

HIGH FORCE LINEAR MOTOR SYSTEM FOR POSITIONING A LOAD

Field of the invention

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The present invention relates to a high force linear motor that is used to position a load. The present invention is suitable for a XY table that requires very high dynamics and performance, such as in wire bonding applications.

10 Background and discussion of prior art

Linear motors are now widely used to position loads in equipment used for manufacturing electronic components and semiconductors. The commonly known advantages of using direct drive are higher acceleration, higher speed, higher accuracy, reduced moving mass, simplified design without complicated transmission systems, and better reliability without any wear and tear of moving parts associated with transmission mechanisms.

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One type of linear motor commonly used for positioning XY tables is the moving coil linear motor, or what we commonly call ironless linear motor. The ironless linear motor comprises only copper coils molded together to form a coil assembly, without any iron laminations. US patent 6,713,903 B2 and US patent 6,983,703 B2 both describe the use of moving coil linear motors to drive an XY table. While this type of linear motor is already implemented widely, one disadvantage of such motors is its high costs. Two rows of high energy rare earth magnets need to be placed between the moving coil to generate large forces when current is passed through the coils. The magnets used are typically Neodymium magnets, a rare earth, high energy permanent magnet made from an alloy of neodymium, iron and boron. Due to the limited supply of such rare earth material used to make such magnets, the cost of such magnets has been increasing very significantly in the last few years. Another disadvantage of such motors is the fact that the cable that supplies current to the coil is always moving with the coil. At high accelerations and speed, the reliability of the cable has to be considered, and the resistance force from the bending of the cable affects the precise control of the motion system. Heat generated in the coils is also difficult to remove, and the heat can be transferred to the load, affecting the accuracy of the system due to expansion. US patent 5,808,379 B2 also describes another moving coil linear motor that can be used for position a load, where a large volume of magnets need to be used.

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Another linear motor commonly used to position loads for an XY table is the iron core linear motor. US patent 5,910,691 B2 describes such a motor system.

- A simplified drawing of an iron core motor of the prior art is shown in Fig 1. Magnets 1a, 1b and 1c are magnets with alternating polarity and are part of a row of magnets which are mounted on magnet back iron 2. The coil assembly comprises coils 3 which are inserted into the slots formed by laminations 4 stacked together. The laminations act as the coil back iron and are used to reduce eddy current losses, although normal magnetic soft iron can also be used. Two magnetic circuits 5a and 5b are shown in the figure, which allows some of the flux to cut through the coils as it circulates around the slots of the laminations.
- 10 The advantage of the iron core linear motor is the large force it can generate, compared to the ironless and coreless linear motors. However, the moving mass of the coil is relatively large and this limits the acceleration it can achieve, even without any load. While it is also possible to move the magnets and have the coil stationary, the total mass of the magnets and the magnet back iron is also very significant. Another big disadvantage of the iron core motor is
- 15 the large attraction force between the magnets and the coil laminations. Due to the small air gap needed for this type of motor to work properly, which is typically in the range of 0.8 mm to 1.1 mm, the attraction force becomes very large. Large bearings with high load rating need to be used to support the motor. Large static friction force is therefore associated with this type of motor system, and this affects the response of the motor during start of motion and
- 20 end of motion settling performance.

Summary Of Invention

- A first object of the invention is a n improved high force linear motor system comprising a linear motor with a first coil assembly, a second coil assembly and a plurality of magnets forming a row of magnets, wherein
- the row of magnets is positioned between the first coil assembly and the second coil assembly,
- 30 the first coil assembly is aligned along the length of the row of magnets, and the second coil assembly is aligned along the length of the row of magnets,
- so each coil assembly is geometrically and exactly opposite one another and equidistant from one another about a center mirror line formed by the horizontal axis of the row of magnets; and
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the force of attraction between the row of magnet and the first coil assembly being completely balanced by the force of attraction between the row of magnets and the second coil assembly

- 5 Preferably, the magnets in the row of magnets are movable along the length of the center mirror line formed by the horizontal axis of the row of magnets.

Preferably, the magnets in the row of magnets are each held by a magnet support structure, which is non magnetic.

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Preferably, the row of magnets are held by a magnet support structure made from Aluminum.

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Alternatively, the row of magnets are held by a magnet support structure made from other light but stiff non-metallic materials.

It is also possible that the row of magnets be held by a magnet support structure made from fiber reinforced resin.

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It is also possible that the row of magnets be held by a magnet support structure made from plastic.

Preferably, the improved high force linear motor system has the following relationships:

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$$S_x = M_x - C_x$$

$$S_y = M_y - C_y$$

$$C_{yx} - M_{yx} > S_x$$

where

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S_x is the maximum stroke of the X axis

C_x is the length of the X coil assembly in the direction of travel

M_x is the distance between the edges of the magnets for the X motor in the direction of X travel

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S_y is the maximum stroke of the Y axis

C_y is the length of the Y coil assembly in the direction of Y travel

M_y is the distance between the edges of the magnets for the Y motor in the direction of Y travel

C_y is the length of the Y coil assembly in the direction of X travel

M_{yx} is the distance between the edges of the magnets for the Y motor in the direction of X travel

5 A second object of the Invention is an improved high force linear motor system in a XY table, comprising a X axis high force linear motor and a Y axis high force linear motor, the high force linear motor of each axis having a first coil assembly, a second coil assembly s and a plurality of magnets forming a row of magnets, wherein

10 the row of magnets is positioned between the first coil assembly and the second coil assembly;

the first coil assembly is aligned along the length of the row of magnets, and the second coil assembly is aligned along the length of the row of magnets;

15 so each coil assembly is geometrically and exactly opposite one another and equidistant from one another about a center mirror line formed by the horizontal axis of the row of magnets; and

20 the force of attraction between the row of magnets and the first coil assembly being completely balanced by the force of attraction between the row of magnet and the second coil assembly

25 Preferably, the row of magnets are not mounted onto any back iron, but are held by a magnet support structure.

Preferably, the row of magnets are held by a magnet support structure, which is non magnetic.

30 Preferably, the row of magnets are held by a magnet support structure made from Aluminum.

Alternatively, the row of magnets are held by a magnet support structure made from other light but stiff non-metallic materials.

35 It is also possible the row of magnets be held by a magnet support structure made from fiber reinforced resin.

It is also possible the row of magnets be held by a magnet support structure made from plastic.

Preferably, the XY table for positioning a load, using an X axis high force linear motor and a Y axis high force linear motor has the following relationships:

$$S_x = M_x - C_x$$

$$S_y = M_y - C_y$$

$$C_{yx} - M_{yx} > S_x$$

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where

S_x is the maximum stroke of the X axis

C_x is the length of the X coil in the direction of travel

M_x is the distance between the edges of the magnets for the X motor in the direction of X travel

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S_y is the maximum stroke of the Y axis

C_y is the length of the Y coil in the direction of Y travel

M_y is the distance between the edges of the magnets for the Y motor in the direction of Y travel

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C_{yx} is the length of the Y coil in the direction of X travel

M_{yx} is the distance between the edges of the magnets for the Y motor in the direction of X travel

25 Brief Description Of The Drawings

Fig 1 is a simplified drawing of an iron core motor of the prior art.

Fig 2 is an illustration of the high force linear motor of the invention.

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Fig 3 is an illustration of a possible design of how the magnets are mounted in a support structure.

Fig 4 is an illustration of the inventive device having two coil assemblies with a geometrically symmetrical arrangement.

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Fig 5 is an illustration of the improved high force linear motors in an XY table, such as for wire bonding application.

Fig 6 shows a plan view of the X axis of the improved high force linear motor in a XY Table.

5 Fig 7 shows a plan view of the Y axis of the improved high force linear motor in a XY Table.

Fig 8 shows another embodiment of a XY table, using 2 motors according to the invention.

10 Fig 9 shows a plan view of the X axis linear motor.

Fig 10 shows a plan view of the Y axis linear motor.

Fig 11 shows a magnet support structure where the magnets are skewed at an angle.

15 Detailed Description Of The Preferred Embodiment

The present invention provides a linear motor with very high force, low moving mass and zero net attraction force between the magnets and the coil laminations. The motor also uses a relatively small volume of magnets, thereby reducing the costs of production.

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The arrangement of this high force linear motor is illustrated in Fig 2. A row of magnets 6 is positioned in the center, between two coil assembly, a 1st coil assembly 7a and a 2nd coil assembly 7b. The two coil assemblies are aligned exactly along the length of the row of magnets, so that in essence the 2nd coil assembly is geometrically an exact and opposite image of the 1st coil assembly, with the horizontal axis of the row of magnets forming a center line equidistant from the 1st and 2nd coil assemblies. In other words, the row of magnets form a center mirror line equidistant from the 1st and 2nd coil assemblies. The flux circuit 8 illustrates the flow of the flux, with the flux lines flowing in the same direction as the polarity of the magnets, without any magnet back iron necessary. With this arrangement, it is desirable to move the magnets instead of the coil assemblies. Hence, without the heavy magnet back iron of the conventional iron core motor, the moving mass is greatly reduced. With the coil assembly stationary, very large force and very high accelerations can be achieved by just moving the magnets. No moving cable is also necessary and the heat generated can be easily removed from the coil either through natural convection, heat sinks or other means of cooling.

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One of the biggest advantages of this arrangement compared to the conventional iron core linear motor is the elimination of the attraction force. The attraction force between the

magnets and the 1st coil assembly is completely balanced by the force of attraction between the magnets and the 2nd coil assembly. This allows the use of smaller linear bearings, or even frictionless air bearings. It is needless to say that it is also possible to have the magnets stationary, and to move the coil with this design, although it is not a preferred way unless
5 there is some special reason to do so.

It should be mentioned that the magnets are not free to float in the air, but are mounted on a support structure. In this new design, the support structure need not and should not be magnetic soft iron. A light weight, non magnetic material, such as aluminum or fiber
10 reinforced plastic or resin material can be used. The material need not be magnetically permeable because this support structure does not close the magnetic flux as in the case of the conventional motor design. The flux flows through each magnet independently, in the same direction as the polarity of the magnets, so the support structure does not play a part in closing the magnetic circuit. The sole purpose of this support structure is to hold the magnets in place.

15 Fig 3 is an illustration of a possible arrangement of the magnet in the support structure. This involves machining pockets or slots in the support structure that fit the magnets exactly and the magnets are fixed easily into their respective position and orientation. Magnets 9a and 9b are inserted into the support structure 10. The face of magnets 9a, 9b, may flush with
20 the surface of the support structure 10, or the magnets 9a, 9b can be slightly thinner than the support structure 10. The magnets 9a, 9b can be held onto this support structure by means of high strength epoxy. This support structure can be mounted to a linear guidance system, to keep it at the horizontal axis (or mirror centre line) of the row of magnets so that the 1st and 2nd coil assemblies are exact and opposite and equidistant from each other. This
25 arrangement allow motion in the desired direction

PCT Publication WO 2004/047258 A2 also describes a linear motor with a center row of magnets between two coil assemblies. However, the two coil assemblies are offset from each other, so as to possess an array pitch difference. In order to actuate and move the magnets, the
30 coils have to be energized in a complicated manner, and in the proper sequence. A customized controller and drive system need to specially designed for this purpose.

Another PCT Publication WO 93/15547 also describes a similar linear motor with two coil assemblies and one row of magnets, where the two coil assemblies are also offset from each
35 other, such that the emf of the phase of one coil assembly is substantially 90 electrical degrees apart from the emf of the phase of the other coil assembly.

The inventive device, as shown in Fig 4, consists of two coil assemblies which are geometrically symmetrical, so there is no offset between the 1st coil assembly and the 2nd coil assembly. The coils are also energized in the same manner for the 1st coil assembly and the 2nd coil assembly. For example, coils 11 and coils 12 have currents flowing inwards or in a positive direction, while coils 13 and coils 14 have a current direction flowing outwards, in a negative direction. Unlike PCT Publications WO 2004/047258 A2 and WO 93/15547, the invention allows use of conventional servo control amplifiers that work with all three phase brushless servo motors.

A performance comparison was made between linear motors using the high force linear motor system of this invention versus a conventional linear motor. The performances of the linear motor of the prior art of Fig 1 and the performances of the high force linear motor system of this invention as illustrated in Fig 2 is shown in the Table below.

Motor Type	Coil resistance (ohm)	Force constant (N/A)	Motor constant (N/SqRt(W))	Moving mass (Kg)	Force constant/Mass Ratio
Conventional iron core linear motor (Fig 1 Prior Art)	3.8	25.2	12.9	0.65	38.8
High Force Linear Motor of this Invention (Fig 2)	7.6	45.4	16.5	0.25	181.6

The results showed that the high force linear motor system of this invention gives about 1.8 times the amount of force compared to the conventional linear motor of the prior art, with a force constant of 45.4 N/A with this invention compared to 25.2 N/A with the conventional linear motor. The inventive high force linear motor also has a much higher motor constant of 16.5 N/SqRt(W), which is a measure of the efficiency of the motor. The moving mass of the inventive high force linear motor is also much smaller, thereby yielding a high force constant/mass ratio of 181.6 compared to 38.8 for the conventional linear motor of the prior art. This allows us to achieve higher acceleration and performance with the invention.

Fig 5 shows the application of the improved high force linear motor of this invention in an XY table, such as for wire bonding application. The load or work piece is mounted on XY table 115, which are typically guided by cross roller bearings, which give high stiffness. The

X direction of motion is driven by the X axis high force linear motor 116, while the Y direction of motion is driven by the Y axis high force linear motor 117.

A person skilled in the art will observe that the 2 motors are decoupled. "Decoupling" means separating two motors in a configuration that will enable both motors to work simultaneously and yet the whole weight of one motor is not carried or supported by another motor. Decoupling effectively does not reduce the number of motors. It is merely a clever way of arranging the motors and the bearings that guide the motion. Instead of mounting an entire motor onto the moving carriage of another motor, which will mean that the entire weight has to be supported, the effect of decoupling motors means that only part of the weight of the motor is carried, while the other part is mounted onto a stationary support. In Fig 5, the coils of both the X high force linear motor and the Y high force linear motor are fixed, and only the magnet support structures are being moved.

Fig 6 shows a plan view of the X axis improved high force linear motor. The motor comprises the coil 118 which has a 1st and a 2nd portion according to the invention although the 2nd section is hidden in this view. Coil 118 is fixed to the base, while the moving part is the magnet support structure 119, which can be made of Aluminum, for example.

The maximum stroke or travel of the X axis,

$$S_x = M_x - C_x$$

where

S_x is the maximum stroke of the X axis

C_x is the length of the X coil assembly in the direction of travel

M_x is the distance between the edges of the magnets for the X axis high force linear motor in the direction of X travel

Fig 7 shows a plan view of the Y axis high force linear motor. The motor comprises the coil assembly 120 which has a 1st and a 2nd portion according to this invention although the 2nd section is hidden in this view. Coil assembly 120 is fixed to the base, while the moving part is the magnet support structure 121.

It may be observed that the coil assembly 120 is substantially wider than the magnet support structure, to enable the motor to be decoupled from the X axis high force linear motor. The following relationships may be established for the Y axis high force linear motor,

$$S_y = M_y - C_y$$

and

$$5 \quad C_{yx} - M_{yx} > S_x$$

where

S_y is the maximum stroke of the Y axis

C_y is the length of the Y coil assembly in the direction of Y travel

10 M_y is the distance between the edges of the magnets for the Y axis high force linear motor in the direction of Y travel

C_y is the length of the Y coil assembly in the direction of X travel

M_{yx} is the distance between the edges of the magnets for the Y axis high force linear motor in the direction of X travel

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It should be also be noted that the desired travel in the X and Y directions can be less than S_x and S_y , the maximum travels allowed.

Fig 8 shows another embodiment of a XY table, using 2 other motors according to the invention. The load or work piece is mounted on XY table 122, which are typically guided by cross roller bearings, which give high stiffness. The X direction of motion is driven by the X axis linear motor 123, while the Y direction of motion is driven by the Y axis linear motor 124.

25 Unlike the previous embodiment, the coil assemblies of the motors in this embodiment are longer than the magnet structure of the same motors in the direction of motion or driving force.

Fig 9 shows a plan view of the X axis linear motor. The motor comprises the coil assembly 125 which has a top and a bottom portion according to the invention although the top portion is hidden in this view, so that the magnet support structure 126 can be exposed. Coil assembly 125 is fixed to the base, while the moving part is the magnet support structure 126.

The maximum stroke or travel of the X axis,

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$$S_x = C_x - M_x$$

where

Sx is the maximum stroke of the X axis

Cx is the length of the X coil assembly in the direction of travel

Mx is the distance between the edges of the magnets for the X motor in the direction of X travel

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Fig 10 shows a plan view of the Y axis linear motor. The motor comprises the coil assembly 127 which has a top and a bottom portion according to this invention although the top portion is hidden in this view, so that the magnet support structure 128 can be exposed. Coil assembly 127 is fixed to the base, while the moving part is the magnet support structure 128.

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The following relationships may be established for the Y axis motor,

$$S_y = C_y - M_y$$

15 and

$$C_{yx} - M_{yx} > S_x$$

where

20 Sy is the maximum stroke of the Y axis

Cy is the length of the Y coil assembly in the direction of Y travel

My is the distance between the edges of the magnets for the Y motor in the direction of Y travel

Cyx is the length of the Y coil assembly in the direction of X travel

25 Myx is the distance between the edges of the magnets for the Y motor in the direction of X travel

It should be also be noted that the desired travel in the X and Y directions can be less than Sx and Sy, the maximum travels allowed.

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While the magnets shown in all the magnet support structure are aligned with their lengths perpendicular to the direction of motion, those skilled in the art will observe that it is possible to skew the magnets at an angle, to reduce cogging force. Fig 11 shows a magnet support structure 129 where the magnets 130 are skewed at an angle.

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While the high force linear motors described above are configured to drive the X and Y axis of a XY table, they can also be used independently as a single motor axis.

For example, Fig 6 shows a plan view of a single axis linear motor where the moving magnet track is longer than the linear motor coil assembly, while Fig 9 shows another single axis linear motor where the linear motor coil assembly is longer than the moving magnet track.

- 5 The single axis high force linear motor system shown in Fig 6 has the following relationships:

$$S_x = M_x - C_x,$$

- 10 while the single axis high force linear motor system shown in Fig 9 has the following relationships:

$$S_x = C_x - M_x,$$

where

- 15 S_x is the maximum stroke of the linear motor system in the direction of travel or driving force
 C_x is the length of the coil assembly in the direction of travel or driving force
 M_x is the distance between the edges of the magnets for the linear motor in the direction of travel or driving force
- 20 Fig 7 and Fig 10 shows two other single axis linear motor assemblies. These two linear motor assemblies allow motion two directions, one in the direction of the driving force, and another in the direction perpendicular to its driving force.

- 25 The single axis high force linear motor system shown in Fig 7 has the following relationships:

$$S_y = M_y - C_y$$

$$C_{yx} - M_{yx} > S_x$$

- 30 while the single axis high force linear motor system shown in Fig 10 has the following relationships:

$$S_y = C_y - M_y$$

$$C_{yx} - M_{yx} > S_x$$

- 35 where

S_y is the maximum stroke of the linear motor system in the direction of travel or driving force
 C_y is the length of the coil assembly in the direction of travel or driving force

My is the distance between the edges of the magnets for the linear motor in the direction of travel or driving force

Sx is the maximum stroke of the linear motor system in the direction perpendicular to its driving force.

Cyx is the length of the coil assembly in the direction perpendicular to its driving force.

Myx is the distance between the edges of the magnets in the direction perpendicular to its driving force.

10 Advantageous Effects Of The Invention

This invention allows us to have an iron core motor without any magnetic back iron for the magnets. With the elimination of the magnet back iron, many more types of materials can be explored for holding the magnets, since these materials are no longer limited to having high magnetic permeability. Aluminum or other light and stiff non-metallic materials, such as fiber reinforced resin or plastic materials can be used. This results in the reduction of moving mass. Hence, higher accelerations can be achieved when moving the useful load, which is critical in a wire bonding application.

20 The invention allows us to produce higher force with a linear motor. With a corresponding reduction in the moving mass, the performance of the motor is greatly enhanced.

In the case of the conventional iron core type of linear motor, there is a large attraction force between the coil and the magnets. With this inventive arrangement, there is no net attraction force on the magnets. This allows us to use smaller linear bearings in the system design, and simplifies the assembly process. The elimination of the attraction force also improves the motor system performance, since the static friction is greatly reduced. Response time during the start of motion and the end of travel settling times will be shortened.

30 With this inventive arrangement, unlike the conventional moving coil design, a moving cable is no longer necessary, since the coils are stationary. This improves the reliability of the motor, since the motor cables will be fixed and there will not be any constant bending of the cables. A moving cable also creates a drag force, or opposing force when it is bent during motion. With this invention, this problem is eliminated completely.

35 With the coil mounted to a coil back iron, the heat generated by the coils can be removed easily from the motor. Additional heat sinks can be added, or cooling fluids can be used to further improve the cooling of the coils, thereby increasing the continuous current and

continuous force of the motor. By moving only the magnets, the heat generated by the coils will not be directly transferred to the load, which will affect the accuracy of the motion system.

- 5 The invention also allows decoupling of the motors, so that the moving mass only involves the moving magnet structures of the 2 motors, and not the entire mass of any motor.

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Claims:

1. An improved high force linear motor system comprising a linear motor with a first coil assembly, a second coil assembly and a plurality of magnets forming a row of magnets, wherein

the row of magnets is positioned between the first coil assembly and the second coil assembly,

- the first coil assembly is aligned along the length of the row of magnets, and the second coil assembly is aligned along the length of the row of magnets,

- so each coil assembly is geometrically and exactly opposite one another and equidistant from one another about a center mirror line formed by the horizontal axis of the row of magnets; and

the force of attraction between the row of magnet and the first coil assembly being completely balanced by the force of attraction between the row of magnets and the second coil assembly

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2. An improved high force linear motor system as claimed in Claim 1 wherein the magnets in the row of magnets are movable along the length of the center mirror line formed by the horizontal axis of the row of magnets.

3. An improved high force linear motor system as claimed in Claim 1 wherein the magnets in the row of magnets are each held by a magnet support structure, which is non magnetic.

4. An improved high force linear motor system as claimed in Claim 1 wherein the row of magnets are held by a magnet support structure made from Aluminum.

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5. An improved high force linear motor as claimed in Claim 1 wherein the row of magnets are held by a magnet support structure made from other light but stiff non-metallic materials.

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6. An improved high force linear motor system as claimed in Claim 1 wherein the row of magnets are held by a magnet support structure made from fiber reinforced resin.

7. An improved high force linear motor as claimed in Claim 1 wherein the row of magnets are held by a magnet support structure made from plastic.
8. An improved high force linear motor as claimed in Claim 1 wherein the magnets are skewed at an angle, to reduce cogging force.
9. An improved high force linear motor system in a XY table, comprising a X axis high force linear motor and a Y axis high force linear motor, the high force linear motor of each axis having a first coil assembly, a second coil assembly and a plurality of magnets forming a row of magnets, wherein
- the row of magnets is positioned between the first coil assembly and the second coil assembly;
- the first coil assembly is aligned along the length of the row of magnets, and the second coil assembly is aligned along the length of the row of magnets;
- so each coil assembly is geometrically and exactly opposite one another and equidistant from one another about a center mirror line formed by the horizontal axis of the row of magnets; and
- the force of attraction between the row of magnets and the first coil assembly being completely balanced by the force of attraction between the row of magnet and the second coil assembly
10. An improved high force linear motor system in a XY table as claimed in Claim 9 wherein the row of magnets are not mounted onto any back iron, but are held by a magnet support structure.
11. An improved high force linear motor system in a XY table as claimed in Claim 9 or Claim 10, wherein the row of magnets are held by a magnet support structure, which is non magnetic.
12. An improved high force linear motor system in a XY table as claimed in Claim 9 or Claim 10, wherein the row of magnets are held by a magnet support structure made from Aluminum.

13. An improved high force linear motor system in a XY table as claimed in Claim 9 or Claim 10, wherein the row of magnets are held by a magnet support structure made from other light but stiff non-metallic materials.
- 5 14. An improved high force linear motor system in a XY table as claimed in Claim 9 or Claim 10, wherein the row of magnets are held by a magnet support structure made from fiber reinforced resin.
- 10 15. An improved high force linear motor system in a XY table as claimed in Claim 9 or Claim 10, wherein the row of magnets are held by a magnet support structure made from plastic.
- 15 16. An XY table for positioning a load, using an X axis high force linear motor and a Y axis high force linear motor as claimed in Claim 9 having the following relationships:
- $S_x = M_x - C_x$
 $S_y = M_y - C_y$
 $C_{yx} - M_{yx} > S_x$
- 20 where
 S_x is the maximum stroke of the X axis
 C_x is the length of the X coil in the direction of travel
 M_x is the distance between the edges of the magnets for the X motor in the direction of X travel
- 25 S_y is the maximum stroke of the Y axis
 C_y is the length of the Y coil in the direction of Y travel
 M_y is the distance between the edges of the magnets for the Y motor in the direction of Y travel
- 30 C_{yx} is the length of the Y coil in the direction of X travel
 M_{yx} is the distance between the edges of the magnets for the Y motor in the direction of X travel
- 35 17. An XY table for positioning a load, using an X motor and a Y motor as claimed in Claim 9 having the following relationships:
- $S_x = C_x - M_x$
 $S_y = C_y - M_y$

$$C_{yx} - M_{yx} > S_x$$

where

S_x is the maximum stroke of the X axis

5 C_x is the length of the X coil in the direction of travel

M_x is the distance between the edges of the magnets for the X motor in the direction of X travel

S_y is the maximum stroke of the Y axis

10 C_y is the length of the Y coil in the direction of Y travel

M_y is the distance between the edges of the magnets for the Y motor in the direction of Y travel

C_{yx} is the length of the Y coil in the direction of X travel

15 M_{yx} is the distance between the edges of the magnets for the Y motor in the direction of X travel

18. An improved, single axis high force linear motor system as claimed in Claim 1 having the following relationships:

20 $S_x = M_x - C_x$, where M_x is longer than C_x

OR

$S_x = C_x - M_x$, where C_x is longer than M_x

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where

S_x is the maximum stroke of the linear motor system in the direction of travel or driving force

C_x is the length of the coil assembly in the direction of travel or driving force

30 M_x is the distance between the edges of the magnets for the linear motor in the direction of travel or driving force

19. An improved, single axis high force linear motor system as claimed in Claim 1 having the following relationships:

35 $S_y = M_y - C_y$, where S_y is longer than C_y

$$C_{yx} - M_{yx} > S_x$$

Or

$S_y = C_y - M_y$, where C_y is longer than M_y

$C_{yx} - M_{yx} > S_x$

where

5 S_y is the maximum stroke of the linear motor system in the direction of travel or driving force

C_y is the length of the coil assembly in the direction of travel or driving force

M_y is the distance between the edges of the magnets for the linear motor in the direction of travel or driving force

10 S_x is the maximum stroke of the linear motor system in the direction perpendicular to its driving force.

C_{yx} is the length of the coil assembly in the direction perpendicular to its driving force.

M_{yx} is the distance between the edges of the magnets in the direction perpendicular to its driving force.

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