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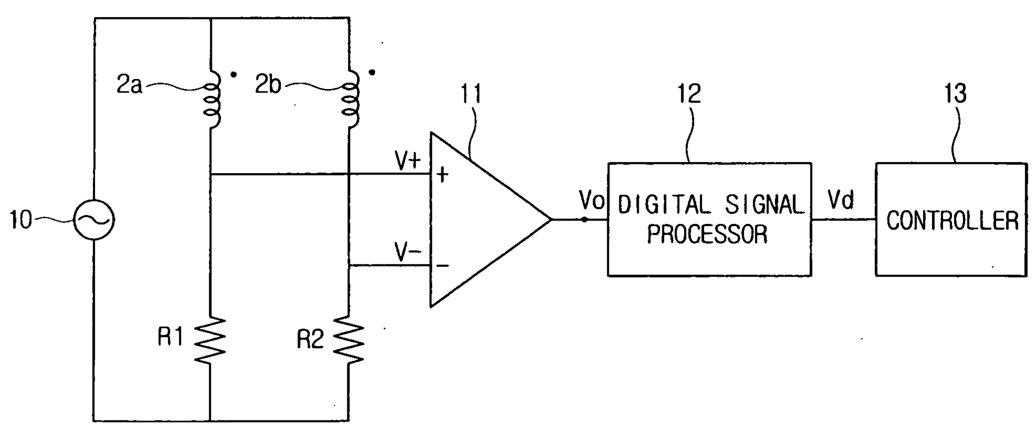
(54) **Linear compressor and control method thereof**

(57) Disclosed is a linear compressor having a core (4) combined to one end of a piston to detect a position of the piston reciprocally moving up and down, and a bobbin (1) having a first sensor coil (2a) and a second sensor coil (2b) that detect the position of the core. A controller (13) determines the state of a load on the piston by measuring the time the core takes to exit and enter the bobbin from an inhale stroke through a compression stroke of the piston and control a position of the piston based on the measured state of the load. Also disclosed is a method for controlling the operation of the linear compressor including timing the core driven by a piston through a stroke cycle, receiving the time and computing a load on the piston, outputting a piston position signal based on the load computed, and controlling a piston stroke according to the piston position signal, by varying the power driving the linear compressor.

FIG. 5



EP 1 496 255 A2

Description

[0001] The present invention relates to a linear compressor and a control method thereof. A linear compressor is widely used to compress coolant in a freezing cycle such as in equipment like a refrigerator, freezer, etc. The linear compressor measures the magnitude of a stroke of a piston, and controls an operation of the piston by applying a current to a driving motor of the linear compressor based on an analysis of the measured magnitude of the stroke.

[0002] Figure 1 is a cross-sectional view of a position detection sensor for a piston of a conventional linear compressor. As illustrated in Figure 1, the position detection sensor comprises a bobbin 100, a sensor coil 101, a core support 102, and a core 103.

[0003] The bobbin 100 includes the sensor coil 101 inside, and the sensor coil 101 is connected in series to a first sensor coil 101a and a second sensor coil 101b each having the same inductance value, size, and number of turns. The core support 102 is made of non-magnetic material and supports the core 103 and is combined to the piston (not shown).

[0004] As the core 103 combined to the piston of the compressor reciprocally moves back and forth along an inner hole of the bobbin 100, a predetermined reactance is generated in the sensor coil 101 according to reciprocal movement of the piston.

[0005] Figure 2 is a diagram of a conventional position detection circuit for the piston of the conventional linear compressor. As illustrated in Figure 2, two serial sensor coils 101 are connected in parallel with two serial dividing resistors Ra and Rb, and a triangle pulse is input as a power source 105. A difference of voltages divided by the dividing resistors Ra and Rb is amplified by an amplifier 104 to detect a maximum output voltage according to the piston in which the core 103 moves back and forth starting from a center point between the first sensor coil 101a and the second sensor coil 101b. An analog signal processor 106 receives an output pulse from the amplifier 104 and detects the position of the piston through a predetermined signal process.

[0006] Figure 3 illustrates an output pulse from the amplifier 104 in Figure 2 according to the reciprocal movement of the piston of the linear compressor. As illustrated in Figure 3, the output voltage from the amplifier (line "a") has a linear output property for the reciprocal movement of the piston. The position of the piston can be detected with the output voltage because the output voltage is proportional to the position of the piston.

[0007] However, the sensor circuit of the conventional linear compressor may vary the angle of slope of the linear graph according to external environmental conditions such as temperature and pressure. If the sensor circuit of the conventional linear compressor follows the linear property represented by a small angle of the slope like a line "b" due to the external environmental conditions, the piston controlled according to a steady operation when in a high cooling capacity may collide with a valve of a cylinder.

[0008] The conventional linear compressor uses a control method for controlling the reciprocal movement of the piston by determining a state of a load on the linear compressor based on a measured temperature or a measured driving current for a motor. The conventional control method of determining the state of the load on the linear compressor may respond to a change of the load on the piston late. Additionally it is hard to measure the temperature and the driving current accurately in a linear compressor, even if measuring points for the temperature and the driving current are properly selected.

[0009] Accordingly, it is an aim of embodiments of the present invention to provide a linear compressor outputting cooling power actively and controlling a stroke of a piston by determining state of a load on the piston accurately regardless of an external environment.

[0010] Additional aspects and/or advantages of the invention will be set forth in part in the description which follows and, in part, will be obvious from the description, or may be learned by practice of the invention.

[0011] According to a first aspect of the present invention, there is provided a linear compressor having a core combined to one end of a piston to detect a position of the piston reciprocally moving up and down, and a bobbin having a first sensor coil and a second sensor coil detecting the position of the core, comprising a controller determining state of a load of the piston by measuring an elapsed time for the core to exit and enter the bobbin from an inhale stroke through a compression stroke of the piston and controlling a position of the piston based on the measured state of the load.

[0012] Preferably, the core has a length shorter than one half of the length of the first sensor coil and the second sensor coil in series.

[0013] Preferably, the controller increases a top clearance of the piston if the amount of time taken for the core to exit and enter the bobbin increases greatly over a predetermined critical time.

[0014] Preferably, the linear compressor includes a first branch including the first sensor coil and a predetermined first dividing resistor connected in series, a second branch including the second sensor coil and a predetermined second dividing resistor connected in series, a power source applied to the first branch and the second branch, and a voltage comparator with voltage inputs applied to the first dividing resistor and the second dividing resistor.

[0015] Preferably, the voltage comparator has voltage inputs applied to the opposite terminals of each of the first sensor coil and the second sensor coil.

[0016] Preferably, the controller determines the state of the load on the piston on a basis of difference of time taken for the piston to be positioned near the bottom dead center making output of the voltage comparator zero (0) so as to control the position of the piston.

[0017] Preferably, the controller determines the state of the load on the piston on a basis of difference of time taken for the piston to be positioned near the bottom dead center making output of the voltage comparator zero (0), so as to control the position of the piston.

[0018] According to a second aspect of the present invention, there is provided a control method of a linear compressor having a core combined to one end of a piston to detect a position of the piston reciprocal moving up and down, and a bobbin having a first sensor coil and a second sensor coil detecting the position of the core, including measuring time taken for the core to exit and enter the bobbin from an inhale stroke through a compression stroke of the piston; and controlling a position of the piston by determining state of a load on the piston on a basis of the time taken for the core to exit and enter the bobbin.

[0019] Preferably, the control method of the linear compressor further comprising forming length of the core to be shorter than a half of length of the first sensor coil and the second sensor coil connected in series.

[0020] Preferably, the above and other aspects may be achieved by providing the control method of the linear compressor including increasing a top clearance of the piston if the time taken for the core to exit and enter the bobbin increases greatly than a predetermined critical time.

[0021] According to a third aspect of the present invention, there is provided a method for controlling an operation of a linear compressor, comprising: timing a core driven by a piston through a stroke cycle; receiving the time and computing a load on the piston; outputting a piston position signal based on the load computed; and controlling a piston stroke according to the piston position signal, by varying the power driving the linear compressor.

[0022] According to a fourth aspect of the present invention, there is provided a linear compressor piston control device, comprising: a bobbin defining an aperture; a sensor coil disposed in the bobbin; a core attached to a piston disposed coaxially in the aperture of the bobbin, wherein the core is less than one half the length of the sensor coil; a controller controlling a position of the piston by determining a load based on signals from the sensor coil sensing the position of the core.

[0023] For a better understanding of the invention, and to show how embodiments of the same may be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawings in which:

Figure 1 is a cross-sectional view of a position detection sensor for a piston of a conventional linear compressor;

Figure 2 is a diagram of a position detection circuit for the piston of the conventional linear compressor;

Figure 3 illustrates an output waveform from an amplifier in Figure 2 according to reciprocal movement of the piston of the linear compressor;

Figure 4 is a cross-sectional view of a position detection sensor for a piston of a linear compressor according to an embodiment of the present invention;

Figure 5 is a block diagram of a position detection circuit for the piston of the linear compressor according to an embodiment of the present invention;

Figures 6A-6C and 7A-7C are input waveforms of a voltage comparator according to reciprocal movement of the linear compressor;

Figure 8 is a control block diagram of the linear compressor according to an embodiment of the present invention;

Figure 9 is an output waveform of the voltage comparator according to a position of the piston of the linear compressor according to the embodiment of the present invention.

[0024] Reference will now be made in detail to the embodiments of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout. The embodiments are described below to explain the present invention by referring to the figures.

[0025] Figure 4 is a cross-sectional view of a position detection sensor for a piston of a linear compressor according to an embodiment of the present invention. As illustrated in Figure 4, the position detection sensor comprises a bobbin 1, a sensor coil 2, a core support 3, and a core 4.

[0026] The bobbin 1 includes a sensor coil 2 inside, and the sensor coil 2 comprises a first sensor coil 2a and a second sensor coil 2b. The first sensor coil 2a and the second sensor coil 2b have the same inductance value, size, and number of turns and are connected in series. The core support 3 is made of non-magnetic material and supports the core unit 4 and is combined to the piston (not shown).

[0027] The core unit 4 comprises a core 4a having a short predetermined length. In this embodiment, the length of the core 4a is less than one half of the length of the sensor coil 2 comprising the first sensor coil 2a and the second sensor coil 2b. The core support 3 connects the core 4a with the piston so that the core 4a can move according to the reciprocal movement of the piston.

[0028] As the core 4a combined to the piston of the compressor reciprocally moves back and forth along an inner hole of the bobbin 1, a predetermined reactance is generated in the sensor coil 2 according to the reciprocal movement of the core 4a within the sensor coil 2.

[0029] The core 4a moves reciprocally, centering around the first sensor coil 2a through a complete cycle of the piston. Further the core 4a is adjusted to reach near the second sensor coil 2b through a middle point between the first sensor coil 2a and the second sensor coil 2b (will be referred as a coil origin) when the piston arrives in a top dead center. Also, the size of the bobbin and the piston should be preferably configured so that the core 4a can come out of the bobbin 1 during an expansion stroke.

[0030] If the state of the load on the linear compressor turns into an overloaded state, a stroke of the piston comes out of the bobbin 1 in an expansion stroke.

[0031] Such change of the state of the load can be determined by measuring time taken for the center point of the core 4a to exit and enter the bobbin 1.

[0032] A controller 13 as shown in Figure 5, measures the time that the core 4a takes to exit and enter the bobbin 1 to determine the state of the load. In a case of overload, the controller 13 applies a high current to a driving motor of the linear compressor.

[0033] However, in case of an extreme overload, the top clearance of the piston may be increased by a partial amount of the load calculated and controlled by the controller when the change of the measured load is greater than a predetermined critical amount of the load. A reason for increasing the top clearance is that the overcontrolled piston may collide with a valve of the linear compressor if the state of the overload turns into the state of a steady load abruptly as the magnitude of the stroke of the piston during the overload increases. Accordingly, it is beneficial to prevent an abnormal operation of the piston by setting the top clearance of the piston to a value that is adequate over a broad load range.

[0034] The position of the piston may be controlled by determining the state of the load by measuring the time that the core 4a takes to exit and enter the bobbin 1. Hereinbelow, a method to measure the time that the core 4a takes to exit and enter the bobbin 1 will be described. Figure 5 is a block diagram of a position detection circuit for the piston of the linear compressor according to an embodiment of the present invention.

[0035] As illustrated in Figure 5, the position detection circuit comprises a first sensor coil 2a, a second sensor coil 2b, a first dividing resistor R1, a second dividing resistor R2, a power source 10, a voltage comparator 11, a digital signal processor 12, and a controller 13.

[0036] The power source 10 applies power to a first branch having the first sensor coil 2a and the first dividing resistor R1 connected in series, and to a second branch having the second sensor coil 2b and the second dividing resistor R2 connected in series.

[0037] The voltage comparator 11 receives voltages taken from a terminal of each of the first dividing resistor R1 and the second dividing resistor R2 as a comparison signal V+ and a comparison signal V-, respectively. Also, the voltage comparator 11 may receive voltage taken from the opposite terminals of each of the first sensor coil 2a and the second sensor coil 2b.

[0038] The digital signal processor 12 transmits a rectangular pulse to the controller 13 according to an output of the voltage comparator 11, and then the controller 13 controls a driving motor (not shown) of the linear compressor on the basis of the rectangular pulse.

[0039] Figures 6A through 6C and 7A through 7C are input waveforms of a voltage comparator according to reciprocal movement of the piston of the linear compressor.

[0040] Figure 6A represents a triangle pulse from the power source 10, and Figure 6B represents waveforms input to a positive terminal and a negative terminal of the voltage comparator 11.

[0041] Figure 6B represents the input waveform of the voltage comparator 11 when a center point of the upper core 4a (will be referred to as a core origin) passes a middle point between the first sensor coil 2a and the second sensor coil 2b (will be referred to as a coil origin), or when the piston reaches near a top dead center by a compression stroke. If the triangle pulse is applied from the power source 10, an inductance L2 of the second sensor coil 2b becomes greater than an inductance L1 of the first sensor coil 2a. Accordingly, the input waveform V- input into the negative terminal of the voltage comparator 11 has a time delay longer than the time delay of the input waveform V+ input into the positive terminal of the voltage comparator 11.

[0042] As illustrated in Figure 6C, the digital signal processor 12 generates a rectangular waveform Vd having high level when the input waveform V+ of the positive terminal of the voltage comparator 11 is greater than the input waveform V- of the negative terminal.

[0043] Figures 7A through 7C are waveforms when the core origin is inclined toward the first sensor coil 2a from the coil origin. In this case, the inductance L1 of the first sensor coil 2a becomes greater than the inductance L2 of the second sensor coil 2b. Accordingly, the input waveform V+ input into the positive terminal of the voltage comparator 11 has a longer time delay. Figure 7B illustrates input waveforms of the voltage comparator 11 in such case, and Figure 7C illustrates a rectangular waveform Vd outputted from the digital signal processor 12 corresponding to the waveforms in Figure 7B.

[0044] Figure 9 is a waveform output from the voltage comparator 11 according to a position of the piston of the linear compressor according to this embodiment of the present invention.

[0045] As illustrated in Figure 9, a waveform "c" has two zero points corresponding to the input waveforms illustrated in Figures 6B and 7B.

[0046] If the core origin of the core 4a passes the coil origin, the output waveform V_0 of the voltage comparator 11 has a second zero point, and it has a first zero point if the core origin of the core 4a comes out of the bobbin 1.

[0047] Figure 8 is a control block diagram of the linear compressor according to an embodiment of the present invention. Hereinbelow, the embodiment of the present invention will be described in reference to Figures 4 through 8.

[0048] At operation S1, the time for the core origin of the core 4a to exit and enter the bobbin 1 according to an inhale stroke of the piston is measured, or the time that is taken for the output V_0 of the voltage comparator 11 having the first zero point to have the first zero point again according to the compression stroke is measured. Then, at operation S2, the state of the load on the piston can be determined based on the measured result.

[0049] In operation S4, the controller 13 checks the trend of the load. If the load decreased, the controller 13 will control the stroke of the piston to decrease accordingly in operation S3, however, if the state of the load is determined to be the overload, it is decided whether the amount of the change of the load is greater than the amount of the predetermined critical load at operation S4 then the controller must adjust the top clearance of the piston in operation S5.

[0050] The controller 13 increases the driving current for the driving motor to increase the stroke of the piston if the state of the load is determined to be the overload at operation S6. However, the piston may collide with the valve as the piston becomes uncontrollable with a big stroke because the driving current for the driving motor increases when the increased amount of the load is greater than the amount of the critical load, or because a controlled velocity of the motor becomes lower than a changing velocity of the load when the state of the load turns into the steady state suddenly.

[0051] Accordingly, when the magnitude of the change of the load is great, it is desirable to change the magnitude of the stroke slowly by setting a target magnitude of the controlled stroke greater than the present magnitude of the stroke by some amount rather than to change the magnitude of the stroke of the piston abruptly by increasing the driving current for the driving motor. However, the collision of the piston and the valve may be prevented by increasing the top clearance by adjusting the target magnitude of the controlled stroke at operation S5. The linear compressor according to this embodiment of the present invention detects the amount of the load and controls the cooling power based on the detected amount of the load.

[0052] Waveforms "c" and "d" in Figure 9 are the output waveforms V_0 of the voltage comparator 11 when the external environmental conditions of the sensor such as the temperature and the pressure change. The waveform "d" illustrates that the zero point does not vary even if the external conditions changed compared to the waveform "c". Accordingly, it can be inferred that the external environment does not affect the zero points, which enables accurate determination of the state of the load and controlling the position of the piston based on the zero points.

[0053] This embodiment provides the present invention a control of high quality on the stroke of the piston by determining the state of the load regardless of the external environment.

[0054] Although a few embodiments of the present invention have been shown and described, it would be appreciated by those skilled in the art that changes may be made in this embodiment without departing from the principles and spirit of the invention, the scope of which is defined in the claims and their equivalents.

[0055] Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

[0056] All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

[0057] Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[0058] The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A linear compressor having a core (4) combined to one end of a piston to detect a position of the piston reciprocally moving up and down, and a bobbin (1) having a first sensor coil (2a) and a second sensor coil (2b) detecting the position of the core, comprising:

   a controller (13) determining a state of a load of the piston by measuring time that the core takes to exit and enter the bobbin from an inhale stroke through a compression stroke of the piston and controlling a position of the piston on a basis of the determined state of the load.

2. The linear compressor according to claim 1, wherein the core (4) has a length shorter than one half of the length of the first sensor coil (2a) and the second sensor coil (2b) in series.

3. The linear compressor according to claim 1 or 2,

wherein the controller increases a top clearance of the piston if the time that the core takes to exit and enter the bobbin increases over a predetermined critical time.

4. The linear compressor according to any one of the preceding claims, further comprising:

a first branch comprising the first sensor coil (2a) and a predetermined first dividing resistor (R1) connected in series;

a second branch comprising the second sensor coil (2b) and a predetermined second dividing resistor (R2) connected in series;

a power source (10) applied to the first branch and the second branch; and

a voltage comparator (11) with input voltages applied from the first dividing resistor and the second dividing resistor.

5. The linear compressor according to claim 4, wherein the voltage comparator receives input voltages applied from the terminals of each of the first sensor coil and the second sensor coil.

6. The linear compressor according to claim 4 or 5, wherein the controller determines the state of the load on the piston based on the time that the piston takes to be positioned near the bottom dead center making output of the voltage comparator 0, so as to control the position of the piston.

7. The linear compressor according to claim 5 or 6, wherein the controller determines the state of the load on the piston on a basis of difference of time that the piston takes to be positioned near the bottom dead center making output of the voltage comparator 0, so as to control the position of the piston.

8. A control method of a linear compressor having a core (4) combined to one end of a piston to detect a position of the piston reciprocally moving up and down, and a bobbin (1) having a first sensor coil (2a) and a second sensor coil (2b) detecting the position of the core, comprising:

measuring a time that the core takes to exit and enter the bobbin from an inhale stroke through a compression stroke of the piston; and

controlling a position of the piston by determining state of a load on the piston on a basis of the time that the core takes to exit and enter the bobbin.

9. The control method of the linear compressor according to claim 8, further comprising forming a length of the core (4) to be shorter than a half of length of the first sensor coil (2a) and the second sensor coil (2b) connected in series.

10. The control method of the linear compressor according to claim 8 or 9, further comprising increasing a top clearance of the piston if the time that the core takes to exit and enter the bobbin increases above a predetermined critical time.

11. A method for controlling an operation of a linear compressor, comprising:

timing a core (4) driven by a piston through a stroke cycle;

receiving the time and computing a load on the piston;

outputting a piston position signal based on the load computed; and

controlling a piston stroke according to the piston position signal, by varying the power driving the linear compressor.

12. The method of claim 11, wherein the method further comprises controlling the piston stroke, wherein the piston stroke is increased as the load increases and the piston stroke is decreased as the load decreases.

13. The method of claim 11 or 12, wherein the method further comprises if the load computed is greater than a predetermined critical load amount, then increasing a top clearance of the piston.

14. The method of any one of claims 11-13, wherein timing the core is based on the elapsed time when the core exits the sensor coil aperture during a compression stroke, and then enters the sensor coil aperture during an inhale stroke of the piston.

15. A linear compressor piston control device, comprising:

a bobbin (1) defining an aperture;

a sensor coil (2) disposed in the bobbin;

a core (4) attached to a piston disposed coaxially in the aperture of the bobbin, wherein the core is less than one half the length of the sensor coil;

a controller (13) controlling a position of the piston by determining a load based on signals from the sensor coil sensing the position of the core.

16. The control device according to claim 15, wherein the controller determines the load based on the elapsed time when the core exits the sensor coil aperture during a compression stroke and then enters the sensor coil aperture during an inhale stroke of the piston.

17. The control device according to claim 16, further comprising the controller adjusting a top clearance of the piston based on the elapsed time.

18. The control device according to claim 17, wherein the controller increases the top clearance if the elapsed time is above a predetermined critical time.

19. The control device according to any one of claims 15-18, wherein the sensor coil includes a first sensor coil (2a) and a second sensor coil (2b).

20. The control device according to claim 19, wherein the first sensor coil and the second sensor coil have the same number of turns, size and inductance value.

21. The control device according to claim 20, wherein the control device further comprises:

a first branch having a first predetermined dividing resistor (R1) connected in series with the first sensor coil (2a);
a second branch having a second predetermined dividing resistor (R2) connected in series with the second sensor coil (2b).

22. The control device according to claim 21, further comprising:

a voltage comparator (11) that receives voltage inputs from the first branch and the second branch and outputs a comparator signal;

a digital signal processor (12) that receives the comparator signal and sends an output signal to the controller based on the comparator signal.

23. The control device according to claim 22, wherein the controller (13) determines the load by measuring the time that elapses between the comparator signal equaling 0 a first time during a compression stroke and the comparator signal equaling 0 a second time during an inhale stroke.

FIG. 1
(PRIOR ART)

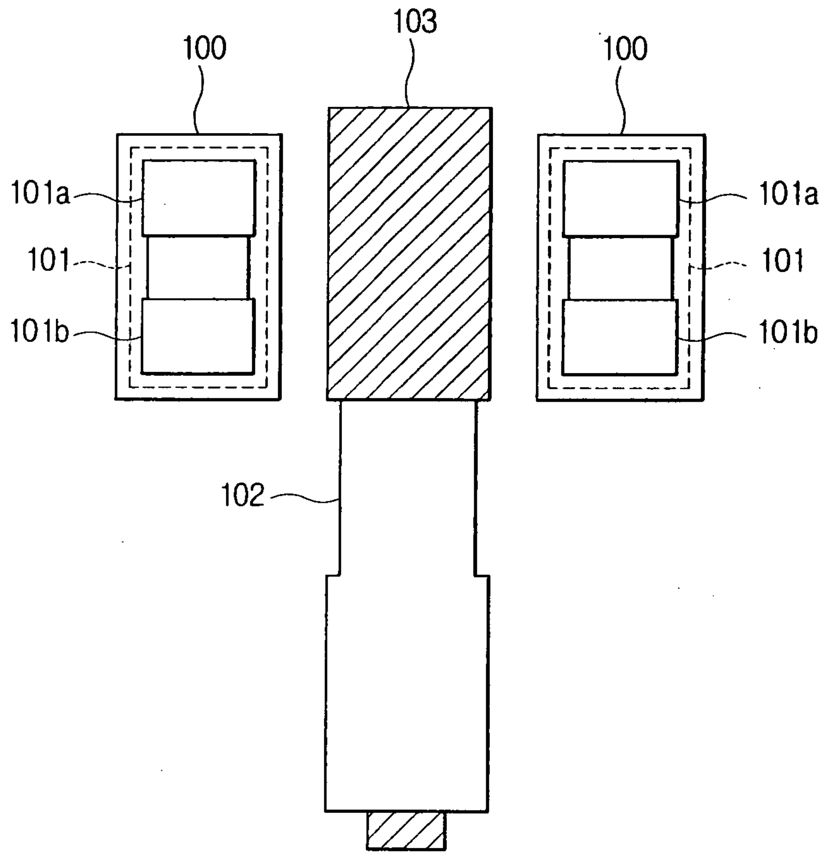


FIG. 2
(PRIOR ART)

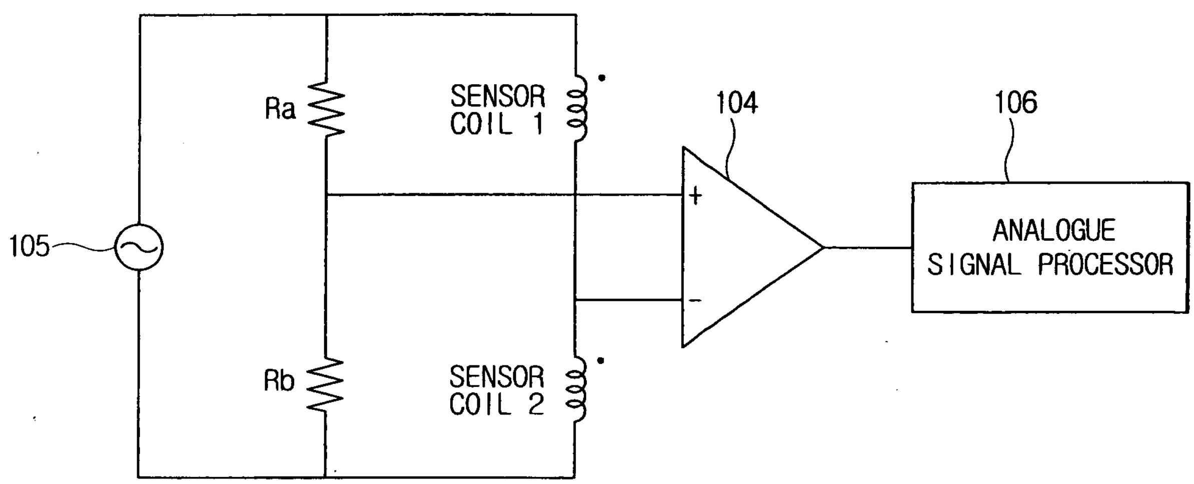


FIG. 3
(PRIOR ART)

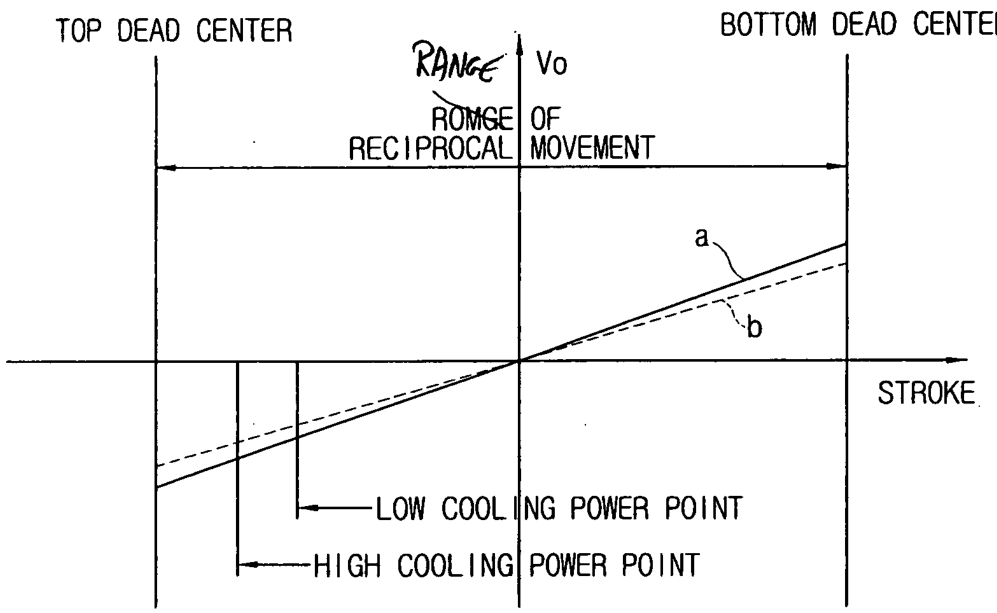


FIG. 4

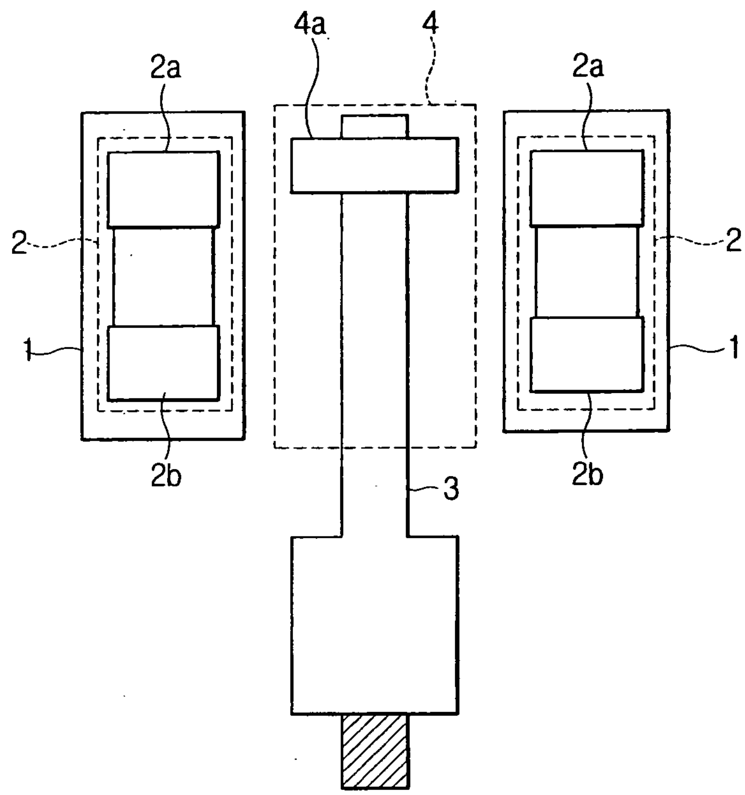


FIG. 5

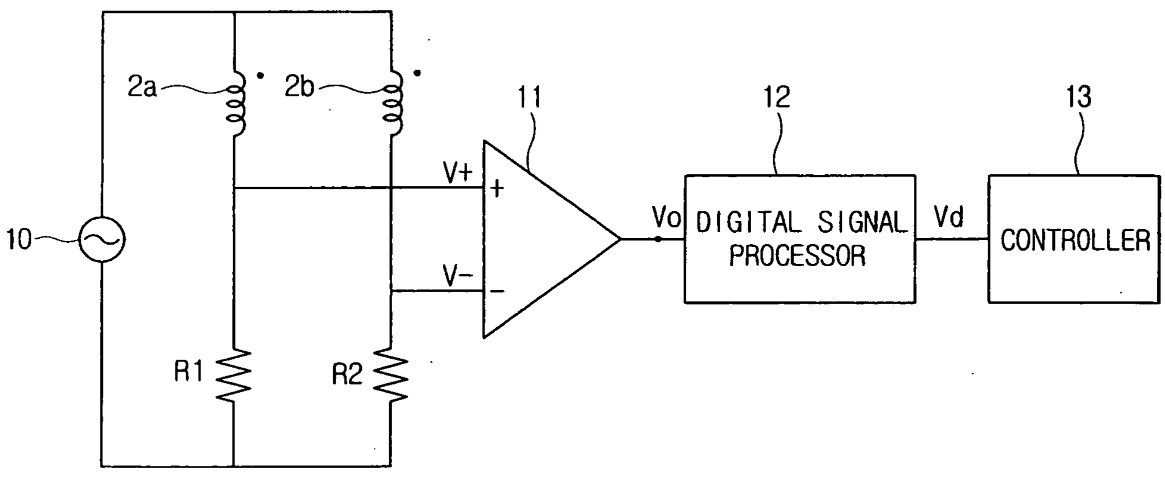

2a
2b
11
12
13
10
V+
V−
Vo
DIGITAL SIGNAL PROCESSOR
Vd
CONTROLLER
R1
R2

FIG. 6

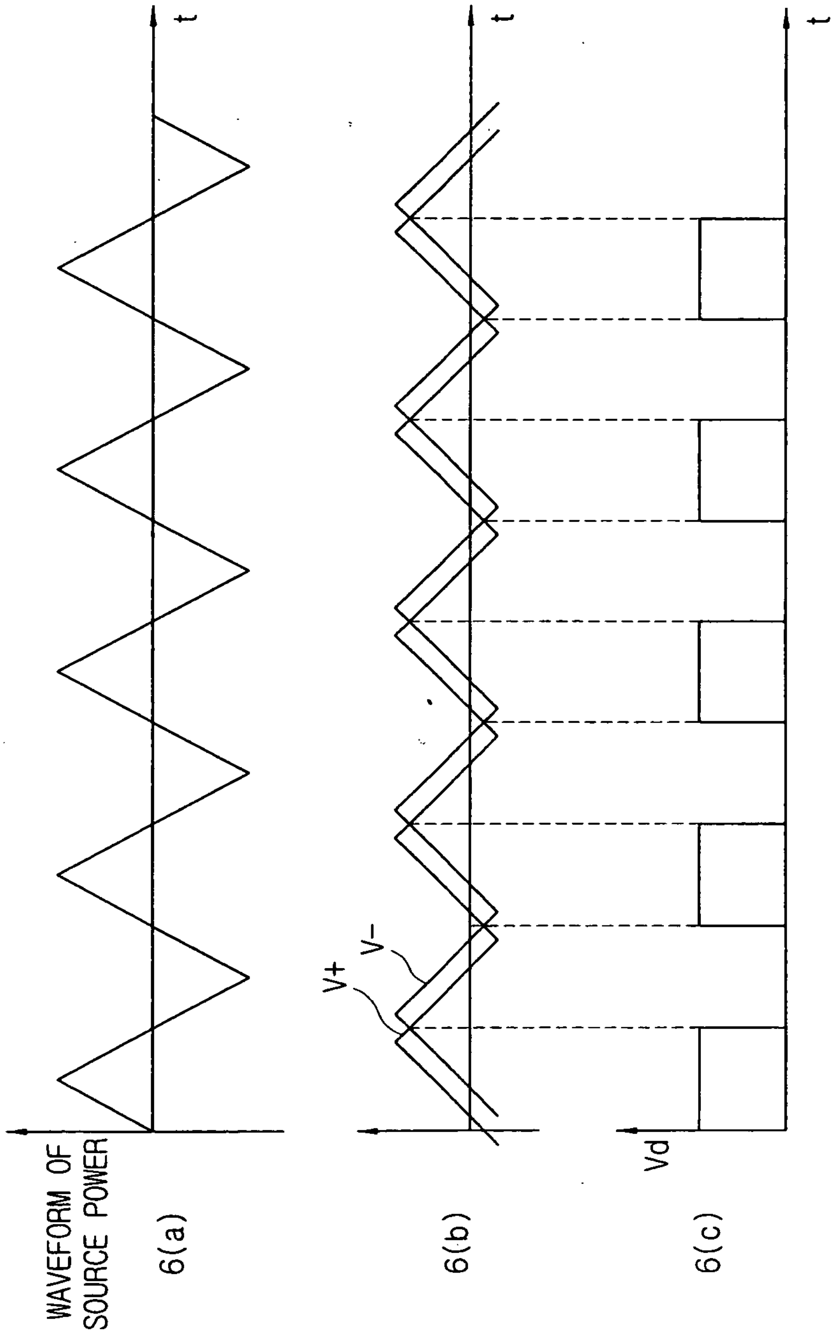


FIG. 7

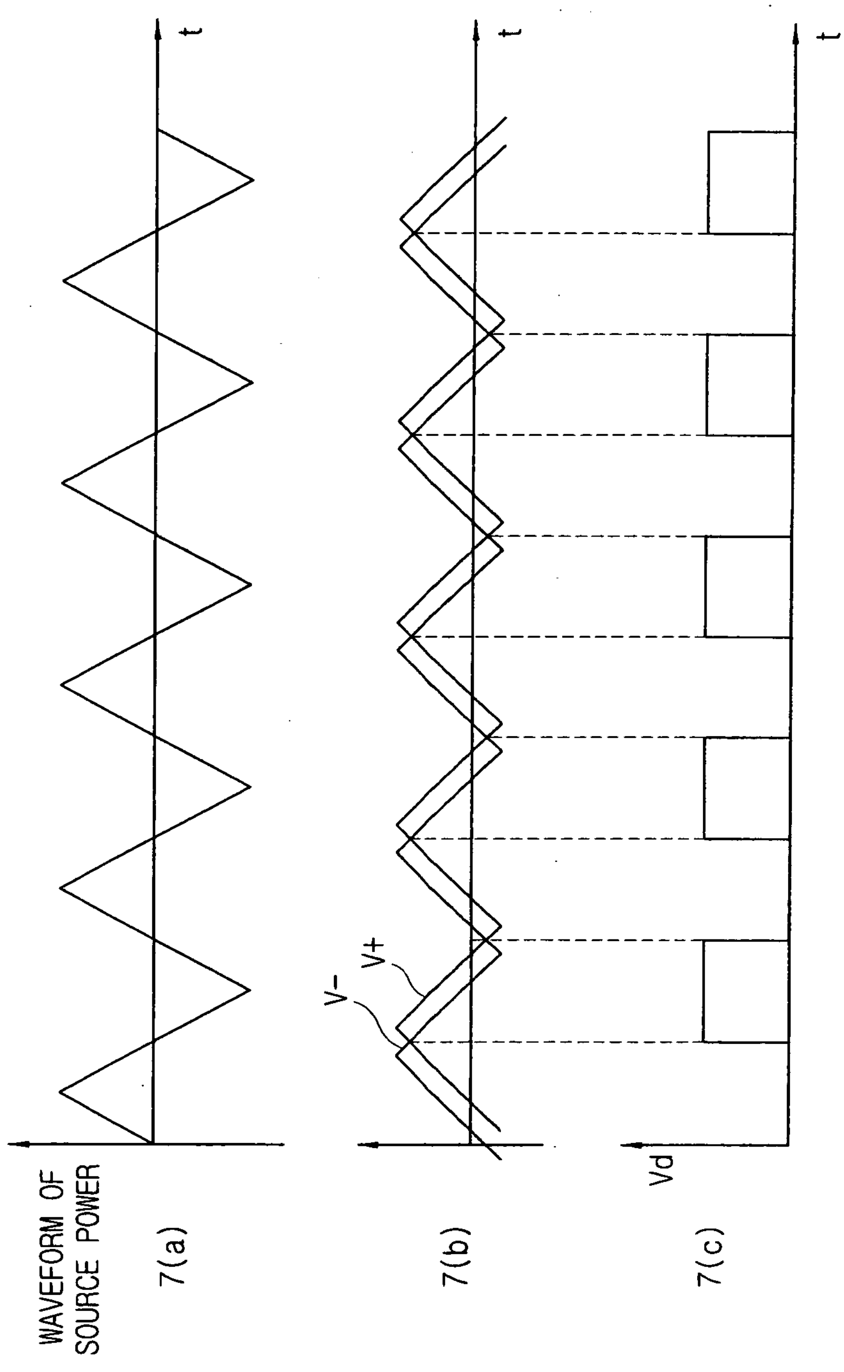


FIG. 8

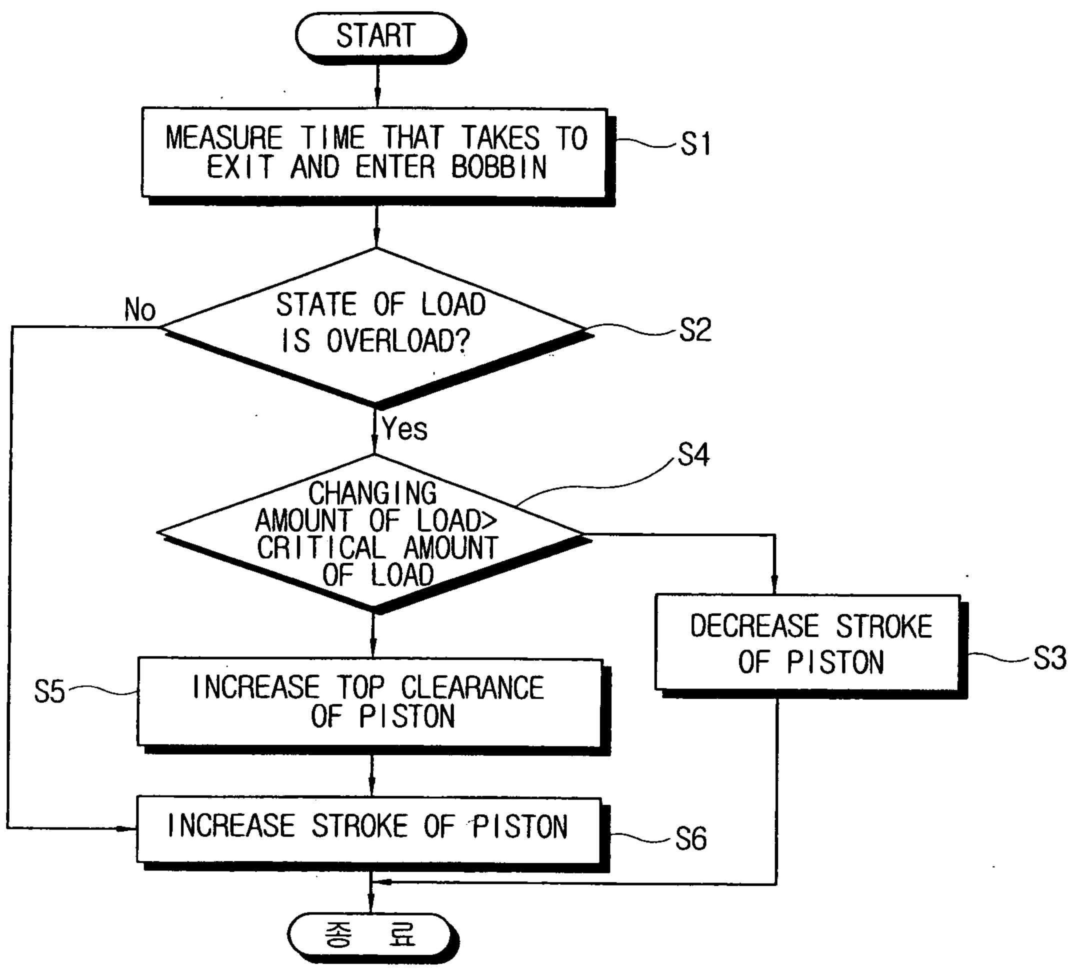
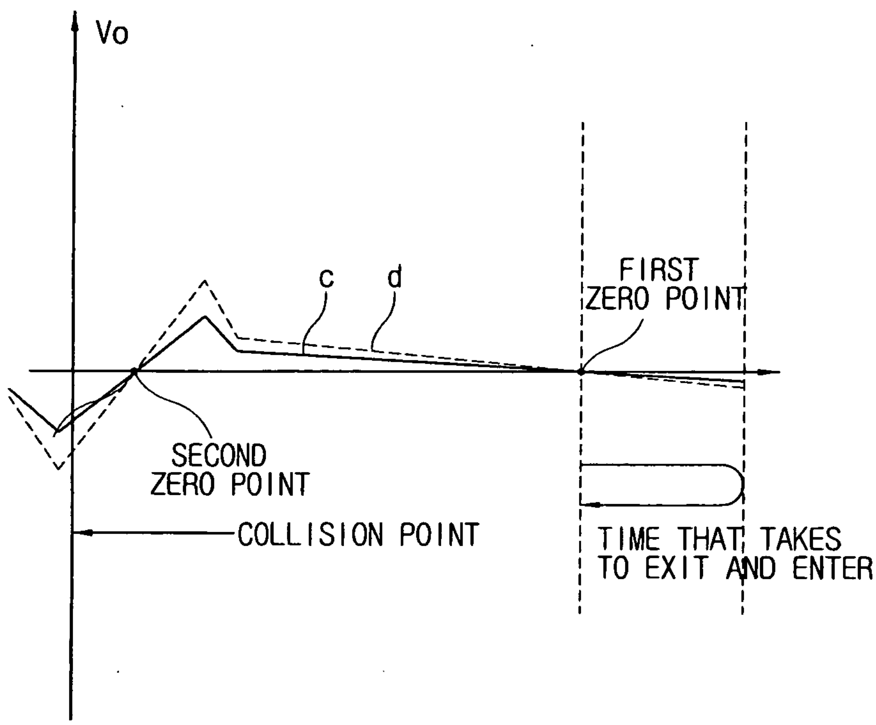

START
MEASURE TIME THAT TAKES TO EXIT AND ENTER BOBBIN
S1
STATE OF LOAD IS OVERLOAD?
S2
No
Yes
S4
CHANGING AMOUNT OF LOAD> CRITICAL AMOUNT OF LOAD
DECREASE STROKE OF PISTON
S3
S5
INCREASE TOP CLEARANCE OF PISTON
INCREASE STROKE OF PISTON
S6
종 료

FIG. 9


Vo
c
d
FIRST
ZERO POINT
SECOND
ZERO POINT
COLLISION POINT
TIME THAT TAKES
TO EXIT AND ENTER