

IMPROVED COIL DESIGN FOR THREE PHASE LINEAR MOTORS AND METHOD OF FORMING COIL

5 FIELD OF THE INVENTION

This invention relates to an improved integrated coil used in, for example, linear motors. In particular, this invention relates to an integrated coil assembly for a 3 phase linear motor and method for forming the integrated coil.

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DESCRIPTION OF RELATED ART

Existing linear motors typically include wire coils that form magnetic circuits to conduct current and thereby enable such motors to produce a linear force. Generally, the linear
15 force produced is proportional to the current passing through coil windings of the wire coils and magnetic flux density of the magnetic circuits.

As a result of the electrical resistance of such wire coils, the current conducted through the coil windings also generate heat. In some instances, overheating may arise. This
20 is caused by production of a continuous large current output to obtain a sufficiently large linear force to move a heavy load. Efficient heat dissipation is therefore necessary to prevent overheating in such instances.

Another problem associated with existing multi-phase linear motors is the uneven
25 generation of heat. Consequently, the heat generated is also not dissipated evenly.

Reissued U.S. Pat. No. 34,647, issued to Beakley et al on Jul. 26, 1994 and assigned to Trilogy Systems, describe techniques to improve heat dissipation using improved coil designs. This patent describes that the individual coil loop side thickness is
5 approximately the said individual coil loop total width divided by two times the number of phases and wherein at least one individual coil loop forming a pole of a phase overlaps portions of said individual coil loops forming two poles of each other phase.

One side of an individual coil loop is located directly adjacent one side of another
10 individual coil loop of the same phase.

US 2002/0125773 Lim et al describes an integrated coil assembly where coil loops for each multiphase coil are wound before the coil loops of another multi-phase coil are wound. The coil loops of different multi-phase coils are interweaved at two opposing
15 portions. At each of the two opposing portions, coil loops of a subsequent multi-phase coil are larger than coil loops of a preceding multi-phase coil by the thickness of coil windings of the preceding multi-phase coil.

US 2003/0184425 A1 Mori et al describes an individual, single coil with an
20 approximately rectangular ring-like shape is formed by fixture and bent into shapes with tilted sides. The individual coil units are then arranged and piled together to form a coil assembly.

The separate coils in the above prior art are still subject to uneven heat dissipation in
25 certain circumstances. This is because individual coils are formed separately and then placed sequentially offset from adjacent phases to form a coil assembly. Such

placement is difficult to control and, where inaccurate placement occurs, the power output of a multi-phase linear motor using the coil assembly is thus subject to inconsistency and therefore undesirable.

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Therefore, a need clearly exists for a coil assembly for multi-phase linear motors that enables a consistent linear force to be provided for different phases and in which heat can be more effectively dissipated.

10 **PROBLEM TO BE SOLVED BY THE INVENTION**

The coils of the prior art are based on essentially two approaches of coil design and forming of coils.

- 15 The first approach uses individual coil forming and then assembling them together (as described in Re.34,674 Beakley et al and US 2003/0184425 A1 Mori et al). The individual coil design enables all coils to be made of the same size and shape, thereby enabling mass manufacturing to be easy and fast (Re. 34,674 Beakley and 2003/0184425 A1 Mori et al) However, this method has the disadvantage of the coils
20 being subject to uneven heat dissipation in certain circumstances.

- Uneven heat dissipation occurs because the individual coils are formed separately and then placed sequentially offset from adjacent phases to form a coil assembly. Moreover, the placement of the individual coils is difficult to control and, where inaccurate
25 placement occurs, the power output of a multi-phase linear motor using the coil assembly is thus subject to inconsistency and therefore undesirable (US2003/0125773)

The second approach is an integrated coil approach where each coil is wound on a preceding coil (as described in US 2003/0125773 Lim et al). The integrated coil design approach has the advantages of more even heat dissipation and more accurate placement of the coils. However, the design and assembly causes the two opposing portions to be very large. The interwoven coils at these opposing portions significantly increase the height of the coil assembly. The interwoven portions are also not used in generating force as they are not cutting the magnetic flux. Furthermore, the interwoven portions increase the coil volume and coil mass, thereby increasing the force/mass ratio, causing reduction of the efficiency of motor performance.

To overcome the problems associated with the first and second approach to coil design, the inventors proposed a more optimized and balanced approach. In this third approach, all the 3 coils are wound on a same fixture but each coil's winding is completed before moving to the next coil. In essence, the coils are wound individually but systematically on a same fixture that is designed for the multi coil assembly. In this way, a multi-phase coil assembly is produced which has the characteristics of accurate placement of coils, good heat dissipating characteristics and yet without the large interwoven opposing portions that makes the motor large and heavy.

SUMMARY OF THE INVENTION

An object of the invention is to provide an integrated coil assembly having a plurality of three-phase coil assemblies, comprising

a first coil assembly has a large size coil loop 1A, a medium size coil loop 1B and a small size coil loop 1C,

5 a second coil assembly has a small size coil loop 1A', a medium size coil loop 1B' and a large size coil loop 1C',

a third coil assembly has a large size coil loop 2A, a medium size coil loop 2B and a small size coil loop 2C,

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a fourth coil assembly has a small size coil loop 2A', a medium size coil loop 2B' and a large size coil loop 2C',

the first coil assembly, second coil assembly, third coil assembly and fourth
15 coil assembly being placed in series with each other

arranged in a manner such that the large size coil loop 1A, medium size coil loop 1B and small size coil loop 1C of the first coil assembly are connected to the small size coil loop 1A', medium size coil loop 1B' and large size coil loop 1C' of the second coil assembly respectively,
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the small size coil loop 1A', medium size coil loop 1B' and large size coil loop 1C' of the second coil assembly are connected to the large size coil loop 2A, medium size coil loop 2B and the small size coil loop 2C of the third coil assembly respectively and
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the large size coil loop 2A, medium size coil loop 2B and small size coil loop 2C of the third coil assembly are connected to the small size coil loop 2A', medium size coil loop 2B' and large size coil loop 2C' of the fourth coil assembly.

- 5 Advantageously, the coil loops of the integrated coil assembly are neatly arranged next to each other thereby utilizing the space available completely.

Advantageously, the coil loops of the integrated coil assembly are neatly arranged next to each other thereby improving heat dissipation due to even heat
10 distribution within the coil loops.

Advantageously, the coil loops of the integrated coil assembly are neatly arranged next to each other so that the integrated coil assembly is free from empty pockets.
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Advantageously, hall sensors can be inserted in the portion where the coil ends instead of another separate space.

A second object of the invention is to provide a method of manufacturing an
20 integrated coil assembly comprising a plurality of three-phase coil assemblies, using a winding fixture and a wire dispenser, the method of manufacturing comprising the following steps:-

25 making a first winding for a large size coil loop, completing a predetermined number of turns and ending in a first predetermined position;

making a second winding for a medium size coil loop, from the first predetermined position, completing a predetermined number of turns and ending in a second predetermined position;

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making a third winding for a small size coil loop, from the second predetermined position, completing a predetermined number of turns and ending in a third predetermined position, thereby completing the first coil assembly;

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arranging each coil assembly in series such that the large size coil loop, medium size coil loop and small size coil loop of the first coil assembly is connected to the small size coil loop, medium size coil loop and large size coil loop of the second coil assembly respectively,

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the small size coil loop, medium size coil loop and large size coil loop of the second coil assembly is connected to the large size coil loop, medium size coil loop and the small size coil loop of the third coil assembly respectively and

20 the large size coil loop, medium size coil loop and small size coil loop of the third coil assembly is connected to the small size coil loop, medium size coil loop and large size coil loop of the fourth coil assembly.

Advantageously, in the method of manufacturing an integrated coil assembly
25 comprising a plurality of three-phase coil assemblies, the coil loops of each coil

assembly are neatly arranged next to each other thereby utilizing the space available completely.

Advantageously, in the method of manufacturing an integrated coil assembly comprising a plurality of three-phase coil assemblies, the coil loops of each coil assembly are neatly arranged next to each other thereby improving heat dissipation due to even heat distribution within the coil loops.

Advantageously, in the method of manufacturing an integrated coil assembly comprising a plurality of three-phase coil assemblies, the coil loops are neatly arranged next to each other so that the integrated coil assembly is free from empty pockets.

Lastly, it is the third object of the invention to provide a coil winding method to manufacture a coil assembly, using a winding fixture and a wire dispenser, the coil winding method comprising the following sequence:-

making a first winding for a large size coil loop, completing a predetermined number of turns and ending in a first predetermined position;

making a second winding for a medium size coil loop, from the first predetermined position, completing a predetermined number of turns and ending in a second predetermined position;

making a third winding for a small size coil loop, from the second predetermined position, completing a predetermined number of turns and ending in a third predetermined position;

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thereby completing the coil assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

10 For a better understanding of the invention, its advantages, and the objects attained by its use, reference should now be made to the accompanying drawings. The accompanying drawings illustrate one embodiment of the invention and together with the description herein, serve to explain the workings and principles of the invention.

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Fig.1 is an illustration of the coil winding sequence and method of the present invention.

Fig.2 shows the configuration of a coil assembly, showing the individual coil phases.

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Fig.3 is a coil assembly in track.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

25 An embodiment of the present invention will now be described with reference to the accompanying drawings.

To better describe the improved coil assembly, reference is made to Fig 1, a winding sequence of a coil assembly of a 3 phase motor is given herein. For a 3 phase motor, since there are 3 phases, the coil therefore comprises 3 coil loops. The number of coil loops per coil is equivalent to the number of phases. The winding of the coil loops is supported by a winding fixture and a wire dispenser (not shown in Fig 1). The winding fixture and wire dispenser are used in the art and does not form any part of the claims of this invention. However, the winding sequence of forming the coil loops are part of the claimed invention.

The winding sequence begins, for example, at position 10 in Fig 1A to wind a first winding for coil loop 1A. The winding goes in a clockwise direction as indicated by the arrow and completes a predetermined number of turns before ending at position 11 as shown in Fig 1A.

Upon full completion of coil loop 1A, the wire dispenser is positioned at position 11 where it starts winding another predetermined number of windings for the second coil loop 1B. The windings for coil loop 1 B are in the same clockwise direction indicated by the arrow. It should be noted that coil loop 1B is offset relative from coil loop 1A and is typically wound smaller than coil loop 1A to maximize the space usage. The winding ends at position 12 after completing the predetermined number of windings.

Upon full completion of coil loop 1B, the wire dispenser is now positioned at position 12 where it starts winding another predetermined number of windings for the third coil loop 1C. The windings for coil loop 1C are again in the same clockwise direction indicated by the arrow. Coil loop 1C is also offset relative from coil loop 1B and is typically wound

smaller than coil loop 1B to maximize the space usage. The winding ends at position 13 after completing the predetermined number of windings. With winding of coil loops 1A, 1B and 1C, coil assembly is completed.

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Fig 2 shows how the configuration of a coil assembly. The coil is made using a special fixture designed for this purpose. For the coil that is shown, it is made for a 3 phase motor and therefore comprises 3 coil loops. The number of coil loops per coil is equivalent to the number of phases.

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Each coil is made smaller than the preceding coil on the same winding fixture. In this way, for a 3 phase motor, 3 sizes of coils are formed on the assembly. In order that the resistance of the 3 phases are balanced, a corresponding coil assembly is placed in series with the first coil assembly and connected such that coil A has a large coil connected with a small coil. Coil C also has a small coil connected to a large coil whereas coil B has 2 medium size coils. In this way and by proper selection of coil sizes, the resistance of the coils can be made to be equal. The coil assemblies are therefore always used in pairs.

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20 Using this configuration, space at the coil ends is saved, as shown in Fig 2. This is because each subsequent coil is made slightly smaller or bigger than the preceding coil. In this way, the wires at the coil ends are not "meshed together" but are neatly arranged next to one another, thereby utilizing the space available completely. This reduces the need for large space at the coil ends which is commonly found in the coils of prior art.

25 The space saved has thus enabled the hall sensors (which are used for commutating

the motor) to be inserted in the portion where the coil ends are instead of another separate space. The coil assembly is therefore more compact in design.

- 5 By not having interwoven coils at the coil ends, usage of excess wires required to form the coil assembly is reduced. This reduces the mass of the overall coil assembly which in turn improves the efficiency of the motor.

The coil design also improves heat dissipation between each phase such that the heat is
10 evenly distributed from one phase to another. This is because the coil ends of the different phases are already in close contact. They are further compacted tightly with a fixture while forming the coil assembly. The improved heat dissipation characteristics is especially important in the case where the motor is producing a certain amount of force at a fixed position (eg. in the case of a vertical load). In this case, the current in the
15 phases would be higher in two of the phases compared to the third phase. In this situation, a conventional coil design will result in heat built up in the two phases. With this improved coil design, the third coil will share the load of absorbing the heat produced by the other 2 coils (at the coil ends) as well as transferring the heat to its surroundings.

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Moreover, the coil design of the invention improves the accuracy of coil placement. In prior art, individual coils are made and placed into their positions (by overlapping one another or placed in layers with certain offset distance) before they are formed into a coil assembly. In the winding method for the invention, the relatively positioning of the
25 coils (from one phase to another) is determined by the winding fixture which is more

accurate. It must be noted that accurate positioning of the coils is important for consistent performance of the motors.

Fig.3 is a coil assembly in track. The approach used in the coil design and assembly of this invention therefore allows the entire coil assembly to be free from empty pockets at the extreme ends of the coil assembly, as shown in Fig. 3. In Re. 34,674, Fig 3, (Beakley et al.), it is observed that the coil assembly has some empty spaces equivalent to 2 times the desired coil width. In US 2003/0184425 A1, Fig 3 (Mon et al.), it can also be seen that the coil assembly has an empty space/pocket equivalent to one coil width. This is prevalent in the designs; there must be empty spaces for the coil assembly at both ends. For short coil assemblies, this space is rather significant when compared to the overall coil length. This means that the effective working coil portions (coil which transmits current, cuts the magnetic flux and produces force) is reduced. In the coil design of this invention, there is no empty pockets/space throughout the entire coil assembly.

An integrated coil assembly can save space at the coil ends because each subsequent coil is made slightly smaller or bigger than the preceding coil. The wires at the coil ends are not " meshed together " but arranged neatly next to one another, thus utilizing available space completely. This arrangement allows herein hall sensors (used for commutating the motor) to be inserted in the portion where the coil ends instead of another separate space.

While an embodiment of the invention have been described, it should be apparent, however, that various modifications, rearrangements, substitutions alterations and adaptations to those embodiments may occur to persons skilled in the art with the

attainment of some or all of the advantages of the present invention. Accordingly, it should be clearly understood that the present invention is not intended to be limited by the particular features and structures hereinbefore described and depicted in the accompanying drawings. It is therefore intended to cover all such modifications, alterations and adaptations without departing from the scope and spirit of the present invention as defined by the appended claims.

ADVANTAGEOUS EFFECTS OF THE INVENTION

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The coil design under this invention saves space at the coil ends making the coil more compact. Use of excess wires is also reduced thereby reducing costs and reducing mass of the overall coil assembly, and in turn improving the efficiency of the motor.

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The improved coil design also improves heat dissipation and also promotes more even heat distribution.

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The coil design results in more accurate coil placement which is important for consistent performance of motors.

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CLAIMS

1. An integrated coil assembly having a plurality of three-phase coil assemblies, comprising

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a first coil assembly has a large size coil loop 1A, a medium size coil loop 1B and a small size coil loop 1C,

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a second coil assembly has a small size coil loop 1A', a medium size coil loop 1B' and a large size coil loop 1C',

a third coil assembly has a large size coil loop 2A, a medium size coil loop 2B and a small size coil loop 2C,

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a fourth coil assembly has a small size coil loop 2A', a medium size coil loop 2B' and a large size coil loop 2C',

the first coil assembly, second coil assembly, third coil assembly and fourth coil assembly being placed in series with each other

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characterized in that the large size coil loop 1A, medium size coil loop 1B and small size coil loop 1C of the first coil assembly are connected to the small size coil loop 1A', medium size coil loop 1B' and large size coil loop 1C' of the second coil assembly respectively,

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the small size coil loop 1A', medium size coil loop 1B' and large size coil loop 1C' of the second coil assembly are connected to the large size coil loop 2A, medium size coil loop 2B and the small size coil loop 2C of the third coil assembly respectively and

the large size coil loop 2A, medium size coil loop 2B and small size coil loop 2C of the third coil assembly are connected to the small size coil loop 2A', medium size coil loop 2B' and large size coil loop 2C' of the fourth coil assembly.

2. An integrated coil assembly as claimed in Claim 1 wherein the coil loops are neatly arranged next to each other thereby utilizing the space available completely.

3. An integrated coil assembly as claimed in Claim 1 wherein the coil loops are neatly arranged next to each other thereby improving heat dissipation due to even heat distribution within the coil loops.

4. An integrated coil assembly as claimed in Claim 1 wherein the coil loops are neatly arranged next to each other so that the integrated coil assembly is free from empty pockets.

5. An integrated coil assembly as claimed in Claim 1 wherein hall sensors can be inserted in the portion where the coil ends instead of another separate space.

6. A method of manufacturing an integrated coil assembly comprising a plurality of three-phase coil assemblies, as claimed in Claim 1, using a winding fixture and a wire dispenser, the method of manufacturing comprising at least the following

5 steps:-

making a first winding for a large size coil loop, completing a predetermined number of turns and ending in a first predetermined position;

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making a second winding for a medium size coil loop, from the first predetermined position, completing a predetermined number of turns and ending in a second predetermined position;

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making a third winding for a small size coil loop, from the second predetermined position, completing a predetermined number of turns and ending in a third predetermined position, thereby completing the first coil assembly;

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arranging each coil assembly in series such that the large size coil loop, medium size coil loop and small size coil loop of the first coil assembly is connected to the small size coil loop, medium size coil loop and large size coil loop of the second coil assembly respectively,

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the small size coil loop, medium size coil loop and large size coil loop of the second coil assembly is connected to the large size coil loop, medium size coil loop and the small size coil loop of the third coil assembly respectively and

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the large size coil loop, medium size coil loop and small size coil loop of the third coil assembly is connected to the small size coil loop, medium size coil loop and large size coil loop of the fourth coil assembly.

10 7. A method of manufacturing an integrated coil assembly comprising a plurality of three-phase coil assemblies, as claimed in Claim 6 wherein the coil loops are neatly arranged next to each other thereby utilizing the space available completely.

15 8. A method of manufacturing an integrated coil assembly comprising a plurality of three-phase coil assemblies, as claimed in Claim 6 wherein the coil loops are neatly arranged next to each other thereby improving heat dissipation due to even heat distribution within the coil loops.

20 9. A method of manufacturing an integrated coil assembly comprising a plurality of three-phase coil assemblies, as claimed in Claim 6 wherein the coil loops are neatly arranged next to each other so that the integrated coil assembly is free from empty pockets.

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10. A coil winding method used in the manufacture of a coil assembly as claimed in Claim 1, using a winding fixture and a wire dispenser, the coil winding method comprising the following sequence:-

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making a first winding for a large size coil loop, completing a predetermined number of turns and ending in a first predetermined position;

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making a second winding for a medium size coil loop, from the first predetermined position, completing a predetermined number of turns and ending in a second predetermined position;

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making a third winding for a small size coil loop, from the second predetermined position, completing a predetermined number of turns and ending in a third predetermined position;

thereby completing the coil assembly.

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