications, however, the magnetic fields for two movers which are nominally constructed in an identical manner may be too similar to distinguish different movers. As the complexity of independent cart systems increases and the number of movers present in each system similarly increases, the potential increases for two movers to have magnet arrays generating magnetic fields that are close enough to identical that each permanent magnet array may not be uniquely identified simply due to manufacturing tolerances.

The system for identifying each mover disclosed herein contemplates intentionally varying assembly of the permanent magnet arrays in different vehicles to generate unique magnetic fields for each vehicle. Numerous methods of varying construction of the magnet array are contemplated. For example, the length of a single magnet or the length of multiple magnets may vary. Further, multiple different lengths may be used for different magnets. Magnets of varying lengths may be aligned at the midpoint of each magnet or along one edge of the magnet. A magnet may be inserted into the array in which the magnet is polarized in a manner such that the orientation of the magnetic field varies. Either a single magnet or multiple magnets in an array may have an orientation other than orthogonal. Materials from which the magnets or from which structural components of the magnet array are constructed may vary. Each different arrangement of magnets will generate a unique magnetic field.

Turning initially to FIG. 1, an exemplary transport system for moving articles or products includes a track 10 made up of multiple segments 12. According to the illustrated

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embodiment, multiple segments **12** are joined end-to-end to define the overall track configuration. The illustrated segments **12** are both straight segments having generally the same length. It is understood that track segments of various sizes, lengths, and shapes may be connected together to form the track **10** without deviating from the scope of the invention. The track **10** is illustrated in a horizontal plane. For convenience, the horizontal orientation of the track **10** shown in FIG. 1 will be discussed herein. Terms such as upper, lower, inner, and outer will be used with respect to the illustrated track orientation. These terms are relational with respect to the illustrated track and are not intended to be limiting. It is understood that the track may be installed in different orientations, such as sloped or vertical, and include different shaped segments including, but not limited to, straight segments, inward bends, outward bends, up slopes, down slopes, right-hand switches, left-hand switches, and various combinations thereof. The width of the track **10** may be greater in either the horizontal or vertical direction according to application requirements. The movers **100** will travel along the track and take various orientations according to the configuration of the track **10** and the relationships discussed herein may vary accordingly.

According to the illustrated embodiment, each track segment **12** includes an upper portion **17** and a lower portion **19**. The upper portion **17** is configured to carry the movers **100** and the lower portion **19** is configured to house the control elements. As illustrated, the upper portion **17** includes a pair of rails **14** extending longitudinally along the upper portion **17** of each track segment **12** and defining a channel **15** between the two rails. Clamps **16** affix to the sides of the rails **14** and secure the rails **14** to the lower portion **19** of the track segment **12**. Each rail **14** is generally L-shaped with a side segment **11** extending in a generally orthogonal direction upward from the lower portion **19** of the track segment **12**, and a top segment **13** extending inward toward the opposite rail **14**. The top segment **13** extends generally parallel to the lower portion **19** of the track segment **12** and generally orthogonal to the side segment **11** of the rail **14**. Each top segment **13** extends toward the opposite rail **14** for only a portion of the distance between rails **14**, leaving a gap between the two rails **14**. The gap and the channel **15** between rails **14** define a guideway along which the movers **100** travel.

According to one embodiment, the surfaces of the rails **14** and of the channel **15** are planar surfaces made of a low friction material along which movers **100** may slide. The contacting surfaces of the movers **100** may also be planar and made of a low friction material. It is contemplated that the surface may be, for example, nylon, Teflon®, aluminum, stainless steel and the like. Optionally, the hardness of the surfaces on the track segment **12** are greater than the contacting surface of the movers **100** such that the contacting surfaces of the movers **100** wear faster than the surface of the track segment **12**. It is further contemplated that the contacting surfaces of the movers **100** may be removably mounted to the mover **100** such that they may be replaced if the wear exceeds a predefined amount. According to still other embodiments, the movers **100** may include low-friction rollers **122**, **124** (See e.g., FIG. 6) to engage the surfaces of the track segment **12**. Optionally, the surfaces of the channel **15** may include different cross-sectional forms with the mover **100** including complementary sectional forms. Various other combinations of shapes and construction of the track segment **12** and mover **100** may be utilized without deviating from the scope of the invention.

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Turning next to FIGS. 2-5, one embodiment of the mover **100** is configured to slide along the channel **15** as it is propelled by a linear drive system. The mover **100** includes a body **102** configured to fit within the channel **15**. The body **102** includes a lower portion **104**, configured to hold magnets **130** (see also FIG. 10), and an upper portion **108**, configured to engage the rails **14**. The lower portion has a lower surface **106** to slide along the bottom surface of the channel **15**. The upper portion **108** includes side contacting surfaces **107** which slide along an interior surface of the side segments **11** of the rails **14** and upper contacting surfaces **109** which slide along an interior surface of the top segments **13** of the rails **14**. The mover **100** also includes a platform **110** mounted to the body **102** of the mover. An upper surface of the platform **110** includes multiple threaded openings **112** to which a fixture, or workpiece, may be mounted. Various workpieces, clips, fixtures, and the like may be mounted on the top of each platform **110** for engagement with a product to be carried along the track by the mover **100** according to an application's requirements. The platform **110** also includes a pair of openings **114** through which a threaded fastener **116** such as a bolt may be used to secure the platform **110** to the body **102** of the mover **100**. A central guide portion **118** of the platform **110** extends downward toward the body **102** of the mover **100**. The central guide portion **118** has a width less than the gap between the two rails **14** and fits within the gap between rails when the mover **100** is mounted on the track. The central guide portion **118** also extends further than lower contacting surfaces **120** on the platform **110** creating a gap between the upper contacting surfaces **109** of the body **102** and the lower contacting surfaces **120** of the platform **110** equal to the width of the top segment **13** of the rails **14** such that the lower contacting surfaces **120** of the platform **110** slide along an exterior surface of the top segments **13** of the rails. According to the illustrated embodiment, the platform **110** is generally square and has a sectional area similar to the sectional area of the body **102** as viewed from the top of the mover **100**. It is contemplated that platforms **110**, or attachments, of various shapes may be secured to the body **102**.

Turning next to FIGS. 6-9, another embodiment of the mover **100** is configured to roll along the track as it is propelled by a linear drive system. The mover **100** includes a body **102** configured to fit within the channel **15**. The body **102** includes a lower portion **104**, configured to hold magnets **130** (see also FIG. 10), and an upper portion **108**, configured to engage the rails **14**. The lower portion has a lower surface **106** to slide along the bottom surface of the channel **15**. The upper portion **108** includes side wheels **122** mounted in a horizontal configuration to roll along an interior surface of the side segments **11** of the rails **14**. The mover **100** also includes a platform **110** mounted to the body **102** of the mover. An upper surface of the platform **110** includes multiple threaded openings **112** to which a fixture, or workpiece, may be mounted. Various workpieces, clips, fixtures, and the like may be mounted on the top of each platform **110** for engagement with a product to be carried along the track by the mover **100** according to an application's requirements. The platform **110** also includes a pair of openings **114** through which a threaded fastener **116** such as a bolt may be used to secure the platform **110** to the body **102** of the mover **100**. The platform includes top wheels **124** mounted in a vertical orientation to roll along an exterior surface of the top segment **13** of each rail **14**. A central guide portion **118** of the platform **110** extends downward toward the body **102** of the mover **100**. The central guide portion **118** has a width less than the gap between the two rails **14**

and fits within the gap between rails when the mover **100** is mounted on the track. The central guide portion **118** also extends further than top wheels **124** on the platform **110** creating a gap between the top wheels **124** and the side wheels **122** at least as large as the width of the top segment **13** of the rails **14** such that the top segment **13** of the rails fits between the top and side wheels. The central guide portion **118** further includes a center wheel **126** which may engage an edge of a rail **14** if the mover **100** moves too far to one side or the other of the channel **15**. The center wheel **126** also assists in directing the mover **100** along switches between different track segments **12**. According to the illustrated embodiment, the platform **110** is generally rectangular and has a length similar to a length of the body **102** as viewed from the top of the mover **100**. It is contemplated that platforms **110**, or attachments, of various shapes may be secured to the body **102**.

The mover **100** is carried along the track **10** by a linear drive system. The linear drive system is incorporated in part on each mover **100** and in part within each track segment **12**. One or more drive magnets **130** are mounted to each mover **100**. With reference to FIG. **10**, the drive magnets **130** are arranged in a block on the lower surface of each mover. With reference also to FIG. **11**, the illustrated embodiment includes five drive magnets **130** placed adjacent to each other in a Halbach array to define the block of magnets. Each magnet **130** has a length **132** extending in the z-axis, a width **134** extending in the x-axis, and a height **136** extending in the y-axis. As will be discussed in more detail below, each magnet **130** in the array may have identical lengths **132**, widths **134**, and heights **136** or, alternately, one or more of the magnets **130** may have a length **132**, width **134**, or height **136** that is different than the other magnets. From left-to-right in FIG. **11**, a first drive magnet **130** has a north pole oriented along a y-axis toward the track when the mover **100** is mounted on the track. A second drive magnet **130** has a north pole oriented along an x-axis, and a third drive magnet **130** has a north pole oriented along the y-axis away from the track. A fourth drive magnet **130** has a north pole oriented along the x-axis in a direction opposite the second magnet, and a fifth drive magnet **130** has the north pole again oriented toward the track along the y-axis. As also illustrated, an orientation of the magnetic field is illustrated by the arrow pointing from the south pole toward the north pole. For movers **100** having a greater length, this rotation of the orientation for the drive magnets **130** may continue along the length of the mover **100**. The Halbach array configuration has an advantage of cancelling magnetic flux tending to extend upward into the rest of the mover **100** while increasing the magnetic flux tending to extend downward toward the track for interaction with the linear drive system. The illustrated embodiment for the arrangement of drive magnets **130** is not intended to be limiting. Various other configurations of the drive magnets **130** may be utilized as non-illustrated embodiments of the invention.

The linear drive system further includes a series of coils **150** spaced along the length of the track segment **12**. With reference also to FIG. **12**, the coils **150** may be positioned within a housing for the lower portion **19** of the track segment **12** and below the surface of the channel **15**. The coils **150** are energized sequentially according to the configuration of the drive magnets **130** present on the movers **100**. The sequential energization of the coils **150** generates a moving electromagnetic field that interacts with the magnetic field of the drive magnets **130** to propel each mover **100** along the track segment **12**.

A segment controller **50** is provided within each track segment **12** to control the linear drive system and to achieve the desired motion of each mover **100** along the track segment **12**. Although illustrated in FIG. **1** as blocks external to the track segments **12**, the arrangement is to facilitate illustration of interconnects between controllers. As shown in FIG. **10**, it is contemplated that each segment controller **50** may be mounted in the lower portion **19** of the track segment **12**. Each segment controller **50** is in communication with a node controller **170** which is, in turn, in communication with an industrial controller **200**. The industrial controller may be, for example, a programmable logic controller (PLC) configured to control elements of a process line stationed along the track **10**. The process line may be configured, for example, to fill and label boxes, bottles, or other containers loaded onto or held by the movers **100** as they travel along the line. In other embodiments, robotic assembly stations may perform various assembly and/or machining tasks on workpieces carried along by the movers **100**. The exemplary industrial controller **200** includes: a power supply **202** with a power cable **204** connected, for example, to a utility power supply; a communication module **206** connected by a network medium **160** to the node controller **170**; a processor module **208**; an input module **210** receiving input signals **211** from sensors or other devices along the process line; and an output module **212** transmitting control signals **213** to controlled devices, actuators, and the like along the process line. The processor module **208** may identify when a mover **100** is required at a particular location and may monitor sensors, such as proximity sensors, position switches, or the like to verify that the mover **100** is at a desired location. The processor module **208** transmits the desired locations of each mover **100** to a node controller **170** where the node controller **170** operates to generate commands for each segment controller **50**.

With reference also to FIG. **13**, the node controller **170** includes a processor **174** and a memory device **172**. It is contemplated that the processor **174** and memory device **172** may each be a single electronic device or formed from multiple devices. The processor **174** may be a microprocessor. Optionally, the processor **174** and/or the memory device **172** may be integrated on a field programmable gate array (FPGA) or an application specific integrated circuit (ASIC). The memory device **172** may include volatile memory, non-volatile memory, or a combination thereof. An optional user interface **176** may be provided for an operator to configure the node controller **170** and to load or configure desired motion profiles for the movers **100** on the node controller **170**. Optionally, the configuration may be performed via a remote device connected via a network and a communication interface **178** to the node controller **170**. It is contemplated that the node controller **170** and user interface **176** may be a single device, such as a laptop, notebook, tablet or other mobile computing device. Optionally, the user interface **176** may include one or more separate devices such as a keyboard, mouse, display, touchscreen, interface port, removable storage medium or medium reader and the like for receiving information from and displaying information to a user. Optionally, the node controller **170** and user interface may be an industrial computer mounted within a control cabinet and configured to withstand harsh operating environments. It is contemplated that still other combinations of computing devices and peripherals as would be understood in the art may be utilized or incorporated into the node controller **170** and user interface **176** without deviating from the scope of the invention.

The node controller 170 includes one or more programs stored in the memory device 172 for execution by the processor 174. The node controller 170 receives a desired position from the industrial controller 200 and determines one or more motion profiles for the movers 100 to follow along the track 10. A program executing on the processor 174 is in communication with each segment controller 50 on each track segment via a network medium 160. The node controller 170 may transfer a desired motion profile to each segment controller 50. Optionally, the node controller 170 may be configured to transfer the information from the industrial controller 200 identifying one or more desired movers 100 to be positioned at or moved along the track segment 12, and the segment controller 50 may determine the appropriate motion profile for each mover 100. Various features of the present application will be discussed herein as being executed within the segment controller 50, the industrial controller 200, and the node controller 170. As illustrated in FIGS. 1 and 13, these controllers are interconnected by the network media 160. According to other, non-illustrated embodiments of the invention, various features discussed herein as implemented on one of the controllers 50, 200, 170 may be implemented on another controller with communication via the network media 160 transmitting data required to perform the functions between the various controllers.

A position feedback system provides knowledge of the location of each mover 100 along the length of the track segment 12 to the segment controller 50. According to one embodiment of the invention, the position feedback system includes one or more position magnets mounted to the mover 100. According to another embodiment of the invention, illustrated in FIGS. 10 and 14, the position feedback system utilizes the drive magnets 130 as position magnets. Position sensors 145 are positioned along the track segment 12 at a location suitable to detect the magnetic field generated by the drive magnets 130. According to the illustrated embodiment, the position sensors 145 are located below or interspersed with the coils 150. The sensors 145 are positioned such that each of the drive magnets 130 are proximate to the sensor as the mover 100 passes each sensor 145. The sensors 145 are a suitable magnetic field detector including, for example, a Hall Effect sensor, a magneto-diode, an anisotropic magnetoresistive (AMR) device, a giant magnetoresistive (GMR) device, a tunnel magnetoresistance (TMR) device, fluxgate sensor, or other microelectromechanical (MEMS) device configured to generate an electrical signal corresponding to the presence of a magnetic field. The magnetic field sensor 145 outputs a feedback signal 225 (See FIG. 15) provided to the segment controller 50 for the corresponding track segment 12 on which the sensor 145 is mounted. The position sensors 145 are spaced apart along the length of the track. According to one aspect of the invention, the position sensors 145 are spaced apart such that adjacent position sensors 145 generate a feedback signal 225 which is offset from each other by ninety electrical degrees (90°). Multiple position sensors 145 are, therefore, generating feedback signals 225 in tandem for a single mover 100 as the mover is travelling along the track 10. The feedback signals 225 from each position sensor 145 are provided to a feedback circuit 58 which, in turn, provides a signal to the processor 52 corresponding to the magnet 130 passing the sensor 145.

The segment controller 50 also includes a communication interface 56 that receives communications from the node controller 170 and/or from adjacent segment controllers 50. The communication interface 56 extracts data from the

message packets on the industrial network and passes the data to a processor 52 executing in the segment controller 50. The processor may be a microprocessor. Optionally, the processor 52 and/or a memory device 54 within the segment controller 50 may be integrated on a field programmable gate array (FPGA) or an application specific integrated circuit (ASIC). It is contemplated that the processor 52 and memory device 54 may each be a single electronic device or formed from multiple devices. The memory device 54 may include volatile memory, non-volatile memory, or a combination thereof. The segment controller 50 receives the motion profile or desired motion of the movers 100 and utilizes the motion commands to control movers 100 along the track segment 12 controlled by that segment controller 50.

Each segment controller 50 generates switching signals to generate a desired current and/or voltage at each coil 150 in the track segment 12 to achieve the desired motion of the movers 100. The switching signals 72 control operation of switching devices 74 for the segment controller 50. According to the illustrated embodiment, the segment controller 50 includes a dedicated gate driver module 70 which receives command signals from the processor 52, such as a desired voltage and/or current to be generated in each coil 150, and generates the switching signals 72. Optionally, the processor 52 may incorporate the functions of the gate driver module 70 and directly generate the switching signals 72. The switching devices 74 may be a solid-state device that is activated by the switching signal, including, but not limited to, transistors, thyristors, or silicon-controlled rectifiers.

According to the illustrated embodiment, the track receives power from a distributed DC voltage. A DC bus 20 receives a DC voltage, VDC, from a DC supply and conducts the DC voltage to each track segment 12. The illustrated DC bus 20 includes two voltage rails 22, 24 across which the DC voltage is present. The DC supply may include, for example, a rectifier front end configured to receive a single or multi-phase AC voltage at an input and to convert the AC voltage to the DC voltage. It is contemplated that the rectifier section may be passive, including a diode bridge or active, including, for example, transistors, thyristors, silicon-controlled rectifiers, or other controlled solid-state devices. Although illustrated external to the track segment 12, it is contemplated that the DC bus 20 would extend within the lower portion 19 of the track segment. Each track segment 12 includes connectors to which either the DC supply or another track segment may be connected such that the DC bus 20 may extend for the length of the track 10. Optionally, each track segment 12 may be configured to include a rectifier section (not shown) and receive an AC voltage input. The rectifier section in each track segment 12 may convert the AC voltage to a DC voltage utilized by the corresponding track segment.

The DC voltage from the DC bus 20 is provided at the input terminals 21, 23 to a power section for the segment controller. A first voltage potential is present at the first input terminal 21 and a second voltage potential is present at the second input terminal 23. The DC bus extends into the power section defining a positive rail 22 and a negative rail 24 within the segment controller. The terms positive and negative are used for reference herein and are not meant to be limiting. It is contemplated that the polarity of the DC voltage present between the input terminals 21, 23 may be negative, such that the potential on the negative rail 24 is greater than the potential on the positive rail 22. Each of the voltage rails 22, 24 are configured to conduct a DC voltage having a desired potential, according to application require-

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ments. According to one embodiment of the invention, the positive rail **22** may have a DC voltage at a positive potential and the negative rail **24** may have a DC voltage at ground potential. Optionally, the positive rail **22** may have a DC voltage at ground potential and the negative rail **24** may have a DC voltage at a negative potential. According to still another embodiment of the invention, the positive rail **22** may have a first DC voltage at a positive potential with respect to the ground potential and the negative rail **24** may have a second DC voltage at a negative potential with respect to the ground potential. The resulting DC voltage potential between the two rails **22**, **24** is the difference between the potential present on the positive rail **22** and the negative rail **24**.

It is further contemplated that the DC supply may include a third voltage rail **26** having a third voltage potential. According to one embodiment of the invention, the positive rail **22** has a positive voltage potential with respect to ground, the negative rail **24** has a negative voltage potential with respect to ground, and the third voltage rail **26** is maintained at a ground potential. Optionally, the negative voltage rail **24** may be at a ground potential, the positive voltage rail **22** may be at a first positive voltage potential with respect to ground, and the third voltage rail **26** may be at a second positive voltage potential with respect to ground, where the second positive voltage potential is approximately one half the magnitude of the first positive voltage potential. With such a split voltage DC bus, two of the switching devices **74** may be used in pairs to control operation of one coil **150** by alternately provide positive or negative voltages to one the coils **150**.

The power section in each segment controller **50** may include multiple legs, where each leg is connected in parallel between the positive rail **22** and the negative rail **24**. According to the illustrated embodiment, three legs are shown. However, the number of legs may vary and will correspond to the number of coils **150** extending along the track segment **12**. Each leg includes a first switching device **74a** and a second switching device **74b** connected in series between the positive rail **22** and the negative rail **24** with a common connection **75** between the first and second switching devices **74a**, **74b**. The first switching device **74a** in each leg may also be referred to herein as an upper switch, and the second switching device **74b** in each leg may also be referred to herein as a lower switch. The terms upper and lower are relational only with respect to the schematic representation and are not intended to denote any particular physical relationship between the first and second switching devices **74a**, **74b**. The switching devices **74** include, for example, power semiconductor devices such as transistors, thyristors, and silicon-controlled rectifiers, which receive the switching signals **72** to turn on and/or off. Each of switching devices may further include a diode connected in a reverse parallel manner between the common connection **75** and either the positive or negative rail **22**, **24**.

The processor **52** also receives feedback signals from sensors providing an indication of the operating conditions within the power segment or of the operating conditions of a coil **150** connected to the power segment. According to the illustrated embodiment, the power segment includes a voltage sensor **62** and a current sensor **60** at the input of the power segment. The voltage sensor **62** generates a voltage feedback signal and the current sensor **60** generates a current feedback signal, where each feedback signal corresponds to the operating conditions on the positive rail **22**. The segment controller **50** also receives feedback signals corresponding to the operation of coils **150** connected to the power seg-

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ment. A voltage sensor **153** and a current sensor **151** are connected in series with the coils **150** at each output of the power section. The voltage sensor **153** generates a voltage feedback signal and the current sensor **151** generates a current feedback signal, where each feedback signal corresponds to the operating condition of the corresponding coil **150**. The processor **52** executes a program stored on the memory device **54** to regulate the current and/or voltage supplied to each coil and the processor **52** and/or gate driver module **70** generates switching signals **72** which selectively enable/disable each of the switching devices **74** to achieve the desired current and/or voltage in each coil **150**. The energized coils **150** create an electromagnetic field that interacts with the drive magnets **130** on each mover **100** to control motion of the movers **100** along the track segment **12**.

In operation, the position sensors **145** spaced along the track **10** are used to identify each mover **100** in the independent cart system. Upon power-up, the segment controller **50** in each track segment **12** monitors the position feedback signal generated by a mover **100** present on the track segment to identify which mover is present. In some applications, either the industrial controller **200**, the node controller **170**, each segment controller **50**, or a combination thereof may maintain a record of the mover locations prior to cycling power. Initial operation of the independent cart system may begin using the prior mover identities and locations, and a verification process may use the first feedback signal generated by a position sensor **145** to confirm that each mover **100** corresponds to the data stored prior to power being cycled and that no mover has been removed, inserted, or relocated while power was removed. Optionally, a temporary identifier may be assigned to each mover **100**. Either the identifier stored prior to cycling power or the temporary identifier may be used for each mover **100** such that an initial motion command may be transmitted to each segment controller **50** to cause a small motion of each mover **100**. The small motion may be, for example, a forward and/or reverse motion for a distance to generate one cycle of a waveform **225** (see FIG. **15**) from a position sensor **145** proximate each mover **100**. The one cycle of the waveform **225** is then used to identify each mover **100** present on a track segment **12**. After identifying each mover **100**, the temporary identifier is replaced and full operation of the independent cart system may resume.

According to one aspect of the invention, multiple movers **100** may be arranged as a virtual link. The movers **100** are not physically connected to each other, but rather maintain a record of at least one other mover adjacent to the corresponding mover. A mover **100** with one adjacent link may maintain a record of either the upstream or the downstream mover. A mover **100** with two adjacent links may maintain a record of both the upstream and downstream movers adjacent to the corresponding mover. During operation, a segment controller **50** responsible for a mover **100** included within a virtual link obtains a record of the identifier not just for the corresponding mover, but also for the mover(s) present in the virtual link. During an initial commissioning process, the segment controller **50** first obtains the identify for each mover, as discussed in more detail below, but also then receives the identity of the mover(s) present in the virtual link. A table is established which creates a correlation between each mover **100** and the other movers present in the virtual link. The segment controller **50** responsible for each of the movers **100** in the virtual link is able to compare the identities associated with each mover **100** to the identities associated with each of the other movers **100** present in the

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virtual link. If a difference exists, then the segment controller is aware of a misidentification of one of the movers **100**. The error may occur during operation if, for example, the identities of each mover **100** are periodically checked. When a mover **100** receives a new identity of an adjacent mover, it may compare the new identity to the prior identity to verify that each mover has been properly identified.

When power is cycled and no change is made to the number or location of movers during a power cycle, the identities of each mover **100** may be verified by the comparing the identities associated with one mover **100** to the identities associated with the other movers within the virtual link. Such a shut down may commonly occur overnight, for example, for independent cart systems operated during a single shift. The next morning, when a system is powered up, the segment controller **50** responsible for each mover **100** first determines its corresponding identity. When passing the corresponding identity for one mover **100** to the other movers **100** within a virtual link, the segment controller **50** responsible for the other movers may compare the new identity to the previously stored identity of the other movers in the virtual link. If one of the identities in the virtual link does not match, an error in determining the identities of the movers **100** is detected.

As a mover **100** travels past a position sensor **145**, the position sensor **145** generates a waveform **225** corresponding to the magnetic field generated by the magnets **130** present on the mover **100**. With reference to FIG. **15**, an exemplary waveform **225** is illustrated, which corresponds to the magnetic field generated by the magnet array illustrated in FIG. **11**. Under ideal conditions, each waveform **225** would be identical for each mover **100** travelling past each position sensor **145**. However, variations in manufacturing, device tolerances, offset values in sensors, and other such device tolerances results in waveforms **225** that vary between movers **100**. Device tolerances exist in both the position sensors **145** and in the magnets **130** mounted on the movers **100**. The present invention utilizes variations in the magnets **130** and in the magnetic fields generated by the magnets **130** to uniquely identify each mover **100**.

With reference to FIG. **21**, variations between a waveform **245** generated by a position sensor **145** and a nominal waveform **240** for the position feedback signals is illustrated. The nominal waveform **240** for each position feedback signal corresponds to an ideal feedback signal generated by one of the position sensors **145** if the array of magnets **130** and each position sensor **145** are manufactured and installed according to their respective nominal configuration and without variations in manufacturing tolerances. Numerous data points along the nominal waveform **240** may be stored in memory **54** of each segment controller **50** for use in compensating feedback signals from individual position sensors **145**. The second waveform **245** is a non-ideal position feedback signal for comparison to the nominal position feedback signal **240**. As the second waveform **245** is compared to the first waveform **240**, there are clear differences between the signals. For example, at the zero position along the horizontal axis, corresponding to time at which the position feedback signal is being generated with no magnet **130** proximate to the position sensor **145**, the nominal waveform **240** is equal to zero. However, the non-ideal waveform **245** is equal to a negative two-tenths, indicating an offset error in the position sensor **145** generating the second waveform **245**. Further, the peak-to-peak range for the nominal waveform **240** is approximately one and three-tenths. However, the peak-to-peak range for the second waveform **245** is approximately eight-tenths, indi-

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cating a gain error in the position sensor **145** generating the second waveform. FIG. **21** illustrates differences between a waveform **245** generated by a single position sensor **145** and a nominal waveform **240** for the position feedback signal. Each position sensor **145** may have different variations in the waveform generated by the variations between different position sensors **145** as a result of manufacturing tolerances in the sensors, in locations at which the position sensor is mounted on the track segment **12**, in the quality of the material covering the position sensor and located between the sensor and the magnet, or a combination thereof.

When power is cycled, however, the exact location of each mover **100** may vary along the track according to the process being performed by the independent cart system prior to power being removed. When power is restored, each position sensor **145** must be able to identify a mover **100** as a function of the magnetic field generated by the array of magnets **130** present on the mover. Variations in the waveforms generated by different position sensors would result in different identification of movers **100** as a function of which position sensor **145** is being used to perform the identification.

In order to eliminate variations between position sensors **145** from generating differences in waveforms **225**, an initial calibration routine is performed by each segment controller **50** for each of the position sensors **145** located along the corresponding track segment **12**. According to one aspect of the invention, a compensation table may be stored in the memory **54** of the segment controller **50**. Initially, the values of the waveform **240** for the nominal position feedback signal may be utilized to generate the compensation table for each of the position sensors **145** on the track segment **12**. Values for the position feedback signal **245** from each position sensor **145** are compared to values for the nominal feedback signal **250** which determines variations in the gain and/or offset present on a particular feedback sensor **145**. During the initial calibration routine a mover **100** having an array of magnets **130** generating a known magnetic field may be driven past each of the position feedback sensors **145** on the track segment **12**. Each value for the waveform **245** generated as the known array of magnets **130** passes one of the position feedback sensors **145** is compared to the values for the waveform **240** of the nominal position feedback signal. A difference between the values at the zero location, when the magnets **130** on the mover **100** are not close enough to the sensor **145** to generate a position feedback signal, may be stored in the compensation table for each sensor **145** to provide an initial offset compensation for each position feedback sensor **145**. The peak-to-peak values generated by the second waveform **245** may be stored in the compensation table for each sensor **145** or, optionally, the processor **52** may use the peak-to-peak value to determine an initial sensor gain for each position sensor **145** and the initial sensor gain may be stored in the compensation table to provide gain compensation. The offset and gain calculations are used to normalize the waveforms **245** generated by each position feedback sensor **245** to a nominal waveform **240**.

Referring still to FIG. **21**, the nominal waveform **240** is divided into three segments **226**, **228**, **230**. Each segment **226**, **228**, **230** corresponds to a peak of the nominal waveform **240**. A corresponding peak of the second waveform **245** exists for each peak of the nominal waveform **240**. However, as further illustrated in FIG. **21**, the first peak and the third peak of the nominal waveform **240** reach the same value. The first peak and the third peak of the second waveform **245** do not reach the same value. As a result, a



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single gain and offset value applied to the second waveform 245 will not end up having both the first and third peaks of the second waveform 245 correspond to the nominal waveform 240. Rather, a single gain and offset value for the second waveform 245 may be selected to have either the first or third peak correspond to the first or third peak of the nominal waveform while having some variation between the other peak. Similarly, each position feedback sensor 145 may have one point of the waveform 245 generated by the sensor 145 adapted to match the corresponding point in the nominal waveform 240. However, other values along the second waveform 245 may vary from the nominal waveform 240. Further, the variations in manufacturing observed by each position feedback sensor 145 may make different points on the second waveform 245 correspond to the nominal waveform for each sensor.

To further eliminate variations in the second waveform 245 as a result of the variations in manufacturing tolerances for the position sensors 145, the second waveform 245 may first be divided into segments, and each segment of the waveform is normalized. According to one aspect of the invention, the waveform is divided into segments which correspond to each peak value of the waveform. Turning to FIG. 15, the illustrated waveform 225 includes three peak values, with a first peak value and a third peak value at a positive value and a second peak value at a negative value. A first segment 226 corresponds to the first peak value, a second segment 228 corresponds to the second peak value, and a third segment 230 corresponds to the third peak value. Each segment of the waveform is normalized in a similar manner to that discussed above. A first offset value and a first gain value are determined for the first segment 226, a second offset value and a second gain value are determined for the second segment 228, and a third offset value and a third gain value are determined for the third segment 230. The compensation table for each position sensor 145 includes three offset values and three gain values which are applied to the measured position feedback signal as a mover travels past the position sensor, normalizing each of the three segments 226, 228, 230 independently according to their respective offset and gain values. As a result of normalizing the waveform 225 by segments, each peak value for the measured waveform more closely corresponds to the nominal waveform which reduces variation in the measured waveform as a result of variations in the position sensors 145.

According to another aspect of the invention, the waveform 225 generated by each position feedback sensor 145 may be normalized by position. Each position sensor 145 generates a continuous analog feedback signal which is provided to the feedback circuit 58 in the segment controller. This analog feedback signal is converted to a digital value for use in the processor 52 to perform the features described herein. Under traditional program execution, the analog feedback signal is converted to digital values at discrete time intervals. The sampling may occur in the feedback circuit 58 or in the processor 52. Commonly, an interrupt routine, clock-driven routine, or other periodic signal causes the segment controller to obtain a value for the feedback signal. Values sampled at periodic intervals are referred to as time-based samples.

As a mover 100 travels along the track 10, certain track segments 12 may cause the mover 100 to travel over that track segment 12 differently on successive passes. For example, debris in the channel 15 may cause extra friction during one pass over a track segment 12, where the debris is cleaned out on another pass. Travelling around a curved track segment may cause the mover 100 some jitter as the

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mover 100 temporarily contacts a side segment 11 or a top segment 13 of a rail 14. The location within a curved track segment that the mover 100 makes contact during a curve may vary on successive runs. Extra friction, curves, or still other variables in motion may cause the mover 100 to travel at an inconsistent speed along a track segment 12 during different passes by a position feedback sensor 145. Using time-based sampling, the waveforms 225 generated by the position feedback sensor may similarly illustrate these jitters.

With reference to FIG. 22, an example of the jitter that may be introduced due to time-based sampling is illustrated. A first waveform 250 for position feedback is illustrated when the mover 100 is travelling at a constant speed. Because the mover 100 is travelling at a constant speed, the position interval traversed by the mover 100 between samples is constant and the resulting waveform corresponds to the exemplary waveform illustrated in FIG. 15. A second waveform 255 is also shown during which non-ideal conditions such as friction, travelling along a curve, or any other interference between the mover 100 and the track segment 12 cause some variation in the speed at which a mover 100 travels. An increase in friction or rubbing along the rail 14 may temporarily slow the mover 100 such that the position does not track the constant speed waveform 250. The segment controller 50 will compensate for motion error and return the mover 100 to the desired position. In some instances, some overshoot may occur and the mover 100 may be slightly ahead of the desired position illustrated by the constant speed waveform 250. Such variations in speed create variations in the shape of the waveform generated by each position feedback sensor 145 and could be interpreted as variations in the magnetic field generated by the magnets 130 on the mover 100.

To minimize the effects of motion jitter on the feedback waveforms, the segment controller is configured to convert the time-based samples to position-based sample via interpolation. If, for example, a speed at which the mover 100 is travelling over a time interval is recorded along with the value of the sampled position feedback waveform, the segment controller 50 can use two successive values of the position feedback waveform along with the corresponding speed at which the mover 100 travelled during the time interval between samples and determine an approximate value of the sampled position feedback waveform at a specific position. The segment controller 50 may then determine values for the position feedback waveform at discrete position intervals rather than at discrete time intervals, resulting in a position-based waveform. Interpolating the second time-based waveform 255 in FIG. 22 to a position-based waveform will result in a waveform approximately equal to the first time-based waveform 250 during which the mover 100 was travelling at a uniform speed. The position-based waveform eliminates, or at least minimizes, jitter introduced from the time-based sampling.

After normalizing the waveform 225, a digital fingerprint for the waveform is determined. With reference still to FIG. 15, the segment controller 50 stores a number of sampled values 235 for the waveform 225. According to one aspect of the invention, the sampled values 235 are taken near the peak values in each segment 226, 228, 230. Sampling the waveform 225 near the peak value in each segment provides for a greater signal-to-noise ratio in the measured waveform and better identifies variations in the magnetic field being represented by the measured waveform. The number of samples taken at each peak may vary. The number of samples may depend, for example, on the magnitude of the

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peak, the duration for which the waveform remains near the peak value, the sampling frequency, and the like. As the number of samples of the waveform 225 increases, the samples are necessarily extending downward along the curve nearer toward zero. Thus, the signal-to-noise ratio decreases at these samples and the likelihood of electrical noise causing variation in the measured waveform rather than differences in the magnetic field being measured causing variation in the measured waveform increases. According to another aspect of the invention, the number of samples taken at a peak value is less than two hundred. For the illustrated embodiment, the number of samples of the first and third peak values may be in a range between about fifty and one hundred, while the number of samples of the second peak value may be in a range between one hundred and one hundred fifty. The number of sampled values is sufficient to identify variations in the measured magnetic fields between different movers 100 while being immune to influences of electrical noise in the measured values.

The sampled values 235 are used to generate a digital fingerprint 59 (see also FIG. 13) for each mover 100. The digital fingerprint 59 is generated as a function of at least one sampled value 235 of the waveform 225 from each segment 226, 228, 230. The digital fingerprint may be an array of values, including the sample value 235 having the greatest amplitude in each segment. Optionally, a number of sampled values 235, such as two, three, or more may be stored for each segment. According to still another option, a number of sampled values 235 in each segment 226, 228, 230 are added together, and the resultant sum for each segment 226, 228, 230 is used to create the digital fingerprint. Normalization of position feedback sensors 145 means each position feedback sensor 145 should generate the same measured waveform 225 for a single mover 100 as the mover passes each of the position feedback sensors 145. As a result, the waveform 225 from each position feedback sensor will generate the same digital fingerprint 59. Variations in the magnetic fields generated by the array of magnets 130 present on each mover 100 will, however, cause the measured waveforms 225 to vary for different movers 100. These variations in the measured waveforms 225, in turn, cause the digital fingerprint 59 for each mover 100 to be different. The digital fingerprints 59 may then be used to uniquely identify each mover 100 in the independent cart system.

In order to identify each mover 100, a correspondence between the digital fingerprint 59 and an identifier for the mover is required. With reference again to FIG. 13, a first embodiment of the invention includes a lookup table 55 in each segment controller 50. The lookup table 55 contains a column of identifiers 57 and a column of digital fingerprints 59. Each identifier 57 is unique and corresponds to one of the movers 100 in the independent cart system. Each identifier 57 also has a unique digital fingerprint 59 associated with the identifier. The digital fingerprint 59 corresponds to the magnetic field generated by the array of magnets 130 present on the mover 100 and the resultant waveform 225 generated by each position sensor 145 as the mover 100 travels past the sensor. Thus, when the segment controller 50 determines a run-time digital fingerprint from a waveform 225 generated by one of the position sensors 145, the segment controller 50 can compare the run-time digital fingerprint to the digital fingerprints 59 stored in the lookup table 55. When the segment controller 50 identifies a stored digital fingerprint 59 matching the run-time digital fingerprint, the segment controller reads the stored identifier 57 corresponding to the stored digital fingerprint 59 to determine the identity of the

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mover 100 which generated the waveform 225 and the corresponding run-time digital fingerprint 59.

According to another embodiment of the invention, artificial intelligence (AI) may be utilized to determine the identifier 57 for each mover 100. A neural network is trained with a set of digital fingerprints 59 and the associated identifier 57 for each digital fingerprint. After training the neural network, run-time digital fingerprints 59 are provided to the AI, and the AI returns the corresponding identifier 57 for the mover 100.

The discussion of the measured waveforms (FIGS. 15, 20, 21) above, focus on measurement of the magnetic field in a single axis. In particular, the strength of the magnetic field in the y-axis (see FIG. 11), extending toward the track 10, is represented by the illustrated waveforms as a mover passes by a position sensor 145. According to another aspect of the invention, the position feedback sensors 145 are multi-axis sensors. Each position sensor 145 may detect a strength of the magnetic field generated by the magnets 130 in at least two axes and, preferably in the x-axis, y-axis, and z-axis, where the axes are illustrated with respect to an array of magnets 130 in FIG. 11. The signals in each axis may be sampled in a manner discussed above with respect to a single axis. The digital fingerprint may be determined as a function of the sampled values in two or in all three axes.

Variations in the manufacturing tolerances, materials, magnetic fields, and the like for each array of magnets 130 present on a mover 100 will create a unique magnetic field for the mover 100 even when the arrays of magnets 130 have nominally identical construction. In some independent cart systems, however, the number of movers is large enough that the potential exists for the magnetic field of a first mover 100 being similar enough to the magnetic field of a second mover 100 such that the segment controller 50 generates the same digital fingerprint for each mover and is unable to uniquely identify each mover. Therefore, it may be desirable to manufacture the arrays of magnets 130 such that variation in the magnetic fields generated by each array is ensured. The arrays of magnets 130 present on each mover 100 may be constructed such that there are differences in the magnetic fields generated by each mover 100. It is desirable that the differences in the magnetic fields do not impact performance of the linear drive system yet have sufficient variation to ensure each mover 100 is uniquely identified.

According to still another aspect of the invention, at least one dimension of the magnets 130 is varied between one or more of the magnets mounted on a mover 100 to vary the magnetic field generated by the array of magnets. Referring to FIGS. 16 and 17, two examples of magnets 130 with different lengths are illustrated. According to the illustrated embodiments, the length 132 of each magnet 130 extends in the z-axis, which is orthogonal to the direction of travel for the mover 100 and is orthogonal to a surface of the track 10 on which the mover travels. In FIG. 16, a first magnet 130A and a fifth magnet 130E have a first length. A second magnet 130B and a fourth magnet 130D have a second length, and a third magnet 130C has a third length. Each of the magnets 130A-130E are positioned on the mover such that the center point of each magnet 130 is aligned. In FIG. 17, a first magnet 130A has a first length. A second magnet 130B has a second length. A third magnet 130C has a third length. A fourth magnet 130D has a fourth length, and a fifth magnet 130E has a fifth length. Each of the magnets 130A-130E are positioned on the mover such that one end of each magnet 130 is aligned. Variation in length is preferably small to minimize overall impact on the magnetic field generated by the magnets 130, where the magnetic field is one half of the

linear drive system for each mover **100**. Incremental changes in length between magnets **130** may be less than one millimeter and, in one example, are one half of one millimeter (0.5 mm). An overall difference in length between a shortest magnet and a longest magnet in an array of magnets **130** may be less than ten millimeters and, in one example, is four millimeters (4 mm) or less. Utilizing magnets **130** with lengths that vary by one half of one millimeter between an initial length (0 mm variation) and up to four millimeters (4 mm) in variation yield nine different potential lengths of magnets **130**. Varying different combinations of one or more magnets **130** selected from the five-magnet array illustrated results in thousands of combinations of different magnet configurations, where each combination generates a unique magnetic field. Thus, intentional variations in magnet configuration can ensure sufficient variation between magnetic fields to yield unique identification of each mover **100** in an independent cart system.

Referring next to FIG. **20**, magnets **130** with varying heights are also illustrated. The height of each magnet extends in the y-axis, which extends away from the surface of the track **10** on which the mover **100** travels. The first magnet **130A** and the second magnet **130B** each have a first height, extending for the entire height of the array of magnets. The third magnet **130C** has a second height, which is less than the first height by the width of a plate **135** mounted along the center magnet. Each of the fourth magnet **130D** and the fifth magnet **130E** similarly have a height different than the first height. A gap **137C** is present between the bottom of the fourth magnet **130D** and the housing **131** in which the array of magnets is mounted. Similarly, a gap **137D** is present from the top of the fifth magnet **130E** to the height of the housing **131** for the array of magnets. The gaps **137C**, **137D** may be filled with a material such as a potting material or with another plate similar to the mounting plate **135** over the center magnet. Optionally, the gaps **137C**, **137D** may be primarily filled with air, where the magnetic field travelling through air affects the overall magnetic field generated by the array of magnets.

With reference still to FIG. **20**, the magnets **130** may also have varying widths. The width of each magnet extends in the x-axis, which is the direction of travel for the mover **100**. The width of the first magnet **130A** in FIG. **20** is less than the width of the first magnet **130A** shown, for example, in FIG. **11**. A gap **137A** is present between the first magnet **130A** and the second magnet **130B**. Similarly, a gap exists between the second magnet **130B** and the third magnet **130C**. The gaps **137A**, **137B** may be filled with a material such as a potting material or another plate similar to the mounting plate **135** over the center magnet. Optionally, the gaps **137A**, **137B** may be primarily filled with air, where the magnetic field travelling through air affects the overall magnetic field generated by the array of magnets. For still other combinations of different magnets **130** in the array, variations in the width and/or height of the magnets **130** may be achieved with magnets directly adjacent to each other, eliminating gaps **130A**, **130B** between magnets. Similarly, gaps **137** between, beneath, or above magnets **130** may be introduced into different arrays having magnets of identical size. The incremental changes in width and/or height between magnets **130** may be less than one millimeter and, in one example, are one half of one millimeter (0.5 mm). An overall difference in width and/or height between magnets in an array of magnets **130** may be less than ten millimeters and, in one example, is four millimeters (4 mm) or less. Similarly, the size of gaps may be incrementally sized with similar dimensions to the variations in the magnet dimen-

sions. The gaps may vary by one half of one millimeter between an initial length (0 mm variation) and up to four millimeters (4 mm). The additional degrees of freedom in varying dimensions between heights and widths of the magnets **130** as well as introducing and varying the widths of gaps between magnets **130** yields thousands of additional combinations for the construction of magnet arrays.

In addition to varying a dimension of the magnet **130**, materials from which the array of magnets **130** is constructed may be varied. With reference to FIG. **11**, a plate **135** is mounted along an upper surface of the center magnet **130**. The plate is a magnetic receptive structure, through which the magnetic field generated by the magnets **130** may pass. The plate includes threaded holes configured to receive a bolt or screw to secure the array of magnets **130** within the lower portion **104** of the body **102** of each mover **100**. Optionally, the plate may have varying dimensions. For example, the plate **135** may extend over the entire top surface of the magnets **130**. Optionally, the plate may be extended over a portion of the magnets **130** or be rotated, for example ninety degrees to the illustrated embodiment. Still other magnetic receptive structures may be mounted to the array of magnets **130**, where the magnetic receptive structure has magnetic properties different than free air and which influence the direction of the magnetic flux generated by the magnets **130**. The plate may be made of electrical steel, which is used in electrical machinery where high magnetic permeability is desired, where electrical steel has a magnetic permeability in the range of four thousand microhenries per meter of thickness (4000  $\mu\text{H/m}$ ). Alternate materials, such as stainless steel, cast iron, or low carbon steel may be used where the materials have a range of magnetic permeability from a high of about two thousand to a low of about sixty microhenries per meter of thickness (60-2000  $\mu\text{H/m}$ ).

In addition to the plate **135** in the center of the array, the magnets themselves may be made of different materials. The strength of the magnetic field is a function, at least in part, of magnetic remanence and magnetic coercivity of the materials from which the magnets **130** are made. Permanent magnets may be constructed of materials such as Neodymium (NdFeB), Samarium Cobalt (SmCo), Alnico (Al-NiCo), ferrite, and the like. The magnetic remanence of these magnets may vary from about thirty-five hundredths to one and four tenths of a Tesla (0.35-1.4 T). The magnetic coercivity may vary from about one hundred to about three thousand two hundred kiloamperes per meter (100-3200 kA/m). Varying materials from which the magnets **130** are made, in combination with varying dimensions of a magnet, as discussed above, further increase the potential different combinations of arrays of magnets **130** present on each mover **100** in the independent cart system, where each combination generates a unique magnetic field.

According to still another aspect of the invention, the magnetic field generated by the array of magnets **130** may be varied by changing the orientation of the magnetic field within one or more of the magnets **130** in the array. Turning to FIGS. **18** and **19**, two examples of magnet arrays in which the magnets **130** have magnetic fields in varying orientations are shown. When compared to the magnet array illustrated in FIG. **11**, the magnet array in FIG. **18** includes a single magnet **130** in which the orientation of the poles is varied. The second magnet **130B** has been polarized differently or mounted within the array in an orientation other than parallel to the lower surface of the array. The orientation of the magnetic field on the second magnet **130B** is illustrated by the arrow extending from the south pole to the north pole. In the embodiment shown in FIG. **18**, the magnetic field for the

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second magnet **130B** has been rotated upward from the embodiment illustrated in FIG. **11**. Similarly, the magnet array in FIG. **19** has two magnets **130** in which the orientation of the poles is varied from the magnet array of FIG. **11**. The first magnet **130A** and the third magnet **130C** each have a magnet field rotated such that the orientation is no longer perpendicular to the lower surface of the array. Incremental changes in the orientation of the magnetic field may include rotation by about five degrees. An overall difference in the rotation between magnets on different arrays may be less than forty-five degrees and, in one example, is less than thirty degrees. Variations in the orientation of the magnetic fields in at least one magnet **130** on a mover **100** yield still another option for generating a unique magnetic field with each mover **100** in an independent cart system.

According to yet another aspect of the invention, an initial measurement of the magnetic field generated by the array of magnets **130** may be performed in a factory. A calibration fixture may include a section of track and a sensor **145** past which a mover **100** travels. As the mover **100** travels past the test sensor, the waveform generated by the sensor **145** is utilized to generate a digital fingerprint of the magnetic field produced by the magnets **130** on the mover. This digital fingerprint is recorded along with an identifier, such as a serial number for the mover, and provided to a customer. In addition, the sensor **145** used in the calibration fixture may include its own offset and gain values. However, the sensor **145** in the calibration fixture may be a single sensor and may not be calibrated to a specific nominal value. Rather, the waveform generated by the sensor **145** may define the nominal value of the waveform to which other sensors **145** are normalized. The offset and gain values for the sensor **145** used to generate the digital fingerprint may be included in data provided to a customer. These offset and gain values may be used as a basis for calibrating each of the sensors **145** in an independent cart system at a customer's facility. A difference between the gain and offset values for each sensor **145** at the customer's facility and the gain and offset values for the factory sensor may generate the gains and offset values used to normalize the waveform for generation of run-time digital fingerprints. Optionally, a predefined nominal waveform may be defined for all sensors **145**, whether used in the factory or in a customer's facility. The offset and gain value for the factory sensor **145** may normalize the waveform for the digital fingerprint generated in the factory to the predefined nominal waveform. Offset and gain values for each sensor **145** in the customer's facility may similarly normalize waveforms generated by each sensor **145** to the predefined nominal waveform.

Each independent cart system is provided with a set of movers **100** for which each mover **100** may be uniquely identified as a function of the magnetic field generated by the magnets **130** present on the mover **100**. Each mover **100** is passed through the calibration fixture at the factory to generate a digital fingerprint for the mover **100**. If the magnetic fields for two movers **100** are too similar to each other because variations in manufacturing tolerances have not provided sufficient differentiation between the two movers **100**, a second mover **100** having the same digital fingerprint as a first mover is rejected for a particular independent cart system. As the number of movers **100** increase for a particular independent cart system, the potential for duplicate digital fingerprints increases. Thus, it may be desirable to utilize one of the methods discussed above for intentionally varying the manufacture of the magnets **130** and/or materials of the movers **100** to provide for movers

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**100** generating unique digital fingerprints. A table including of all the movers **100** in an independent cart system is provided to the customer, where the table includes the unique identifier and the digital fingerprint of each mover. This table is stored as the lookup table against which run-time digital fingerprints are compared or used to train the AI engine present to identify each mover.

In addition to varying physical properties of the magnets **130** to create variations in the magnetic fields generated by the magnets **130** it may be desirable to vary the location of the sensors **145** used to detect the magnetic fields. With reference to FIG. **10**, sensors **145** may be located in a central position beneath the magnets **130**. However, with reference also to FIG. **23**, it may be desirable to locate the sensors **145** in a position that is shifted toward one side of the array of magnets **130**. Depending on the variation in the physical construction of the magnets **130** between different movers, the variation in the magnetic field generated by each array of magnets may be more significant along one edge of the magnet array. Varying the length **132** of each magnet, as shown in FIGS. **16** and **17** can create greater variation in the strength of the magnetic field along one edge of the magnet array. The amplitude of the feedback signal **225** will have greater variation and, therefore, greater variation in the digital fingerprints generated. The increased variation reduces the potential for misidentification of a mover **100**.

With reference also to FIG. **24**, a first set of position sensors **145** may be centrally located beneath the magnets **130**. A second sensor **145**, or second set of sensors, may be located at a single location, or spaced apart at multiple stations, and be positioned off-center along the track **10**. The first set of position sensors **145** may be located in a position with a strong and more consistent magnetic field. A central location may be preferred to obtain position feedback information for the location of each mover **100** and is used to regulate current in the coils **150** for the linear drive system. While there is still variation in the magnetic fields generated at the central alignment and that variation is used to determine an initial identification of each mover **100**, the second set of sensors **145** may be located in a region of high variation of the magnetic field. The increased variation in the magnetic field, allows for increased variation in the digital fingerprints determined for each mover **100** and improves reliability of the identification of each mover **100**. These second sets of sensors may perform a verification check on the identity of each mover **100** as it passes the location with the off-center sensors **145**.

It should be understood that the invention is not limited in its application to the details of construction and arrangements of the components set forth herein. The invention is capable of other embodiments and of being practiced or carried out in various ways. Variations and modifications of the foregoing are within the scope of the present invention. It also being understood that the invention disclosed and defined herein extends to all alternative combinations of two or more of the individual features mentioned or evident from the text and/or drawings. All of these different combinations constitute various alternative aspects of the present invention. The embodiments described herein explain the best modes known for practicing the invention and will enable others skilled in the art to utilize the invention.

In the preceding specification, various embodiments have been described with reference to the accompanying drawings. It will, however, be evident that various modifications and changes may be made thereto, and additional embodiments may be implemented, without departing from the broader scope of the invention as set forth in the claims that

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follow. The specification and drawings are accordingly to be regarded in an illustrative rather than restrictive sense.

We claim:

1. An independent cart system, comprising:
  - a plurality of track segments, each track segment of the plurality of track segments further comprising:
    - a plurality of coils along a length of the track segment, and
    - a segment controller operative to selectively energize the plurality of coils to generate an electromagnetic field with each of the plurality of coils;
  - a plurality of movers, each mover of the plurality of movers including a magnet array having a plurality of magnets, wherein the magnet array generates a magnetic field that interacts with the electromagnetic field generated by the plurality of coils to propel the mover along each of the plurality of track segments;
  - a plurality of position sensors spaced apart along the length of each track segment, each position sensor from the plurality of position sensors generates a position feedback signal with a waveform which is a function of the magnetic field generated by the magnet array on each mover; and
  - a controller operative to:
    - receive the position feedback signal from each position sensor, and
    - determine a unique identifier for each of the plurality of movers as a function of the waveform of the position feedback signal.
2. The independent cart system of claim 1, wherein each magnet from the plurality of magnets in the magnet array for each mover has a length, extending orthogonal to a direction of travel for each mover and parallel to a surface of each track segment; a width, extending in the direction of travel; and a height, extending orthogonal to the direction of travel and orthogonal to the surface of each track segment.
3. The independent cart system of claim 2, further comprising:
  - a first mover, selected from the plurality of movers, including a first magnet array with a first plurality of magnets; and
  - a second mover, selected from the plurality of movers, including a second magnet array with a second plurality of magnets, wherein:
    - each magnet of the first plurality of magnets has a corresponding magnet in the second plurality of magnets, and
    - at least one magnet from the first plurality of magnets has a different length, width, or height than the corresponding magnet in the second plurality of magnets.
4. The independent cart system of claim 3, wherein:
  - each magnet of the first plurality of magnets is aligned at a center point of the magnet, and
  - each magnet of the second plurality of magnets is aligned at one end of the magnet.
5. The independent cart system of claim 2, further comprising:
  - a first mover, selected from the plurality of movers, including a first magnet array with a first plurality of magnets; and
  - a second mover, selected from the plurality of movers, including a second magnet array with a second plurality of magnets, wherein:
    - each magnet of the first plurality of magnets has a corresponding magnet in the second plurality of magnets,

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each magnet of the first plurality of magnets is mounted to the first mover at a first position with respect to the first mover,

each magnet of the second plurality of magnets is mounted to the second mover at a second position with respect to the second mover, and

at least one dimension of the second position is offset from a corresponding dimension of the first position.

6. The independent cart system of claim 1, wherein the magnet array for each mover includes a magnetic receptive structure mounted within the magnetic field generated by the magnet array.

7. The independent cart system of claim 6, wherein the magnetic receptive structure is a plate mounted adjacent to at least one of the plurality of magnets in each magnet array.

8. The independent cart system of claim 6, further comprising:

a first mover, selected from the plurality of movers, including:

a first magnet array with a first plurality of magnets, and

a first magnetic receptive structure; and

a second mover, selected from the plurality of movers, including:

a second magnet array with a second plurality of magnets, and

a second magnetic receptive structure, wherein either a magnetic remanence or a magnetic coercivity for the first magnetic receptive structure is different than a magnetic remanence or a magnetic coercivity for the second magnetic receptive structure.

9. The independent cart system of claim 1 further comprising:

a first mover, selected from the plurality of movers, including a first magnet array with a first plurality of magnets; and

a second mover, selected from the plurality of movers, including a second magnet array with a second plurality of magnets, wherein:

each magnet of the first plurality of magnets has a corresponding magnet in the second plurality of magnets,

each magnet of the first plurality of magnets has a field orientation for a magnetic field generated in the magnet,

each magnet of the second plurality of magnets has a field orientation for a magnetic field generated by the magnet, and

the field orientation for at least one magnet in the first plurality of magnets is different than the field orientation for the corresponding magnet in the second plurality of magnets.

10. The independent cart system of claim 1, wherein the position feedback signal generated by each of the plurality of position sensors is normalized such that the position feedback signal generated from each of the plurality of position sensors is the same for the magnetic field generated by the magnet array on each mover.

11. A system of movers for use in an independent cart system, the system comprising:

a first mover, comprising:

a first magnet array, wherein the first magnet array generates a first array magnetic field that interacts with an electromagnetic field generated by a plurality of coils to propel the first mover along a track for the independent cart system, the first magnet array including a plurality of first magnets, wherein:

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each first magnet from the plurality of first magnets includes a first length, extending orthogonal to a direction of travel for the first mover and parallel to a surface of the track; a first width, extending in the direction of travel; and a first height, extending orthogonal to the direction of travel and orthogonal to the surface of the track segment, and each first magnet from the plurality of first magnets includes a body of the first magnet and a first magnet magnetic field, wherein the first magnet magnetic field has a first orientation through the body of the first magnet; and

a second mover, comprising:

a second magnet array, wherein the second magnet array generates a second array magnetic field that interacts with the electromagnetic field generated by the plurality of coils to propel the second mover along the track for the independent cart system, the second magnet array including a plurality of second magnets, wherein:

each second magnet corresponds to a first magnet in the first magnet array,

each second magnet from the plurality of second magnets includes a second length, extending orthogonal to a direction of travel for the second mover and parallel to the surface of the track; a second width, extending in the direction of travel; and a second height, extending orthogonal to the direction of travel and orthogonal to the surface of the track segment,

each second magnet from the plurality of second magnets includes a body of the second magnet and a second magnet magnetic field, wherein the second magnet magnetic field has a second orientation through the body of the second magnet, and a physical construction of a first magnet differs from a physical construction of a corresponding second magnet such that the first array magnetic field differs from the second array magnetic field.

12. The system of claim 11, wherein:

the first mover further comprises a first unique identifier corresponding to the first array magnetic field; and the second mover further comprises a second unique identifier corresponding to the second array magnetic field, wherein a controller receiving a feedback signal corresponding to the first and second array magnetic fields identifies the first and second unique identifiers, respectively.

13. The system of claim 11, wherein at least one of the first length, the first width, or the first height for one of the

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first magnets is different than the second length, the second width, or the second height of the corresponding second magnet.

14. The system of claim 13, wherein:

each first magnet is aligned at a center point of the first magnet, and

each second magnet is aligned at one end of the second magnet.

15. The system of claim 11, wherein:

each first magnet is mounted to the first mover at a first position with respect to the first mover,

each second magnet is mounted to the second mover at a second position with respect to the second mover, and at least one dimension of the second position is offset from a corresponding dimension of the first position.

16. The system of claim 11, wherein:

the first mover further comprises a first magnetic receptive structure mounted within the first array magnetic field, and

the second mover further comprises a second magnetic receptive structure mounted within the second array magnetic field.

17. The system of claim 16, wherein the first magnetic receptive structure is a plate mounted adjacent to at least one of the first magnets and the second magnetic receptive structure is a plate mounted adjacent to at least one of the second magnets.

18. The system of claim 16, wherein either a magnetic remanence or a magnetic coercivity for the first magnetic receptive structure is different than a magnetic remanence or a magnetic coercivity for the second magnetic receptive structure.

19. The system of claim 11, wherein:

each first magnet has a field orientation for a magnetic field generated in the first magnet,

each second magnet has a field orientation for a magnetic field generated by the second magnet, and

the field orientation for at least one first magnet is different than the field orientation for the corresponding second magnet.

20. The system of claim 11, further comprising a plurality of position sensors spaced along the track for the independent cart system, wherein each of the plurality of position sensors generates a first waveform corresponding to the first array magnetic field and a second waveform corresponding to the second array magnetic field, wherein the first waveform and the second waveform are normalized such that the first waveforms generated by each of the plurality of position sensors is the same and the second waveform generated by each of the plurality of position sensors is the same.

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