

RE-CONFIGURABLE LINEAR MOTOR COIL ASSEMBLY MODULE

FIELD OF INVENTION

This invention relates to linear motors in which the moving coil assemblies are re-configurable and translates to linear thrust force when the coil assembly is incorporated into the magnet assembly. In particular, this invention relates to a moving coil assembly with modular cascading ability and the method for coil setting.

BACKGROUND

The invention relates generally to linear motors utilizing multiple coils connected in succession to increase coil assembly length and hence increases the motor rating.

Ironless linear motors comprises of dual row of periodic alternating permanent magnets embedded onto two parallel ferromagnetic plates with base plate to form the 'U' channel magnet track and the poly phase coil assembly inserted into the channel, shown in Figure 2. When the coil is energized, a linear force is produced which will move either the magnet track or the coil assembly. Depending on the design of the mechanical constraint, the magnetic track can be stationary and the coil moving or vice-versa. Several early prior arts relating to linear motors of this nature include US Patent No. 4151447, issued to von der Heide, which describes the construction and US Patent No. 34647, issued to Beakley, which describes an alternative coil construction with overlapping coil and use of heat sinking medium such as epoxy and aluminum plate to dissipate heat.

In order to increase the motor rating, manufacturers will lengthen the coil length by laying multiple coils side by side and encapsulate it into one single coil assembly module. However, this will become a problem, as there can be many different coil assembly module sizes that need to be produced and stocked. This is a problem with the current trend of high mix low volume production.

Another problem with single coil assembly module linear motor is that if there is any irreversible coil damage or problem due to unintentional impact, usually at the edge or coil burnt due to overloading, replacement has to be made to the entire coil assembly module even if just a localized damaged to a small portion of the coil.

In addition, upgrading of motor rating and parts modification such as cable length extension cannot be made to existing motor and needs to be replaced with a new linear motor of specific specifications, therefore, introducing wastage.

The more commonly used method to allow replacement of cable length for example is to provide connecting cables at one end of the coil assembly as seen in US Patent No. 7170204, such that cable can be readily extended using mating connectors. Connectors can also be embedded onto one end of the coil assembly, eliminating the presence of cables dangling out from the coil assembly.

For long travel applications, it is often more cost effective to have magnet track as the moving member and stationary coil assembly. Prior arts relating to linear motors utilizing moving magnet assembly and stationery coil assembly such as US Patent No. 7345384, issued to Shusaku Yoshida which details the construction of such form of linear motors with use of refrigerant for high cooling capability. However, for long travel applications, this will not be feasible in non-modular linear motor coil for long travel because energizing the entire coil is inefficient and incur significant losses with only a small portion of energized coil within the moving magnet assembly contributing to the output force.

It is therefore many advantages associated with a fully re-configurable coil assembly module design. US Patent No. 7312540 issued to Yasuhiro Miyamoto describes a form of coil assembly module connectivity and requires subsequent coil assembly module to be spaced apart at equal intervals of 120 or 240 electrical degrees. However, this will require each coil assembly module motor phase (U, V, W) to be connected differently to the terminals of the end connectors. As a result, each coil assembly module is slightly different from each other and hence coil assembly modules with the same coil connection cannot be cascaded together and the gap between coil assembly modules increases the coil assembly length further. In addition, multiple coil assembly modules are held in place only on the contact surface of the connector butt, making it weak structurally.

DESCRIPTION OF INVENTION

To solve the problem, the present invention comprises of a plurality of coil assembly module units and inserted into a magnet track for linear motor operation. Each coil assembly module in FIG. 1 features electrical connectors at both ends to electrically connect the plurality of coil assembly module units to achieve re-configurable capability. The connectors are used for electrically linking up all the coil assembly modules windings to become parallel or series

connected to the motor voltage bus. In addition, the connectors serve to connect respective temperature sensors or thermostats found in each motor coil assembly module together to offer thermo-cutoff protection to all cascaded coil assembly modules. Connector at one end can then be connected with the matching connector terminal to the flexible motor cable.

In addition, each coil assembly module in FIG. 1 features assembly grooves to facilitate multiple coil assembly modules to be seamlessly cascaded. Hence, to facilitate the space required for the grooves or edges for modular connection, the spacing between the individual coils is space at 60° electrical degrees interval, as shown in FIG. 2. In this manner, the edge at both ends will have sufficient space of 30° electrical degrees for the adjacent coil assembly module to overlap to form the groove joint. The larger spacing interval has the advantage of allowing sufficient tolerance control such that when multiple units of coil assembly module are cascaded, any offset displacement is kept to minimal and non-cumulative. In addition, the larger spacing interval will provide improved insulation between individual coils in 220V high voltage applications.

More specifically in FIG. 2, the concentrate-wound coils are disposed in a row at equal interval of 120° electrical degrees, forming two sets of Phase A, Phase B, Phase C coils. The winding direction of the first set is such that A-phased coil is wound in the clockwise direction, B-phased coil is wound in the counter-clockwise direction, C-phased coil is wound in the clockwise direction. The winding direction of the second set is such that A-phased coil is wound in the counter-clockwise direction, B-phased coil is wound in the clockwise direction, C-phased coil is wound in the counter-clockwise direction. A total of six coils are required to form one coil assembly module of the re-configurable linear motor.

In each coil assembly module, the connectors are embedded and sealed at both ends during the manufacturing process. Prior to sealing, the end pins of each connector are soldered onto both ends of a PCB board (FIG. 3A and 3B). This PCB board is designed to connect each individual motor phase lead wires as a three-phase Star connection. The person skilled in the art can have the PCB can be designed to achieve Delta connection. The PCB also includes temperature sensors or thermostats to be connected for thermo-cutoff protection.

The coils are then encapsulate-molded using thermally conductive epoxy material and pressed into shape or using injection-molding process. The final process involves embedding the connectors PCB to the molded coil and sealed with a coil assembly cap. Each coil assembly module is capable of running singularly, or re-configured as multiple units of coil assembly modules by using the same coil assembly module for cascading.

In a similar fashion, it is possible to have multiple identical coil assembly module cascaded in succession to become a stationery member and a moving magnet track. In this manner, only the segments of the coil assembly modules that are within the magnetic influence are energized. By using appropriate switching control to trigger the respective coil assembly module segment of the entire coil assembly as the magnet assembly transverse along the motion stroke, the coil assembly can allow for a higher input current than its rating without causing over-heating. This is because there will be a long cooling period when the coil is not energized whenever the moving magnet assembly is not in close proximity.

As described above, the invention brings about the following advantages:

1. Eliminate multiple coil assembly module production and stock because only one standard coil assembly module is required for cascading multiple units of coil assembly modules together to increase the force output.
2. Fully modular and re-configurable coil assembly module allows partial replacement of damaged coil assembly modules and replacement of cables and parts, reducing wastage.
3. Cost-effective and feasible to have long travel moving magnet, stationery coil configuration by incorporating appropriate switching control to trigger the respective coil assembly module segment of the entire coil assembly as the magnet assembly transverse along the motion stroke.
4. Improved insulation between individual coils for high voltage applications.
5. Ease of manufacturing process since only one standard coil assembly module is required for production.

BRIEF DESCRIPTIONS OF THE DRAWINGS

FIG. 1 is the perspective view of the re-configurable linear motor coil assembly module of the first embodiment of the invention and illustrates the features necessary to achieve full modular capability.

FIG. 2 shows the coil layout view of one coil assembly module of the invention and describes the coil spacing and edge spacing in electrical degrees.

FIG. 3 shows the doubled layer PCB artwork that details the coil winding connections with the connector terminals at the edges of the board. **FIG. 3A** shows the top layer artwork routing. **FIG. 3B** shows the bottom layer artwork routing.

FIG. 4 is the perspective view of the ironless linear motor design comprises of a coil assembly unit and magnet track.

FIG. 5 shows the perspective view of the re-configurable linear motor in the second embodiment.

First Embodiment:

FIG. 1 is the perspective view of the of the re-configurable linear motor coil assembly module of the first embodiment of the invention and illustrates the features necessary to achieve full modular capability. A single coil assembly module is designated as **1**. In the drawing, each coil assembly module **1** in **FIG. 1** features electrical connectors **2** at both ends to electrically connect the plurality of coil assembly module units to achieve re-configurable capability. Connectors **2** are used for electrically linking up all the coil assembly modules windings to become parallel or series connected to the motor voltage bus. In addition, Connectors **2** also serve to connect respective temperature sensors or thermostats found internally in each coil assembly module together to offer thermo-cutoff protection to all cascaded modules **1**. Connector **2** at one end can then be connected with the matching connector terminal to the flexible motor cable. To further secure the connectors when coil assembly modules are cascaded in place, locking mechanism **4** is used for all cascading joints. Locking mechanism **4** will prevent the series of interlocking coil assembly modules **1** to disengage during motion and mechanical stress.

Each coil assembly module **1** in **FIG. 1** features assembly grooves **3** to facilitate identical coil assembly modules **1** to be seamlessly cascaded. Hence, to facilitate the space required for the assembly groove **3** or edges for modular connection, the spacing between the individual coils (**7A, 7B, 7C, 8A, 8B, 8C**) is spaced at 60° electrical degrees interval, as shown in **FIG. 2**. In this manner, the groove edge **3** at both ends will have sufficient space of 30° electrical degrees for the adjacent coil assembly module **1** to overlap to form the groove joint. The larger spacing interval has the advantage of allowing sufficient tolerance control such that when multiple units of coil assembly modules are cascaded, any offset displacement is kept to minimal and non-cumulative. The groove edge **3** serves to strengthen the mechanical structure by having the contact surface along the entire edges of the coil assembly module.

In detail, the concentrate-wound coils (**7A, 7B, 7C, 8A, 8B, 8C**) in FIG. 2 are disposed in a row at equal interval of 120° electrical degrees, forming two sets of Phase A, Phase B, Phase C coils. The individual coils will carry the respective current in terms of electrical degree as:

Coil 7A: $I \sin(\theta)$

Coil 7B: $I \sin(\theta + 120^\circ) = -I \sin(\theta + 300^\circ)$

Coil 7C: $I \sin(\theta + 240^\circ) = I \sin(\theta + 600^\circ)$

Coil 8A: $I \sin(\theta) = -I \sin(\theta + 900^\circ)$

Coil 8B: $I \sin(\theta + 120^\circ) = I \sin(\theta + 1200^\circ)$

Coil 8C: $I \sin(\theta + 240^\circ) = -I \sin(\theta + 1500^\circ)$

The winding direction of the first set (**7A, 7B, 7C**) is such that A-phased coil **7A** is wound in the clockwise direction, B-phased coil **7B** is wound in the counter-clockwise direction, C-phased coil **7C** is wound in the clockwise direction. The winding direction of the second set (**8A, 8B, 8C**) is such that A-phased coil **8A** is wound in the counter-clockwise direction, B-phased coil **8B** is wound in the clockwise direction, C-phased coil **8C** is wound in the counter-clockwise direction. The individual set of coil lead wires are reinforced with conducting pins **9, 10, 11, 12, 13, 14** for connections. A total of six coils are required to form one coil assembly module **1** of the re-configurable linear motor.

More specifically, a PCB board **9** in FIG. 3 is designed to connect each individual motor phase lead wires as a three-phase Star configuration. The PCB board **9** has a doubled-layer artwork and the front and back routing artwork is shown in FIG. 3A and FIG. 3B respectively. Pin **9** of FIG. 2 is soldered to solder pad **18** of FIG. 3, Pin **10** of FIG. 2 is soldered to solder pad **19** of FIG. 3, Pin **11** of FIG. 2 is soldered to solder pad **20** of FIG. 3, Pin **12** of FIG. 2 is soldered to solder pad **21** of FIG. 3, Pin **13** of FIG. 2 is soldered to solder pad **22** of FIG. 3, Pin **14** of FIG. 2 is soldered to solder pad **23** of FIG. 3. Terminals **16** and **17** are meant for the pins of the connectors **2** to be inserted. Soldering pad **24** will be soldered with the internal thermal sensor or thermostat inside the coil assembly module **1**. The person skilled in the art can have the PCB can be designed to achieve Delta connection.

The coils module **1** is then encapsulate-molded using thermally conductive epoxy material and pressed into shape or using injection-molding process. The final process involves sealing the molded coil **1** with a coil assembly cap **5** as illustrated in FIG. 1. The coil assembly cap **5** serves as a mounting medium in which external mechanical assembly will be attached.

Attachment is possible using a series of tap holes 6, spaced evenly along the length of the coil assembly cap 5. Tap holes 6 can also be made on the side profile of coil assembly cap 5 for vertical mounting as an option. The coil assembly module 1 is inserted into the magnet track, shown in FIG. 4. The magnet track comprises of dual row of periodic alternating permanent magnets, denoted as 30 and 31. The array of magnets is embedded onto two parallel ferromagnetic plates 26 and 27 with base plate 28 to form the 'U' channel magnet track. Mounting holes 32 are located on both sides of the ferromagnetic plates 26 and 27 and at the bottom of the base plate 28.

Second Embodiment:

FIG. 5 shows the perspective view of the re-configurable linear motor in the second embodiment. The magnet track serves as the moving member and coil modular assembly 1 is made stationery, particularly for long travel applications. The present invention differs from the prior art discussed such that a single motor coil assembly spanning the entire length of motion travel becomes infeasible. The present invention combines the fully re-configurable coil assembly module 1 and the appropriate switching controls to trigger the respective coil assembly module segment. With current control switching, the individual coil assembly 1 will not be energized continuously, thus will allow for a higher input current than its rating without causing over-heating which in turn capable of producing a higher output force. There is a long cooling period when the coil is not energized whenever the moving magnet assembly is not in close proximity.

In a similar fashion to the First Embodiment, the single coil assembly module is designated as 1. In the drawing, each coil assembly module 1 in FIG. 5 features (A) electrical connectors 2 at both ends to electrically connect the plurality of modular coil assembly units to achieve re-configurable capability. Connectors 2 are used for electrically linking up all the coil assembly modules windings to become parallel or series connected to the motor voltage bus. In addition, Connectors 2 also serve to connect respective temperature sensors or thermostats found internally in each coil assembly module together to offer thermo-cutoff protection to all the cascaded coil assembly modules 1. Connector 2 at one end can then be connected with the matching connector terminal to the flexible motor cable. To further secure the connectors when coil assembly modules are cascaded in place, locking mechanism 4 is used for all cascading joints. Locking mechanism 4 will prevent the series of interlocking coil assembly modules 1 to disengage during motion and mechanical stress.

Each coil assembly module 1 in FIG. 5 features assembly grooves 3 to facilitate identical coil assembly modules 1 to be seamlessly cascaded. Hence, to facilitate the space required for the assembly groove 3 or edges for modular connection, the spacing between the individual coils (7A, 7B, 7C, 8A, 8B, 8C) is spaced at 60° electrical degrees interval, as shown in FIG. 2. In this manner, the groove edge 3 at both ends will have sufficient space of 30° electrical degrees for the adjacent coil assembly module 1 to overlap to form the groove joint. The larger spacing interval has the advantage of allowing sufficient tolerance control such that when multiple coil assembly modules are cascaded, any offset displacement is kept to minimal and non-cumulative. The groove edge 3 serves to strengthen the mechanical structure by having the contact surface along the entire edges of the coil assembly module.

The coils module 1 in FIG. 5 is then encapsulate-molded using thermally conductive epoxy material and pressed into shape or using injection-molding process. The final process involves sealing the molded coil 1 with a coil assembly cap 5 as illustrated in FIG. 1. The coil assembly cap 5 serves as a mounting medium in which external mechanical assembly will be attached. Attachment is possible using a series of tap holes 6, spaced evenly along the length of the coil assembly cap 5. Tap holes 6 can also be made on the side profile of coil assembly cap 5 for vertical mounting as an option. The coil assembly module 1 is inserted into the magnet track, shown in FIG. 5. The magnet track comprises of dual row of periodic alternating permanent magnets, denoted as 30 and 31. The array of magnets is embedded onto two parallel ferromagnetic plates 26 and 27 with base plate 28 to form the 'U' channel magnet track. Mounting holes 32 are located on both sides of the ferromagnetic plates 26 and 27 and at the bottom of the base plate 28. In this case, the magnet track module can be cascaded to increase the output force. In a similar fashion to First Embodiment, only a single coil assembly module 1 needs to be replicated and re-configured to achieve longer stroke.

Third Embodiment:

The Third embodiment is a variation of First and Second Embodiment such that the person skilled in the art will note that two extreme edge clearances are half of the coil spacing. This edge spacing can vary without affecting the replicate capability while maintaining the individual coil coils (7A, 7B, 7C, 8A, 8B, 8C) phase displacement of 120° electrical degree. With the Third Embodiment, similar features to those of First and Second Embodiment are present and will not be described further.

In addition, the present invention allows for air or liquid cooling to be incorporated into the coil capping **5**. Cascading of multiple coil assembly modules **1** with this feature can be brought about using appropriate sealant and cooling duct connectors.

CLAIMS

What is claimed is:

1. A linear motor coil assembly module including:
connection means to electrically connect coil windings of the module to coil windings of an adjacent coil assembly module; and
connection means to facilitate cascading connection of modules in the coil assembly such that adjacent modules are in contact along an entire edge of each module.
2. A linear motor coil assembly module as claimed in claim 1 wherein the connection means for electrically connecting coil windings of the module to coil windings of an adjacent module includes mateable electrical connectors disposed at respective ends of each module.
3. A linear motor coil assembly module as claimed in claim 2 wherein the connection means to facilitate cascading connection of modules includes tongue and groove connectors disposed at respective ends of the module.
4. A linear motor coil assembly module as claimed in any preceding claim wherein the assembly is a re-configurable multi-phase coil assembly.
5. A linear motor coil assembly module as claimed in any preceding claim wherein cascading coil assembly modules use the same motor commutation to produce linear thrust force.
6. A linear motor coil assembly module as claimed in any preceding claim wherein each coil assembly module includes two sets of three-phase coils which are inversely spaced with an individual set of coil lead wires.
7. A linear motor coil assembly module as claimed in claim 6 wherein the coil lead wires are reinforced with conducting pins for printed circuit board (PCB) connection.

8. A linear motor coil assembly module as claimed in any preceding claim wherein the mateable electrical connectors are operable to electrically connect the one or more individual coil assembly modules to the motor voltage bus in a parallel or series configuration.
9. A linear motor coil assembly module as claimed in claim 7 wherein the mateable electrical connectors are further operable to electrically connect one or more electronic components of each coil assembly module.
10. A linear motor coil assembly module as claimed in claim 8 wherein the electronic components are selected from the following: temperature sensors; thermostats.
11. A linear motor coil assembly module as claimed in any preceding claim wherein each coil assembly module includes cooling means.
12. A linear motor coil assembly module as claimed in any preceding claim further including locking means for locking the cascading connection of modules in the coil assembly.
13. A linear motor coil assembly module as claimed in any preceding claim wherein a phase displacement between coil windings in the module is 120 electrical degrees.
14. A linear motor coil assembly comprising one or more modules as claimed in any preceding claim.
15. A linear motor coil assembly as claimed in claim 13 wherein the one or more modules are stationary and a magnet track of the assembly is a moving member.
16. A method of coil setting in a linear motor coil assembly, the method including:
 - disposing coil assembly modules in a row at equal intervals of 120 electrical degrees, each coil assembly module having two sets of three phase coils; and
 - spacing the individual coils of each module at an interval of 60 electrical degrees.