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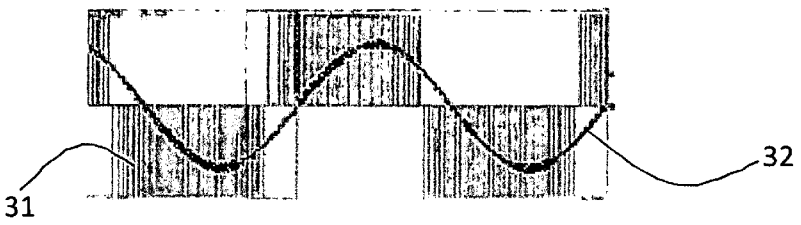


FIG. 3

(57) Abstract: The present invention refers to a new electric drive method for linear motor, and, more specifically, an electric drive method essentially based on the sinusoidal pulse width modulation technique, in which electric voltage (31) of electric signal comprises at least a wave segment of quadratic spectrum and an electric current (32) of electric signal comprises at least a wave segment of essentially sinusoidal spectrum.

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ELECTRIC DRIVE METHOD FOR LINEAR MOTOR

Field of the Invention

The present invention refers to a new electric drive method for linear motor, and, more specifically, to an electric drive method essentially based on the sinusoidal pulse width modulation (PMW) technique capable of improving the efficiency of electromechanical energy conversion in a resonant motor drive motor contained in linear compressors.

Background of the Invention

As known by those skilled in the art, the present state of the art is comprised of different types of fluid compressors and, more particularly, different types of compressors where fluid is used in refrigeration systems.

Among these different types, there can be cited alternative compressors, which essentially comprise a (preferably electric) rotary motor and a compression mechanism basically including at least a cylinder-piston assembly.

In this context, it is also known that piston is commonly associated with a motor rotor (generally through an eccentric edge of the rotor shaft and a piston rod) such that rotational movement of the motor rotor is converted into alternate linear movement of the piston. By this way, said piston that is linear and alternately shifted within the cylinder can compress the fluids previously introduced into said cylinder.

Therefore, one of the control features of a rotary compressor refers to the rotary motor drive.

In this context, and in accordance with specialized technical literature, it is observed that the present state of the art also comprises a plurality of electric drive systems and methods for rotary motors.

One of the commonly used drive methods for rotary motors comprises a power control method based on pulse width modulation of the electric (current) voltage delivered to the motor stator coils. Generally speaking, said method (applied by means of transistorized or microprocessed systems) refers to speed (by altering feed voltage frequency) and power (by altering effective voltage) of rotary electric motors.

Movement in a resonant linear motor is theoretically purely sinusoidal. In a compressor suitable for refrigeration systems, however, there is a small wave form deformation describing a movement caused by compressive strength, this being more intense near the upper dead point.

Due to the sinusoidal characteristic of the movement, back electromotive force generated and induced by magnet movement is also a sinusoidal characteristic. A simplified model for electric analysis is shown in Fig. 1.

Therefore, for efficiency maximization the motor power factor must be unitary, that is, a current in phase with the back electromotive force is free of harmonics when assuming

that this back electromotive force is almost purely sinusoidal.

As known by those skilled in the art, motors like this are driven by square-wave single-pulse inverters. The most common strategy is to drive a motor with a current in phase with back electromotive from the reading thereof when said current therein extinguishes. The ability to directly make the reading of the back electromotive force is one of the advantages of this method; however, it limits the power on the motor shaft and generates a high content of harmonics either in the applied voltage or in the circulating current, mainly when running in medium or low loads. Such content of harmonics causes the currents to be higher than the one that generates work to circulate, thus producing losses in copper. Said content of harmonics further induces components of higher frequency in the magnetic circuit to generate losses by hysteresis and Foucault current and undesired vibrations.

In this regard, it is worthy to emphasize that the formerly mentioned drive of sinusoidal type is commonly used to drive (induction and BLDC motors) rotary motors which employ velocity/torque vector control. Sinusoidal drive is obtained by sinusoidal pulse width modulation.

Hence, it is then noted that there is a need in the state of the art for systems and methods capable of electrically driving resonant linear motors by sinusoidal pulse width modulation.

Objects of the Invention

Therefore, one object of the present invention is to provide an electric drive system for linear motor especially based on sinusoidal pulse width modulation technique. In this regard, another object of the present invention is to provide said drive system comprising a system capable of improving the efficiency of electromechanical conversion of the linear motor by reducing the content of harmonics of the current injected into the motor.

Yet another object of the invention is to provide an electric drive method for linear motor essentially based on the sinusoidal pulse width modulation. Therefore, a further object of the preset invention is that all advantages provided by the sinusoidal pulse width modulation technique (when applied to rotary motors) are delivered to linear compressors.

Summary of the Invention

All the objects of the present invention are achieved by the now disclosed electric drive method for linear motor, which comprises generating electric signal (for electric feed of linear motor essentially comprising a propeller and a shifter) based on the sinusoidal pulse width modulation technique.

In this context, it is noted that electric voltage of the electric signal comprises at least a wave segment of quadratic spectrum and the electric current of the electric signal comprises at least an essentially sinusoidal spectrum wave segment. Said sinusoidal pulse width modulation technique cooperates with the linear motor resonance frequency.

Preferably, said sinusoidal pulse width modulation technique provides three (positive, neutral, and negative) levels. Optionally, said sinusoidal pulse width modulation technique can further provide only two (positive and negative) modulation levels.

Preferably, the electric signal generation is achieved by transistorized systems, or also by microcontrolled systems.

Brief Description of Drawings

The present invention is described in detail on the basis of the figures listed below, wherein:

Fig. 1 illustrates an electric model of resonant linear model;

Fig. 2 illustrates a block diagram of the electric drive system for linear motor in accordance with the present invention;

Fig. 3 illustrates the wave shapes of output voltage and output current supplied by the electric drive system for linear motor in accordance with the present invention; and

Fig. 4 illustrates a comparative experimental result between a linear compressor whose drive is based on methods pertaining to the state of the art, and a linear compressor whose drive is based on the electric drive method for linear motor in accordance with the present invention.

Detailed Description of the Invention

Fig. 1 illustrates a conceptual electric model of a linear motor 1. According to this model, said linear motor 1 can be interpreted as comprising an inductive composition 11, a resistive composition 12 and a back electromotive force 13, both arranged in series. In this regard, said linear motor 1 is ideally fed by a sinusoidal voltage source 2, whose electric voltage frequency is similar and analogous to the frequency of the generated electric current.

Based on this value of "fundamental frequency", in accordance with electric drive methods for linear motor pertaining to the present state of the art it is that the movement of the drive of the linear motor 1 is determined. Hence, said "fundamental frequency" of the sinusoidal voltage source 2 should be adjusted to work in accordance with the resonance frequency of linear motor 1. Nevertheless, from said single pulse modulation, voltage and current are not sinusoidal but rather pulsing and, consequently, they are full of harmonics harmful to the effectiveness of the linear motor 1.

Therefore, and in accordance with concepts and objects mentioned above, an electric drive method for linear motor is herein disclosed, which objective is to associate the drive of a linear motor for a linear compressor with the sinusoidal pulse width modulation technique so as to supply sinusoidal operational current having substantially low content of harmonics to said linear motor.

To this effect, the presently claimed method is preferably carried out by a system as schematically shown in Fig. 2.

Said system comprises a transistorized system conventionally known by those skilled in the art, in full bridge, formed by transistors 21, controllers 22 and the remaining auxiliary circuits which make part of the interface between the signal-generating logic level circuit and said transistors. Such step is responsible for modulating the current supplied to the linear motor in accordance with the desired wave shape. As already known by those skilled in the art, this is, therefore, achieved by commanding the transistors 21 through controllers 22, with pulsing signals counting with pulses varying in their duration in accordance with a sinusoidal signal.

Output signal of this system type, as shown in Fig. 3, provides wave shapes of voltage 31 and current 32 capable of being applied to a linear motor.

Wave shape of voltage 31 is modulated at high frequency but with a component value at the relevant fundamental frequency. Wave shape of current 32 is, nevertheless, almost purely sinusoidal, only having a small wave at high frequency resulting from the filtering effected by a motor inductive component. And said motor is highly benefited since the injected current that generates flow can be converted to work given that the system controls the current phase to be in alignment with the speed of motor 1 or with the back electromotive force 13.

The wave shape of voltage 31 is modulated at high frequency but with component value at the relevant fundamental frequency. Wave shape of current 32 is, nevertheless, purely sinusoidal, possessing only a small wave at high frequency as a result of the filtering effected by a motor inductive component. And said motor is significantly benefited since it is the injected current that generates flow and as such it has substantially low content of harmonics, wherein almost all this flow can be converted to work given that the system controls the phase of said current to be in alignment with the speed of motor 1 or the back electromotive force 13.

It is important to note that for drives from rectangular wave shape the smaller is the drained power the shorter will be the active conduction time, i.e. in which voltage and current are different from zero and having the same polarity. Consequently, this causes the harmonic components proportional to the fundamental to become greater when the power is low, and such situation is commonly seen in refrigerators which normally reach the compressor maximum power only at load transients or in the initial or sporadic temperature decrease.

However, in accordance with the method of the present invention, and specifically in situations where a low power is drained, the obtained current 32 is proportionally low but without losing sinusoidal shape which is a particularity thereof. Therefore, in this range a significant gain that can be obtained by using the method of the present invention is more evident.

Fig 4 shows a comparative experimental result referring to gain in effectiveness of

one same linear motor 1, wherein curve 41 referring to the linear motor 1 driven by the presently disclosed electric drive method (sinusoidal PWM modulation) and curve 42 referring to said linear motor 1 driven by conventional methods pertaining to the present state of the art. The gain of curve 41 is especially interesting in an operation range of important interest for refrigeration applications.

Another important result accomplished by the electric drive method of the present invention refers to an improvement in the capacity of said linear motor 1, since holding the motor at zero current is not required.

Furthermore, the electric drive method of the present invention is especially interesting when used in conjunction with a control of linear motor stroke described in BR Patent Application PI1103776-8 assigned to the same assignee of the present invention. Under this specific circumstance, the electric drive method for linear motor essentially based on sinusoidal pulse width modulation technique permits to optimize the control system of the linear motor drive stroke.

Attention should be drawn to the fact that the description above aims at providing a preferred exemplary embodiment of the present invention.

Therefore, for those skilled in the art it is clear that the scope of the present invention also contemplates other analogous embodiments and/or equivalents, the features of which are disclosed and limited by the appended claims.

CLAIMS

1. Electric drive method for linear motor essentially comprising at least a propeller and a shifter, said method being characterized in that it comprises:

generation of electric signal to provide electrical feed to a linear motor (1), based on the sinusoidal pulse width modulation technique;

electric voltage (31) of electric signal comprising at least a wave segment of quadratic spectrum;

electric current (32) of electric signal comprising at least a wave segment of essentially sinusoidal spectrum; and

wherein said sinusoidal pulse width modulation technique is cooperative with the linear motor (1).

2. Electric drive method for linear motor, in accordance with claim 1, characterized in that said sinusoidal pulse width modulation technique provides three modulation levels.

3. Electric drive method for linear motor, in accordance with claim 1, characterized in that said sinusoidal pulse width modulation technique provides two modulation levels.

4. Electric drive method for linear motor, in accordance with claim 1, characterized in that the generation of electric signal (3) is obtained by means of transistorized systems.

5. Electric drive method for linear motor, in accordance with claim 1, characterized in that said generation of electric signal (3) is obtained by means of microcontrolled systems.

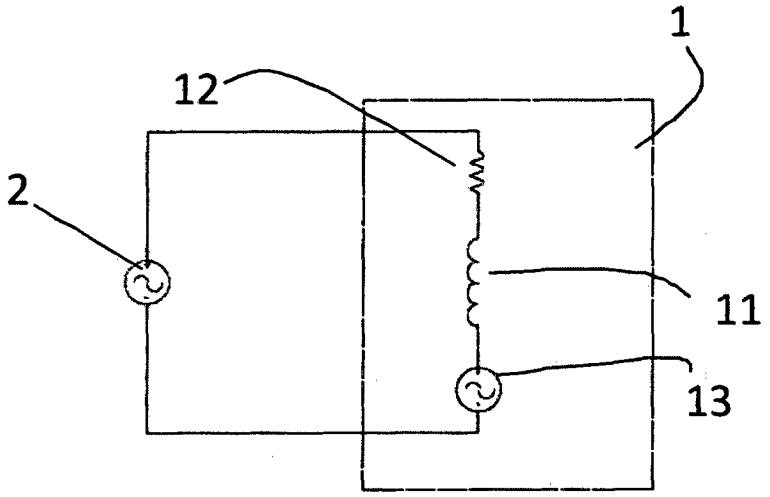


FIG. 1

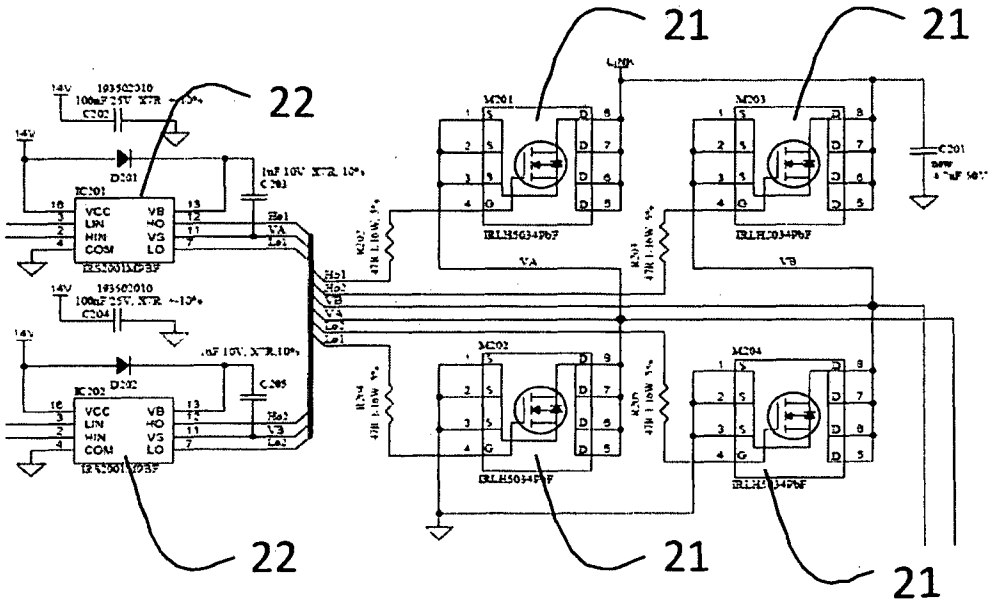


FIG. 2

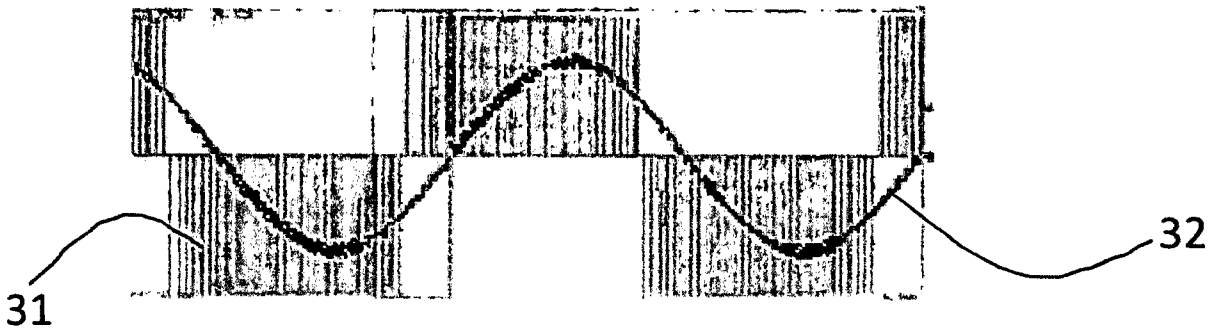

31
32

FIG. 3

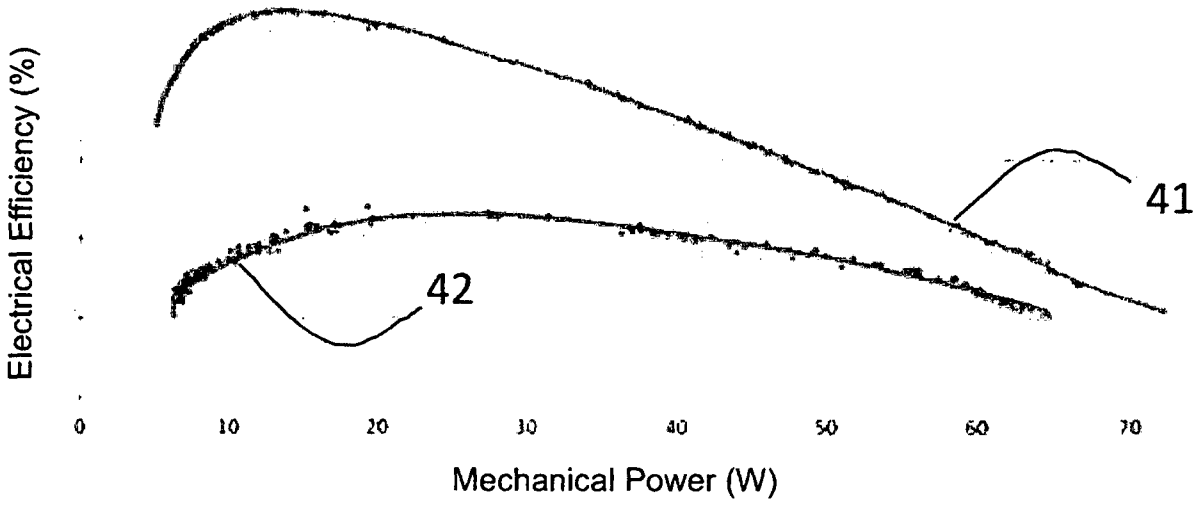

Electrical Efficiency (%)
41
42
0
10
20
30
40
50
60
70
Mechanical Power (W)

FIG. 4