



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
21.12.2005 Bulletin 2005/51

(51) Int Cl.7: **F04B 35/04, F04B 49/06**

(21) Application number: **05103404.9**

(22) Date of filing: **26.04.2005**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IS IT LI LT LU MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR LV MK YU

(72) Inventors:
• **Chang, Keun Sik**
105-701, Dongsuwon LG Village 1
Gyeonggi-do (KR)
• **Chang, Phil Soo 403-1301, Sunkyung Apt.**
Gyeonggi-Do (KR)

(30) Priority: **04.06.2004 KR 2004040994**
13.09.2004 KR 2004073172

(74) Representative: **Geary, Stuart Lloyd et al**
Venner Shipley LLP
20 Little Britain
London EC1A 7DH (GB)

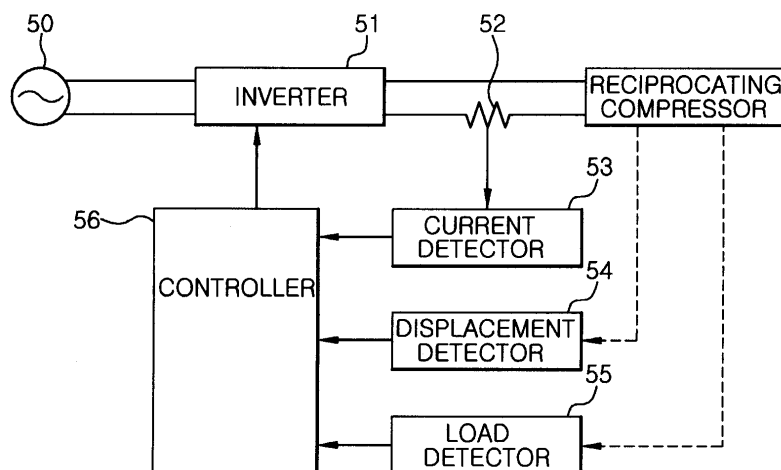
(71) Applicant: **SAMSUNG ELECTRONICS CO., LTD.**
Suwon-si, Gyeonggi-Do 442-742 (KR)

(54) **Compressor System**

(57) A driving unit and control method for a reciprocating compressor for controlling a frequency of input power so that an operational frequency of the compressor follows a resonant frequency, which varies depending on a variation of the load applied to the compressor. The reciprocating compressor includes an inverter to adjust the frequency of the input power, so that the fre-

quency of the input power is set at a value corresponding to the resonant frequency by the inverter. The resonant frequency is set in a range of 60% to 90% of the normal power frequency. The compressor further includes a controller to control the frequency of the input power so that the operational frequency of the compressor follows the resonant frequency, which varies depending on the operation of the compressor.

FIG 2.



Description

[0001] The present invention relates a reciprocating compressor system for compressing a refrigerant, the system comprising a compressing piston and a motor for linearly reciprocating said piston.

[0002] In general, compressors are used in air conditioning systems, refrigerators, etc. to compress a refrigerant. One type of compressor is a reciprocating compressor, which compresses the refrigerant by varying the volume of a compressing chamber by reciprocating a piston. Certain reciprocating compressors employ a rotary motor as the driving unit and others employ a linear motor.

[0003] The reciprocating compressors employing linear motors are configured such that their pistons, which reciprocate in their compressing chambers, are directly connected to rectilinearly reciprocating movers of linear motors and are supported by an elastic resonant spring. In such a reciprocating compressor, the compression of the refrigerant is achieved as the mover rectilinearly reciprocates in correspondence with the frequency of the alternating current power applied to the linear motor. The piston reciprocates in accordance with the rectilinear reciprocation of the mover. The resonant spring facilitates the movement of the piston and ensures smooth reciprocating motion by the piston.

[0004] The operational efficiency of the piston improves when the motion of the piston coincides with the resonant frequency (i.e. natural frequency) of the compressor. Therefore, there have been attempts to make compressor resonant frequencies coincide with typical mains power frequencies for improving compressor efficiency. That is, in order to improve the compression capability of compressors, it is important to adjust the resonant frequencies of the compressors to correspond to the typical power frequencies. Such an adjustment of the resonant frequency of the compressors can be achieved through control of the masses of the moving units, including the pistons and the movers of the linear motors, as well as controlling the elasticities of the resonant springs.

[0005] However, in conventional reciprocating compressors, which are controlled to have a resonant frequency equal to the mains power frequency, the input power must have a high frequency (e.g., the conventional North American 60Hz) must be used as the input power, resulting in an acceleration in the operational speed of the compressors. This makes it difficult to expand the available range of compression capabilities of the compressors and thus limits the operation of the compressors to a relatively low frequency range, and also results in reduced efficiency of the compressors due to motor core loss and mechanical friction loss.

[0006] Furthermore, the conventional reciprocating compressors sometimes experience a variation in resonant frequency due to variations in the gas pressure acting on the piston when the load varies during opera-

tion. Such a variation of the resonant frequency leads to an inconsistency between the resonant frequency and the operational frequency, resulting in a deterioration in the efficiency of the compressors.

[0007] Accordingly, it is an aspect of the present invention to provide a driving unit and control method for a reciprocating compressor for setting a resonant frequency of the compressor at a value less than a frequency of the typical power and making a frequency of input power to be applied to the compressor coincide with the resonant frequency, thereby being capable of expanding. Thus, the available range of compression capabilities of the compressor allows the compressor to resonate in a low frequency range which is less than the frequency of the typical power, resulting in an improvement in efficiency of the compressor.

[0008] It is another aspect of the present invention to provide a driving unit and control method for a reciprocating compressor for allowing an operational frequency of the compressor to coincide with a varying resonant frequency based on a variation of load applied to the compressor, thereby improving efficiency of the compressor.

[0009] Additional aspects and/or advantages of the invention will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the invention.

[0010] The forgoing and/or other aspects may be achieved by providing a reciprocating compressor including an inverter to receive a power and adjust a frequency of the received power and to input the adjusted power to the compressor, wherein: a resonant frequency of the compressor is less than a typical frequency of the received power, and a frequency of the input power corresponds to the resonant frequency.

[0011] The resonant frequency may be between 60% and 90% of the typical frequency of the power.

[0012] The compressor may further include a controller to control operation of the compressor, and the controller may control the frequency of the input power so that an operational frequency of the compressor follows the resonant frequency as the resonant frequency varies depending on the operation of the compressor.

[0013] The controller may determine a phase difference between the frequency of the input power and the operational frequency of the compressor, thereby controlling the inverter to increase or decrease the frequency of the input power according to a correction value corresponding to the phase difference.

[0014] The compressor may further include a current detector to detect the frequency of the input power applied from the inverter to the compressor; and a displacement detector to detect displacement of a piston mounted in the compressor so as to determine the operational frequency.

[0015] The compressor may further include a load detector to detect a load applied to the compressor; the controller may control the inverter so that the frequency

of the input power is equal to the resonant frequency when the load detected by the load detector is a normal load, and the frequency of the input power is greater than the resonant frequency when the detected load is a higher than the normal load.

[0016] The forgoing and/or other aspects are achieved by providing a reciprocating compressor an inverter to adjust a frequency of power input to the compressor including: and a controller to control the inverter so that an operational frequency of the compressor coincides with the frequency of the input power according to a determined phase difference between the operational frequency and the frequency of the input power.

[0017] The forgoing and/or other aspects are achieved by providing a driving unit for driving a reciprocating compressor including: an inverter to adjust a frequency of input power to be applied to the compressor; a load detector to determine a load applied to the compressor; and a controller to control the inverter so that the frequency of the input power is equal to a resonant frequency of the compressor when the load determined by the load detector is a normal load, whereas the frequency of the input power is greater than the resonant frequency when the determined load is greater than the normal load.

[0018] The forgoing and/or other aspects are achieved by providing a driving unit for driving a reciprocating compressor including: a piston; an inverter to adjust a frequency of input power to be applied to the compressor; a current detector to detect the frequency of the input power; a displacement detector to detect a displacement of the piston to thereby determine an operational frequency of the compressor; and a controller to control the inverter to thereby determine a phase difference between the operational frequency and the frequency of the input power and then increase or decrease the frequency of the input power based on the determined phase difference, wherein the operational frequency follows a resonant frequency, which varies depending on an operation of the compressor.

[0019] The forgoing and/or other aspects are achieved by providing a control method for a reciprocating compressor including: determining whether a load applied to the compressor is a high load or normal load; applying a power, having a frequency equal to a resonant frequency of the compressor, to the compressor if the load applied to the compressor is the normal load; and applying a power, having a frequency greater than the resonant frequency of the compressor, to the compressor if the load applied to the compressor is the high load.

[0020] The forgoing and/or other aspects are achieved by providing a control method for a reciprocating compressor having an inverter, including: determining a phase difference between a frequency of input power and an operational frequency of the compressor; and controlling the inverter to increase or decrease the frequency of the input power with a correction value cor-

responding to the phase difference.

[0021] An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a sectional view of a reciprocating compressor according to the present invention;

Figure 2 is a control block diagram of a driving unit provided in the reciprocating compressor of Figure 1; and

Figure 3 is a flowchart illustrating a control method for the reciprocating compressor of Figure 1.

[0022] Referring to Figure 1, the reciprocating compressor includes a hermetically sealed container 10 formed by coupling an upper container 10a and a lower container 10b. The reciprocating compressor further includes a compression unit 20 having a cylinder block 21, a piston 22 and a cylinder head 23 and a linear motor 30. The linear motor 30 drives the compression unit 20 and has a mover 31 and inner and outer stators 32, 33. The compression unit 20 and the linear motor 30 are mounted as a set in the hermetically sealed container 10.

[0023] The cylinder block 21 of the compression unit 20 includes: a cylinder portion 21a internally defining a compressing chamber 24 and a supporting portion 21 b radially extending from the outer circumference of a lower region of the cylinder portion 21a to support the outer stator 33 thereon. The cylinder block 21 is supported, at a lower end of the supporting portion 21 b thereof, by means of a plurality of damping members 25, so that the cylinder block 21 is spaced apart from an inner wall surface of the lower container 10b.

[0024] The piston 22 is mounted in the compressing chamber 24 of the cylinder block 21 in a vertically reciprocable manner. The cylinder head 23 is located under the cylinder block 21 and internally defines an introducing chamber 23a and a discharge chamber 23b. At the introducing chamber 23a of the cylinder head 23 is formed an introducing port 23c containing an introducing valve plate, and at the discharge chamber 23b of the cylinder head 23 is formed a discharge port 23d containing a discharge valve plate. Reference numeral 11 designates an outer introducing pipe, reference numeral 12 designates an introducing pipe connected to the introducing chamber 23a, and reference numeral 13 designates a discharge pipe connected to the discharge chamber 23b so as to extend to the outside of the hermetically sealed container 10.

[0025] The linear motor 30, adapted to actuate the piston 22, is mounted so that the mover 31 is located inside of the cylinder portion 21 a and the inner and outer stators 32 and 33 are located outside of the cylinder portion 21a. The mover 31 has a hollow cylindrical form so that an upper fixing portion 31 a thereof is coupled to the outer circumference of an upper region of the piston 22, thereby allowing the mover 31 to vertically reciprocate.

cate along with the piston 22. The mover 31 has a magnet 35 attached to a lower end of the upper fixing portion 31a. The magnet 35 allows the mover 31 to vertically reciprocate through an interaction between the magnet 35 and the outer stator 33.

[0026] Both the inner stator 32 and the outer stator 33 have a cylindrical form and are located, respectively, inside and outside of the mover 31. The inner stator 32 is fixed to the outer circumference of the cylinder portion 21a and guides the vertical reciprocation of the mover 31 and ensures smooth flow of magnetic flux through the magnet 35 of the mover 31. The outer stator 33 has an exciting coil 34 to electromagnetically interact with the magnet 35. A lower end of the outer stator 33 is supported on the supporting portion 21 b of the cylinder block 21 and an upper end of the outer stator 33 is supported by a fixing frame 36.

[0027] The reciprocating compressor further includes a resonant spring 37 in the form of a multi-layered plate spring. The resonant spring 37 is mounted on the fixing frame 36 to be spaced upward apart from the mover 31. The resonant spring 37 is centrally coupled to an upper end of the piston 22, and an outer circumferential edge of the resonant spring 37 is coupled to a spring supporting member 38 extending upward from the fixing frame 36. The resonant spring 37 configured as described above produces an exciting force by making use of elasticity thereof, so as to improve the movability of the piston 22.

[0028] To the resonant spring 37 are mounted a sensor core 41 and a coil-type displacement detecting sensor 42. The sensor core 41 extends upward from an upper surface of the mover 31 and is reciprocable following reciprocating movements of the mover 31 and the piston 22. The displacement detecting sensor 42 detects a distance of movement of the sensor core 41.

[0029] In the reciprocating compressor configured as described above, the outer stator 33 produces a magnetic field when an alternating current is applied to the exciting coil 34 thereof. The polarity of the produced magnetic field alternates, causing vertical reciprocating movement of the mover 31 having the magnet 35. As the mover 31 reciprocates, the piston 22 correspondingly reciprocates to achieve a compression operation, thereby enabling introduction and discharge of a refrigerant.

[0030] During the compression operation, if an operational frequency of the piston 22 coincides with a resonant frequency, i.e. the natural frequency of the compressor, resonance of the compressor is achieved. This increases the movability of the piston 22 and the mover 31 and improves efficiency of the compressor. As compared to conventional reciprocating compressors wherein the resonant frequency is controlled to coincide with typical power frequency, the reciprocating compressor of the embodiment of the present invention is controlled so that the resonant frequency of the compressor is set at a value less than the typical power fre-

quency. Also, a frequency of input power to be supplied to the reciprocating compressor corresponds to the resonant frequency, which is less than the typical power frequency.

[0031] For example, if the typical frequency of the power is 60Hz, the resonant frequency of the compressor is set at a value of approximately 50Hz, and thus the frequency of the input power is approximately 50Hz. In this case, if the resonant frequency and the frequency of the input power are excessively low, it may result in a deterioration in the efficiency of the compressor. Thus, when the typical frequency of the power is 60Hz, the resonant frequency and the frequency of the input power are in a range of 35 to 55Hz, corresponding to 60% to 90 % of the power frequency.

[0032] Such a configuration of the reciprocating compressor as described above is employed in order to expand the available range of compression capabilities of the compressor as compared to the prior art, so that the compressor resonates even in a relatively low frequency range. This can increase the available range of compression capabilities depending on a load variation of a cooling system using the compressor, as well as the efficiency of the compressor. The fact that the compressor can resonate at the relatively low frequency range, which is less than the typical power frequency, means that the compressor can more effectively operate under a general, low-load, low-speed running condition (hereinafter, referred to as a normal load condition). The compressor operates with the operational frequency, which is less than the frequency of the normal power in the normal load condition to reduce any possible motor core loss or mechanical friction loss, which results in the conventionally apparatus.

[0033] Referring to Figure 2, the driving unit includes an inverter 51 to adjust the voltage and frequency of input power supplied from an alternating current source 50 to the reciprocating compressor, and a current detector 53 to detect the frequency of the input power based on information transmitted from a current sensor 52. The driving unit further includes a displacement detector 54 to detect operational frequencies of the piston 22 and the mover 31 based on information transmitted from the displacement detecting sensor 42, mounted in the compressor, a load detector 55 to detect the temperature and the discharge and induction pressures of the compressor or the load applied to a cooling system containing the compressor, so as to detect the load applied to the compressor, and a controller 56 to control the inverter 51 based on information detected via the current detector 53, the displacement detector 54 and the load detector 55 in order to control the frequency of the input power being applied to the reciprocating compressor.

[0034] Now, the compression operation of the reciprocating compressor according to the embodiment of the present invention and a method for effectively controlling the compression operation will be explained.

[0035] When power, having a frequency of 60Hz, is supplied from the alternating current source 50 to start the compressor, the normal power is converted into input power having a frequency corresponding to a resonant frequency of the compressor by the inverter 51. That is, the frequency of the input power, being applied from the inverter 51 to the compressor, is approximately 50Hz, corresponding to the resonant frequency. Thereby, when the compressor is in a low load state, i.e. normal load state, the piston 22 reciprocates with an operation frequency of approximately 50Hz, performing a compression operation. That is, the compressor resonates in a low frequency range less than the frequency of the normal power, showing improved operational efficiency in the normal load state, which occupies a high running percentage of the compressor.

[0036] In the course of achieving the compression operation as described above, the controller 56 decides whether the load applied to the compressor is a normal load or a high load based on information transmitted from the load detector 55. In the case of the normal load, the controller 56 controls the inverter 51 so that the frequency of the input power corresponds to the resonant frequency of the compressor.

[0037] When the compressor runs in the normal load state, the controller 56 also controls the inverter 51 so that the frequency of the input power always corresponds to the resonant frequency even if the resonant frequency varies depending on a variation of load applied to the compressor. This enables the compressor to continuously resonate, and achieves optimized efficiency of the compressor. During operation of the compressor, although the mass of moving elements such as the piston 22 and the mover 31 and the elasticity of the resonant spring 37 are unchangeable, a gas pressure acting on the piston 22 varies depending on the load variation, inevitably resulting in a variation of the resonant frequency. Therefore, in order to continuously maintain the optimized efficiency of the compressor, the frequency of the input power varies according to the variation of the resonant frequency through a control operation of the controller 56.

[0038] Such a control operation achieved by the controller 56 will now be explained with reference to Figure 3. That is, in order to allow the frequency of the input power to follow the resonant frequency, the displacement detector 54 detects the displacement of the piston 22 to determine an operational frequency of the compressor (operation 61), and the current detector 53 determines the frequency of the input power (operation 62). On the basis of information determined by the detectors 53 and 54, the controller 56 determines a phase difference between the operational frequency and the frequency of the input power (operation 63), and decides whether the determined phase difference is zero, or is greater than or less than zero. This is done in order to decide the presence and magnitude of the phase difference (operations 64 and 65). If the frequency of the

input power is equal to the operational frequency, it can be said that the compressor is in a resonance state. Therefore, if the phase difference is zero, the controller 56 controls the inverter 51 to continuously maintain the frequency of the input power frequency (operation 66). If the phase difference is greater than zero, the controller 56 controls the inverter 51 to increase the frequency of the input power by calculating a correction value corresponding to the phase difference (operation 67). If the phase difference is less than zero, the controller 56 controls the inverter 51 to decrease the frequency of the input power by calculating a correction value corresponding to the phase difference (operation 68). In this way, on the basis of the determined phase difference between the frequency of the input power and the operational frequency, the controller 56 calculates the correction values to increase or decrease the frequency of the input power. Thus, the frequency of the input power (or the operational frequency) is controlled to follow the resonant frequency even if the resonant frequency varies depending on the load variation, resulting in optimized efficiency of the compressor.

[0039] Meanwhile, if the load detector 55 decides that the load applied to the compressor is higher than the normal load and thus the compressor is in the high load state, the controller 56 controls the inverter 51 to increase the frequency of the input power beyond the resonant frequency so that the high frequency of the input power is applied to the compressor in order to improve capability of the compressor. That is, as compared to the case of the normal load, wherein the frequency of the input power is controlled to coincide with the resonant frequency to maximize the efficiency of the compressor, in the case of the high load, the compressor is controlled to operate at the maximum compression rate possible without causing deterioration of the efficiency of the compressor. Since the compressor mainly runs in the normal load state rather than the high load state, the efficiency of the compressor can be maximized by optimizing the efficiency of the normal load state, which occupies a high running percentage of the compressor.

[0040] As is apparent from the above description, the embodiment of the present invention provides a reciprocating compressor in which a resonant frequency of the compressor is set at a value less than a typical power frequency, and a frequency of input power to be applied to the compressor is controlled to coincide with the resonant frequency. This expands the available range of compression capabilities of the compressor to allow the compressor to resonate even in a relatively low frequency range, which is less than the typical power frequency, resulting in an improvement in efficiency of the compressor. This improves the efficiency of the compressor under a normal load state, which occupies a high running percentage of the compressor, achieving optimized efficiency of the compressor.

[0041] Further, according to the embodiment of the present invention, even if the resonant frequency varies

depending on a variation of a load applied to the compressor during operation of the compressor, an operational frequency of the compressor is controlled to follow the varied resonant frequency, so as to allow the continuous resonance of the compressor, resulting in maximized efficiency of the compressor.

Claims

1. A reciprocating compressor comprising:

an inverter to receive a power and adjust a frequency of the received power and to input the adjusted power to the compressor, wherein:

a resonant frequency of the compressor is less than a typical frequency of the received power, and
a frequency of the input power corresponds to the resonant frequency.

2. The compressor according to claim 1, wherein the resonant frequency is between 60% to 90% of the typical frequency of the received power.

3. The compressor according to claim 2, further comprising:

a controller to control an operation of the compressor,

wherein the controller controls the frequency of the input power so that an operational frequency of the compressor follows the resonant frequency as the resonant frequency varies depending on the operation of the compressor.

4. The compressor according to claim 3, wherein the controller determines a phase difference between the frequency of the input power and the operational frequency of the compressor, thereby controlling the inverter to increase or decrease the frequency of the input power according to a correction value corresponding to the phase difference.

5. The compressor according to claim 4, further comprising:

a piston mounted in the compressor;
a current detector to detect the frequency of the input power; and
a displacement detector to detect a displacement of the piston to determine the operational frequency.

6. The compressor according to claim 5, further comprising:

a load detector to detect a load applied to the compressor

wherein the controller controls the inverter so that the frequency of the input power is equal to the resonant frequency when the load detected by the load detector is a normal load, and the frequency of the input power is greater than the resonant frequency when the detected load is higher than the normal load.

7. A reciprocating compressor comprising:

an inverter to adjust a frequency of power input to the compressor; and
a controller to control the inverter so that an operational frequency of the compressor coincides with the frequency of the input power according to a determined phase difference between the operational frequency and the frequency of the input power.

8. The compressor according to claim 7, wherein the controller controls the inverter to increase or decrease the frequency of the input power according to a correction value corresponding to the phase difference, thereby allowing the operational frequency to follow a resonant frequency of the compressor which varies depending on an operation of the compressor.

9. A driving unit for driving a reciprocating compressor, comprising:

an inverter to adjust a frequency of input power to be applied to the compressor;
a load detector to determine a load applied to the compressor; and
a controller to control the inverter so that the frequency of the input power is equal to a resonant frequency of the compressor when the load determined by the load detector is a normal load, whereas the frequency of the input power is greater than the resonant frequency when the determined load is greater than the normal load.

10. A driving unit for driving a reciprocating compressor, comprising:

a piston;
an inverter to adjust a frequency of input power to be applied to the compressor;
a current detector to detect the frequency of the input power;
a displacement detector to detect a displacement of the piston to thereby determine an operational frequency of the compressor; and

a controller to control the inverter to thereby determine a phase difference between the operational frequency and the frequency of the input power and then increase or decrease the frequency of the input power based on the determined phase difference, wherein the operational frequency follows a resonant frequency, which varies depending on an operation of the compressor.

11. A control method for a reciprocating compressor comprising:

determining whether a load applied to the compressor is a high load or normal load;
 applying a power, having a frequency equal to a resonant frequency of the compressor, to the compressor if the load applied to the compressor is the normal load; and
 applying a power, having a frequency greater than the resonant frequency of the compressor, to the compressor if the load applied to the compressor is the high load.

12. A control method for a reciprocating compressor having an inverter, comprising:

determining a phase difference between a frequency of input power and an operational frequency of the compressor; and
 controlling the inverter to increase or decrease the frequency of the input power with a correction value corresponding to the phase difference.

13. The compressor according to claim 4, wherein the controller maintains the frequency of the input power when the determined phase difference is zero.

14. The compressor according to claim 5, wherein the resonant frequency varies according to a gas pressure acting on the piston.

15. A control method for a reciprocating compressor:

inputting a power having a frequency greater than a resonant frequency of the compressor;
 adjusting the input power to the resonant frequency of the compressor; and driving the compressor with the adjusted power.

16. A reciprocating compressor system for compressing a refrigerant, the system comprising:

a compressing piston (22); and
 a motor (32, 34) for linearly reciprocating said piston (22),

characterised by

a variable frequency power supply (51) for driving said motor (22);
 phase detection means (53, 54, 56) for detecting the phase difference between the output current of the power supply (51) and the displacement of the piston (22); and
 control means (56) configured for controlling the frequency of said power supply (51) in dependence on the output of the phase detection means (53, 54, 56) so as to tend to match the frequency of the power supply (51) to the natural reciprocation frequency of the piston (22).

17. A system according to claim 1, including a compressor load detecting means (55), wherein the control means (56) is configured such that when the load is at a first low lever, it controls the frequency of said power supply (51) in dependence on the output of the phase detection means (53, 54, 56) so as to tend to match the frequency of the power supply (51) to the natural reciprocation frequency of the piston (22) and when the load is at a second high level, it controls the frequency of said power supply (51) in dependence on the output of the phase detection means (53, 54, 56) so as to maintain the frequency of the power supply (51) to a frequency above the natural reciprocation frequency of the piston (22).

FIG 1.

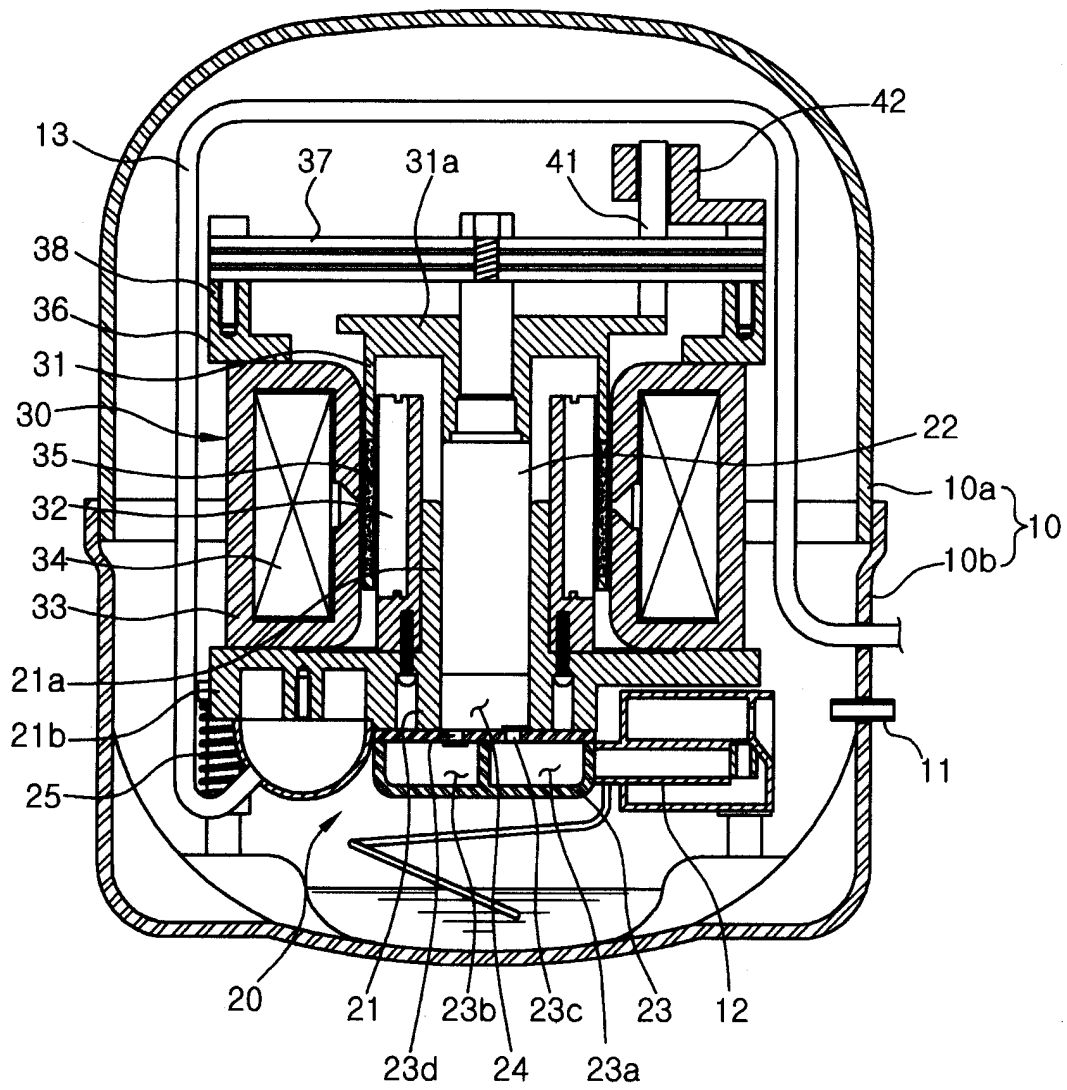


FIG 2.

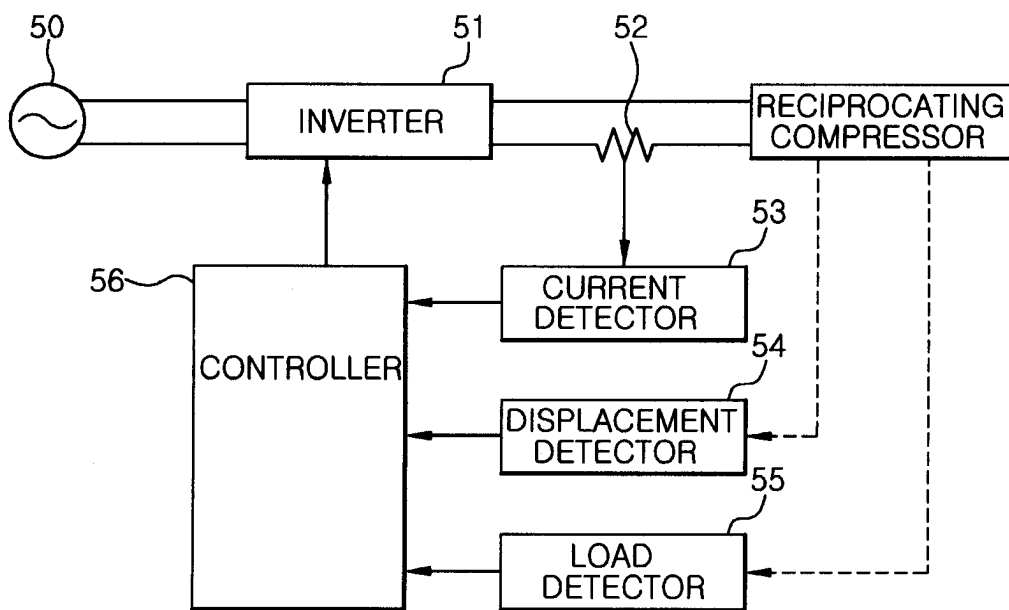


FIG 3.

