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(54) LINEAR MOTOR

(71) We, AGENCE NATIONALE DE VALORISATION DE LA RECHERCHE A.N.V.A.R., a French Body Corporate of 13, rue Madeleine Michelis-92200-NEUILLY-sur-SEINE, France, do hereby declare the invention for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

This invention relates to a linear motor. Linear motors are already known comprising an inductor constituted by a magnetic circuit comprising a succession of coils, for the purpose of creating a sliding magnetic field. Generally, these coils are distributed at the rate of one or more coils per pole and per phase and the current supplied is three-phase current.

The power factor and efficiency obtained by means of these motors are fairly average.

It has been discovered that it is possible to increase the power factor and the efficiency of such a motor by considerable proportions owing to a particular supply of single-phase electrical current.

To this end there is provided according to the invention a linear motor comprising an inductor having a succession of coils distributed in three phases at the rate of one or more coils per pole and phase, these coils following each other in the order of the phases in a repeated manner, i.e. in the order first, second, third-phase, then first, second, third-phase and so on, the last pole possibly being incompletely wound, the coils of the same phase being connected in series in order to form together a winding, the three windings corresponding respectively to the three phases are interconnected in the form of a triangle network, one of the windings comprising the first coil of the succession of coils, considered in the direction of movement of the sliding field, being connected to the terminals of a source of

single-phase alternating voltage, and at least one capacitor being connected in parallel with a second of the windings which comprises a second coil following the first coil in the succession of coils. 50

The effect of the arrangement of the capacitor in parallel with the winding comprising the second coil following the first in the direction of movement is to increase the compound of the direct sliding field with respect to the reverse field which is normally present in linear motors on account of end effects. The result is that in the linear motor supplied with single-phase current in accordance with the invention it is possible to considerably increase the power factor and efficiency of a linear motor, with respect to a linear motor supplied with three-phase current. 55 60

The invention will now be further described, by way of example, with reference to the accompanying drawings in which :

Figure 1 is a diagrammatic representation of the windings of a linear motor formed according to the invention; 65 70

Figure 2 is an equivalent electrical diagram of the linear motor in Figure 1, but including a modification;

Figure 3 is a diagram showing variation of the power factor and efficiency as a function of the speed for a linear motor formed according to the invention, and 75

Figure 4 is a diagram showing variation of power produced by a linear motor formed according to the invention, as a function of speed. 80

Figure 1, which diagrammatically represents the windings of a linear motor, shows that this motor comprises a number *n* of poles designated generally by the references A, B...N. Each of these poles comprises three coils or a multiple of three coils, at the rate of one or more coils per pole. The pole A thus comprises three coils 1a, 2a, 3a, the pole B comprises three coils 1b, 90

2b, 3b and so on as far as the pole N which comprises three coils 1n, 2n and 3n. The coils of each phase are connected in series to form a winding. Figure 1 thus shows that the coils 1a, 1b...1n are connected in series to form a first winding 1, the coils 2a, 2b...2n are connected in series to form a second winding 2 and finally the coils 3a, 3b...3n are connected in series to form a third winding 3.

As appears more clearly from Figure 2, the three windings 1, 2 and 3 are interconnected as a triangle network. The first winding 1, i.e. that which comprises the first coil 1a in the succession of coils, considered in the direction of movement of the sliding field, is connected to the terminals 4, 5 of a source of single-phase alternating voltage. More particularly, the vertices 12 and 31 of the triangle formed by the windings 1, 2, 3 arranged respectively between the windings 1 and 2 on the one hand and 3 and 1 on the other hand, are respectively connected to two terminals 4 and 5.

At least one capacitor is connected in parallel with the winding 2 which comprises the second coil 2a which follows the first coil 1a in the direction of movement of the sliding field. In Figures 1 and 2, such a capacitor 6 is shown as connected in parallel between the vertices 12 and 23 of the triangle, i.e. in parallel with the second winding 2. In the arrangement of Figure 2, a second capacitor 7 is connected in parallel with the first capacitor 6 and may be supplied with current by way of a switch 8, for reasons which will be explained hereafter.

Although in the example described with reference to Figures 1 and 2, the supply source is connected to the terminals of the first winding 1, it could also be connected to the terminals of the third winding 3, i.e. between the vertices 23 and 31 of the triangle. In this case, one would obtain a movement of the sliding field in the reverse direction, with respect to the direction obtained in the case of the first arrangement.

Figures 3 and 4 illustrate results obtained from practical tests with a linear motor supplied firstly with three-phase current and secondly with single-phase current, with two different values of capacitor 6.

In these Figures, the curves drawn in full line represent the results obtained with a single-phase supply resulting from a capacitor 6 having a relatively low capacity (5.93mF for example), the curves drawn in broken line represent the results obtained with a single-phase supply using a capacitor 6 having a greater capacity (15mF for example) and the curves drawn in dot-dash line give the results obtained with a motor supplied in a conventional manner with

three-phase current.

Figure 3 shows three curves a_1 , a_2 , a_3 which respectively give the variation of the power factor $\cos \varphi$, respectively in the case of a three-phase supply, a single-phase supply with a low value capacitor and a single-phase supply with a higher value capacitor. It will be seen that for the normal speed of use of the motor, which is of the order of 50 metres per second, the power factors obtained in the two cases of single-phase supply are very close to 1, whereas that obtained with a three-phase supply is only of the order of 0.7. The curves b_1 , b_2 , b_3 of the diagram of Figure 3 show the variation of efficiency η of the motor as a function of speed, respectively in the case of a three-phase supply, a single-phase supply with a low value capacitor and in that of a single-phase supply with a higher value capacitor. It will be seen that by using a capacitor of low capacity (for example 5.93mF) an efficiency of approximately 0.8 is obtained for a speed close to the optimum speed of 50 metres per second.

The diagram of Figure 4 illustrates the variation of thrust P expressed in DaN as a function of the speed V in metres per second for identical voltages, where N is the Newton and da a factor of 9.81. It will be seen that at low speed, the motor provided with a single-phase supply with a capacitor 6 of low capacity (5.93mF for example) gives a low thrust (curve c_2) less than that obtained with a three-phase supply (curve c_1) which is less than the thrust obtained when one uses a single phase supply with a capacitor 6 of higher capacity (15 mF for example), as indicated by the curve c_3 . On the contrary, in the vicinity of an operating speed of the order of 50 metres per second, it is a single-phase supply with a capacitor of low capacity (curve C_2) which gives a thrust greater than those obtained both with a three-phase supply (curve c_1) as well as with a single-phase supply with a high value capacitor (curve c_3). Furthermore, in the region of this value, it is a single-phase supply with a low value capacitor which gives the best efficiency, as has been seen with reference to the study of Figure 3.

It is thus particularly advantageous to be able to vary the value of the capacity of the capacitor 6 connected in parallel with the second winding 2. This is the reason why it is possible to connect one or more additional capacitors 7 in parallel with this capacitor 6, which capacitors 7 may be selectively connected in shunt, as shown in Figure 2, in order to reduce the capacity of all the capacitors in parallel as the speed increases. In this way, under all operating conditions, one obtains a maximum thrust and finally maximum efficiency when the operating

speed is reached.

In the example of the invention which has just been described, it has been assumed that the inductor of the linear motor comprised a number N of poles each comprising three coils or a multiple of three coils. However, this arrangement is not limiting and the invention also relates to the case where the last pole, of the series (pole N in Figure 1) would be incomplete and comprised only one or two coils.

By way of example, if we consider the operation of the motor at a speed of 45 metres per second, if we consider the diagram of Figure 4, the active power produced is equal to the product of the speed and thrust, i.e. $45 \times 3.5 = 157$ kW. If we consider the diagram of Figure 3, it will be seen that for a speed of 45 metres per second, the product of the efficiency and the power factor of the motor ($\eta \times \cos \phi$), supplied with single-phase current (curve b_2) is 0.68. This is translated as a rated power of 231 kVA. If, under the same conditions, the motor is supplied with three-phase current, the product $\eta \times \cos \phi$ at the same speed, is only 0.55, which is translated as a rated electrical power of 286 kVA. These Figures show the importance in the saving of electrical consumption that the invention makes it possible to achieve.

If we adopt the case of a speed of the motor of 48 metres per second, to which the maximum efficiency of the motor supplied with single-phase current corresponds (0.8 on the curve b_2), the active power is $3.5 \times 48 = 168$ kW, or a loss of 42 kW and an installed power of 222 kVA.

On the other hand, if at the same speed, the motor is supplied with three-phase current, the active power is equal to $3.15 \times 48 = 151$ kW. Since the efficiency is 0.71, the loss is 0.29 or 62 kW. The installed power is thus 296 kVA.

The above calculations clearly show the considerable economy in the consumption of electric current it is possible to achieve with a linear motor formed according to the invention.

WHAT WE CLAIM IS:-

1. A linear motor comprising an inductor having a succession of coils distributed in three phases, at the rate of one or more coils per pole and phase, these coils following each other in the order of the phases, in a repeated manner i.e. first phase, second phase, third phase, then first phase, second phase, third phase and so on, the last pole possibly being incompletely wound, the coils of the same phase being connected in series to form together a winding, the three windings corresponding respectively to the three phases being interconnected in the form of a triangle network, one of the windings comprising the first coil of the

succession of coils, considered in the direction of movement of the sliding field, being connected to the terminals of a source of single-phase alternating voltage, and at least one capacitor being connected in parallel with a second of the windings which comprises a second coil following the first coil in the succession of coils.

2. A linear motor as claimed in Claim 1, further comprising at least one second additional capacitor which can be supplied with current in a selective manner by a switch said second capacitor being connected in parallel both with the first mentioned capacitor and with the second winding.

3. A linear motor as claimed in Claim 1, in which the last pole comprises only one or two coils.

5. A linear motor substantially as hereinbefore described with reference to the accompanying drawings.

MARKS & CLERK,
7th Floor,
Scottish Life House,
Bridge Street,
Manchester, M3 3DP.
Agents for the Applicants.

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COMPLETE SPECIFICATION

2 SHEETS

This drawing is a reproduction of
the Original on a reduced scale
Sheet 1

Fig.1

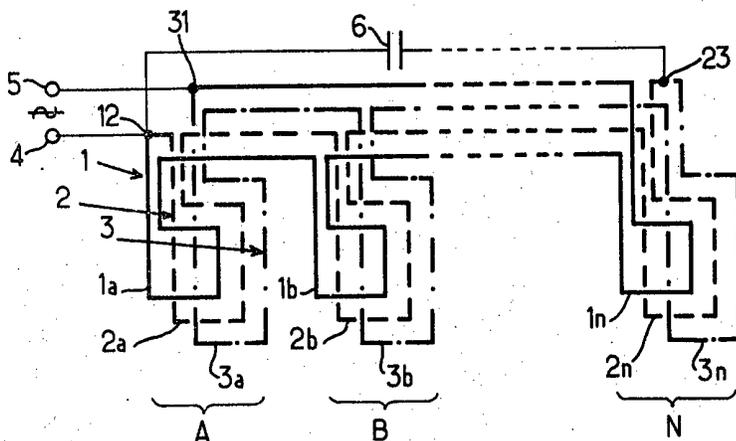


Fig. 2

