(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 691 150 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
16.08.2006 Bulletin 2006/33

(21) Application number: **04720265.0**

(22) Date of filing: **12.03.2004**

(51) Int Cl.:
F25B 49/02 *(2006.01)*

(86) International application number:
PCT/JP2004/003451

(87) International publication number:
WO 2005/028972 (31.03.2005 Gazette 2005/13)

(84) Designated Contracting States:
DE FR GB IT

(30) Priority: **19.09.2003 JP 2003329149**

(71) Applicants:
- **KABUSHIKI KAISHA TOSHIBA**
Tokyo 105-8001 (JP)
- **Toshiba Consumer Marketing Corporation**
Tokyo 101-0021 (JP)
- **Toshiba Ha Products Co., Ltd.**
Ibaraki-shi,
Osaka 567-0013 (JP)

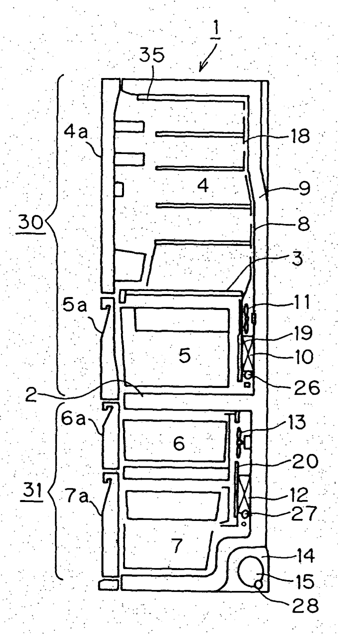
(72) Inventors:
- **ADACHI, Kosaku,**
Toshiba HA Products Co., Ltd.
Ibaraki-shi, Osaka 5670013 (JP)
- **MARUTANI, Yuuki,**
Toshiba HA Products Co., Ltd.
Ibaraki-shi, Osaka 5670013 (JP)
- **NOGUCHI, Akihiro,**
Toshiba HA Products Co., Ltd.
Ibaraki-shi, Osaka 5670013 (JP)
- **SAKUMA, Tsutomu,**
Toshiba HA Products Co., Ltd.
Ibaraki-shi, Osaka 5670013 (JP)

(74) Representative: **Giles, Ashley Simon**
HASELTINE LAKE
Redcliff Quay
120 Redcliff Street
Bristol BS1 6HU (GB)

(54) REFRIGERANT LEAKAGE DETECTING DEVICE AND REFRIGERATOR USING THE SAME

(57) In a refrigerator using a flammable coolant, a coolant leakage detecting device is provided with which it is possible to improve the detection accuracy of coolant leakages certainly in correspondence with input fluctuations of a compressor. When a coolant leak occurs on the low-pressure side of a refrigerating cycle, because the internal pressure of the cycle in operation is negative, air is sucked in and the power increases. When the value of this increase in an instantaneous power for determination Wi(t) rises above a reference increase value G1, it is determined that there is a low-pressure side leak. On the other hand, when a coolant leak occurs on the high-pressure side of the refrigerating cycle, the internal pressure of the cycle in operation decreases and along with this the power decreases. When the value of this decrease in the instantaneous power for detection Wi(t) exceeds a reference decrease value G2, it is determined that there is a coolant leak on the high-pressure side.

FIG. 1



EP 1 691 150 A1

Description

(TECHNICAL FIELD)

[0001] This invention relates to a refrigerator that uses a flammable coolant.

(BACKGROUND ART)

[0002] Because coolants such as hydrocarbons that have been used in refrigerators in recent years are flammable, when a coolant leak occurs there is a possibility of it developing into an accident such as a fire, and it has been necessary to ensure full safety even in this case.

[0003] In related art, coolant leak detection of flammable coolant in an invertor-controlled refrigerator has been carried out by compressor input changes being monitored as duty changes of PWM drive, and it being inferred that a leak has occurred from the low-pressure side of the refrigerating cycle when with the compressor speed in a fixed range the duty has risen above a certain ratio with respect to an initial value and it being determined that a leak has occurred from the high-pressure side of the refrigerating cycle when it has fallen below a certain ratio (for example JP-A-2003-139446).

[0004] However, when making determinations with a duty value of PWM drive like this, there are the following problems.

[0005] First, there is the problem that there is a possibility of a mis-determination of a leak being made when the cycle is normal because the duty changes with fluctuations in the AC input voltage.

[0006] Next, as shown in Fig. 9, there is the problem that changes in the duty value are small with respect to input fluctuations of the compressor, and when the threshold values for determination are made large there is a high probability of mis-determination, and conversely when they are made small it is not possible to detect coolant leaks.

[0007] In this connection, the present invention provides a coolant leakage detecting device with which it is possible in a refrigerator using a flammable coolant to increase the accuracy of detection of coolant leaks certainly in correspondence with input fluctuations of the compressor.

[0008] The invention pertaining to claim 1 is a coolant leakage detecting device characterized in that it has: a refrigerator cycle having at least a compressor driven by a three-phase brushless DC motor, a condenser and an evaporator; an invertor circuit for supplying three-phase drive currents to stator windings of the brushless DC motor; a PWM circuit for supplying PWM signals to the invertor circuit; drive current detecting means for detecting the three-phase drive currents; dq converting means for converting the detected three-phase drive currents into a d-axis current, which is a current component corresponding to the flux of the rotor of the brushless DC motor, and a q-axis current, which is a current component corresponding to the torque of the brushless DC motor; control means for outputting a reference q-axis current and a reference d-axis current on the basis of the converted q-axis current and d-axis current and a speed command signal inputted from outside; voltage converting means for converting the reference q-axis current and the reference d-axis current into a reference q-axis voltage and a reference d-axis voltage; three-phase converting means for converting the converted reference q-axis voltage and reference d-axis voltage into three-phase voltages and outputting them to the PWM circuit; power value calculating means for calculating a power value from the product of the detected q-axis current and the reference q-axis voltage; and determining means for sampling a reference power value from the power value calculated by the power value calculating means, sampling a power value for determination a predetermined time after sampling the reference power value, and determining that a coolant leak has occurred when the difference between the reference power value and the power value for determination is above a predetermined value.

[0009] The invention pertaining to claim 2 is a coolant leakage detecting device according to claim 1 characterized in that both a magnet torque and a reluctance torque are used for the rotation of the rotor of the brushless DC motor and a negative d-axis current is made to flow so that a maximum torque is obtained, and the power calculating means calculates the power value from a value obtained by adding the product of the detected d-axis current and the reference d-axis voltage to the product of the detected q-axis current and the reference q-axis voltage.

[0010] The invention pertaining to claim 3 is a coolant leakage detecting device according to claim 1 characterized in that the after sampling the reference power value the determining means samples multiple power values at intervals of a fixed time and averages these multiple sampled power values to obtain the power value for determination.

[0011] The invention pertaining to claim 4 is a refrigerator characterized in that it uses a coolant leakage detecting device according to at least one of claims 1 to 3.

[0012] The invention pertaining to claim 5 is a refrigerator according to claim 4 characterized in that when it has determined that a coolant leak has occurred the determining means temporarily stops high-voltage parts in the refrigerator while cooling is continued, and after a predetermined time has elapsed from when it determined the coolant leak it cancels the stoppage of the high-voltage parts in accordance with the detected temperature of a temperature sensor mounted in the refrigerator.

[0013] The invention pertaining to claim 6 is a refrigerator according to claim 5 characterized in that the predetermined time is altered in correspondence with a number of openings and closing of a door of the refrigerator.

[0014] In a coolant leakage detecting device of the invention pertaining to claim 1, because a power value is calculated from the product of a detected q-axis current and a reference q-axis voltage and a reference power value is sampled from the calculated power value and a power value for determination is sampled a predetermined time after the sampling of the reference power value and it is determined that a coolant leak has occurred when the difference between the reference power value and the power value for determination is above a predetermined value, coolant leaks can be detected without fail.
[0015] In a coolant leakage detecting device of the invention pertaining to claim 2, when the rotor is of an embedded permanent magnet type, besides the magnet torque a reluctance torque owing to a difference between a q-axis direction inductance and a d-axis direction inductance arises, and the two torques combined exceed the magnet torque. A method of advancing the current phase with respect to the induced voltage (q-axis direction) so as to drive the motor at the point at which this combined torque is a maximum is used. Because a negative Id in this case is made to flow to advance the current phase and achieve the maximum torque, a power also arises on the d-axis. Therefore, the power calculating means calculates the power value from the value obtained by adding the product of the detected d-axis current and the reference d-axis voltage to the product of the detected q-axis current and the reference q-axis voltage.
[0016] In a coolant leakage detecting device of the invention pertaining to claim 3, whereas when an instantaneous power value is calculated variation arises in the course of one rotation of the compressor, to prevent this, an average value of instantaneous power values in one rotation or multiple rotations is calculated.
[0017] In a refrigerator of the invention pertaining to claim 4, a coolant leakage detecting device can be suitably used in a refrigerator using a flammable coolant.
[0018] In a refrigerator of the invention pertaining to claim 5, because it is determined at an early stage that there is a possibility of a coolant leak and high-voltage electrical parts of which it is the case that when the surrounding gas concentration has reached a flammable range and furthermore the part is defective there is a possibility of ignition are stopped, safety in the worst case can be ensured while normal cooling is continued, and when a coolant leak was mis-detected the refrigerator can be restored swiftly and certainly to normal running.
[0019] In a refrigerator of the invention pertaining to claim 6, the time to the determination based on the temperature sensor is altered in correspondence with the number of times the door is opened and closed before the state of the refrigerator based on its temperature is determined, and the cooling capacity condition can be determined with certainty.

(BRIEF DESCRIPTION OF THE DRAWINGS)

[0020]

Fig. 1 is a sectional view of a refrigerator showing a preferred embodiment of the invention;
Fig. 2 is a refrigerating cycle diagram of a refrigerator of the preferred embodiment;
Fig. 3 is a chart showing power changes at the time of a low-pressure leak;
Fig. 4 is a chart showing power changes at the time of a high-pressure leak;
Fig. 5 is a block diagram of a refrigerator according to the preferred embodiment;
Fig. 6 is a vector diagram for performing an $\alpha\beta$ change from three-phase;
Fig. 7 is a vector diagram for performing a dq change from $\alpha\beta$;
Fig. 8 is a graph showing a relationship between a compressor input measured value and a power value Wi; and
Fig. 9 is a graph showing a relationship between a compressor input measured value and duty values in related art.

(BEST MODES FOR CARRYING OUT THE INVENTION)

[0021] A refrigerator 1 constituting a preferred embodiment of the invention will now be described.

(1) Construction of the Refrigerator 1

[0022] First, the construction of the refrigerator 1 will be described, on the basis of Fig. 1 and Fig. 2.
[0023] Fig. 1 is a sectional view of a refrigerator 1 illustrating this preferred embodiment, and Fig. 2 is a schematic view of the refrigerating cycle of the refrigerator 1.
[0024] The cabinet of the refrigerator 1 is made up of an insulating casing 9 and an inner casing 8 and is divided by an insulating partition wall 2 into a refrigerating temperature section 30 and a freezing temperature section 31, and the structure is such that the two temperature sections 30, 31 are completely independently cooled and there is no mixing of cold air between the two.
[0025] The interior of the refrigerating temperature section 30 is divided by a refrigerator partition plate 3 into a refrigerated storage compartment 4 and a vegetable compartment 5, the freezing temperature compartment 31 is made up of a first freezer compartment 6 and a second freezer compartment 7, and the compartments have respective opening

and closing doors 4a, 5a, 6a and 7a. Also, a temperature sensor (hereinafter, R sensor) 34 for detecting the interior temperature and a deodorizing device 35 are disposed in the refrigerated storage compartment 4. A high-voltage part is used as this deodorizing device 35, and it is for example a device of a type that has a photocatalyst disposed between a pair of electrodes and effects deodorization by discharging electricity between these electrodes and thereby producing ozone.

[0026] A refrigerator compartment evaporator 10 and a refrigerator compartment cooling fan 11 are mounted on the back wall of the vegetable compartment 5, and the refrigerator compartment cooling fan 11 is operated as necessary on the basis of interior temperature fluctuations and/or door opening and closing. The back wall of the refrigerated storage compartment 4 constitutes a cold air circulation path 18 for supplying cold air into the refrigerating temperature section 30. A defrosting heater 26 is disposed below the freezer compartment evaporator 12.

[0027] A freezer compartment evaporator 12 and å freezer compartment cooling fan 13 are mounted on the back wall of the first and second freezer compartments 6, 7 and cool the first and second freezer compartments 6, 7 by circulating cold air.

[0028] A compressor 15 and a condenser 21 of a refrigerating cycle shown in Fig. 2 are mounted in a machine compartment 14 at the bottom of the rear wall of the refrigerator 1, and after flammable coolant discharged from the compressor 15 passes through the condenser 21 a flammable coolant switching mechanism of a switching valve 22 switches alternately between flammable coolant flow paths to alternately realize a freezer mode and a refrigerator mode.

[0029] A refrigerator capillary tube 23 and the refrigerator compartment evaporator 10 are connected in turn to one outlet of the switching valve 22, a freezer capillary tube 24 and the freezer compartment evaporator 12 are connected in turn to another outlet of the switching valve 22, and an accumulator 16 is connected to the freezer compartment evaporator 12.

[0030] In a refrigerator 1 of the construction described above, the flammable coolant paths are switched by the switching valve 22, and in the freezer mode, which is for cooling the freezing temperature section 31, flammable coolant is reduced in pressure in the freezer capillary tube 24 and enters the freezer compartment evaporator 12, cools the freezing temperature section 31, and then returns to the compressor 15 again.

[0031] On the other hand, in the refrigerator mode, which is for cooling the refrigerating temperature section 30, flammable coolant constitutes the refrigerating cycle in which the flammable coolant is reduced in pressure in the refrigerator capillary tube 23 and enters the refrigerator compartment evaporator 10, cools the refrigerating temperature section 30, and then returns to the compressor 15 again through the freezer compartment evaporator 12.

[0032] In the freezer mode (called F-cooling in Fig. 3 and Fig. 4), the flammable coolant flows through the freezer capillary tube 24, the freezer compartment evaporator 12 and the accumulator 16 in turn, cold air is circulated around the interior by the operation of the freezer compartment cooling fan 13, and cooling of the first and second freezer compartments 6, 7 is effected.

[0033] In the refrigerator mode (called R-cooling in Fig. 3 and Fig. 4), when the switching valve 22 switches over and the flammable coolant path switches from the freezing temperature section 31 side to the refrigerating temperature section 30 side, flammable coolant flows into the refrigerator compartment evaporator 10, and by the operation of the refrigerator compartment cooling fan 11 the refrigerated storage compartment 4 and the vegetable compartment 5 are cooled.

(2) Construction of the Electrical System of the Refrigerator 1

[0034] The construction of the electrical system of the refrigerator 1 will now be described on the basis of the block diagram of Fig. 5.

[0035] As shown in Fig. 5, the electrical system is made up of a three-phase brushless DC motor (hereinafter, compressor motor) 28 for driving the compressor 15, a drive unit (hereinafter, compressor drive unit) 32 for driving this compressor motor 28, and a main control part 33 of the refrigerator 1 for controlling this compressor drive unit 32. Also, door switches 4b to 7b respectively provided on the doors 4a to 7a of the compartments 4, 5, 6 and 7 are connected to the main control part 33. And the deodorizing device 35, the defrosting heater 26 and the R sensor 34 are also connected to the main control part 33.

[0036] First, the construction of the compressor drive unit 32 will be described.

[0037] The compressor drive unit 32 is made up of an invertor circuit 42, a rectifier circuit 44, an a.c. power supply 46, a PWM formation part 48, an AD convertor part 50, a dq convertor part 52, a speed detector part 54, a speed command outputting part 56, a speed PI-control part 58, a q-axis current PI-control part 60, a d-axis current PI-control part 62, and a three-phase convertor part 64.

[0038] As mentioned above, the compressor motor 28 for rotating the compressor 15 is a three-phase brushless DC motor. The invertor circuit 42 passes driving currents of three phases through stator windings 40u, 40v, 40w of the three phases (u phase, v phase, w phase) of this compressor motor 28.

[0039] This invertor circuit 42 is a full-bridge invertor circuit made up of six transistors Tr1 to Tr6, which are power switching semiconductor devices. Although they are not shown in the figure, diodes are connected in the opposite direction in parallel to these switching transistors Tr1 to Tr6. And, a detection resistance R1 for detecting a drive current is connected in series with the switching transistors Tr1 and Tr4, a detection resistance R2 is connected in series with the switching transistors Tr2 and Tr5, and a detection resistance R28 is connected in series with the switching transistors Tr28 and Tr6.

[0040] The rectifier circuit 44 is supplied with an a.c. voltage from the a.c. power supply 46, which is a commercial power supply (AC100V), and rectifies this and supplies it to the invertor circuit 42.

[0041] The PWM formation part supplies PWM signals to the gate terminals of the six switching transistors Tr1 to Tr6. The PWM formation part 48 performs pulse width modulation on the basis of voltages Vu, Vv, Vw of three phases, which will be further discussed later, and turns ON/OFF the switching transistors Tr1 to Tr6 with a predetermined timing.

[0042] The AD convertor part 50 detects voltage values at the detection resistances R1, R2 and R28, converts the voltage values of the different phases from analog values into digital values, and outputs drive currents Iu, Iv, Iw of the three phases.

[0043] The dq convertor part 52 converts the drive currents Iu, Iv, Iw outputted from the AD convertor part 50 into a d-axis (direct-axis) current Id, which is a current component corresponding to magnetic flux, and a q-axis (quadrature-axis) current Iq, which is a current component corresponding to the torque of the compressor motor 28.

[0044] As the conversion method here, the three phases Iu, Iv, Iw are converted into two phases Iα, Iβ as shown in Exp. (1). Fig. 6 is a vector diagram showing the relationship between the three phase currents and the two phase currents.

Exp. (1)

[0045] Next, the two-phase currents Iα, Iβ obtained by this conversion are converted into a q-axis current Iq and a d-axis current Id using Exp. (2). The relationship between these two-phase driving currents and the converted (detected) q-axis current Iq and d-axis current Id is as shown in the vector diagram of Fig. 7.

Exp. (2)

[0046] In the speed detector part 54, on the basis of the detected q-axis current Iq and d-axis current Id, the rotation angle θ and the speed ω of the compressor motor 28 are detected. The rotation angle θ, which is the position of the rotor of the compressor motor 28, is obtained on the basis of the q-axis current and the d-axis current, and the rotation speed ω is obtained by differentiating this θ.

[0047] The main control part 33 of the refrigerator 1 outputs a speed command signal S on the basis of the q-axis current Iq sent to it from the dq convertor part 52.

[0048] The speed command outputting part 56 outputs a reference rotation speed ωref on the basis of the speed command signal S from the main control part 33 and the rotation speed ω from the speed detector part 54. The reference rotation speed ωref is inputted to the speed PI-control part 58 together with the present rotation speed ω.

[0049] In the speed PI-control part 58, PI-control is carried out on the basis of the differential between the reference rotation speed ωref and the present rotation speed ω, a reference q-axis current Iqref and a reference d-axis current Idref are outputted, and together with the present q-axis current Iq and the present d-axis current Id they are outputted to the q-axis current PI-control part 60 and the d-axis current PI-control part 62 respectively.

[0050] In the q-axis current PI-control part 60, current/voltage conversion and PI-control are carried out, and a reference q-axis voltage Vq is outputted.

[0051] In the d-axis current PI-control part 62, current/voltage conversion and PI-control are carried out, and a reference d-axis voltage Vd is outputted.

[0052] In the three-phase convertor part 64, the reference d-axis voltage Vd and the reference q-axis voltage Vq are first converted to two-phase voltages on the basis of Exp. (3).

Exp. (3)

[0053] These converted two-phase voltages Vα, Vβ are then converted to three-phase voltages Vu, Vv, Vw on the basis of Exp. (4).

Exp. (4)

[0054] These converted three-phase voltages Vu, Vv, Vw are outputted to the above-mentioned PWM formation part 48.
[0055] In this compressor drive unit 32, the rotation speed is detected on the basis of the detected d-axis current Id and q-axis current Iq, feedback control is carried out on the basis of this rotation speed w and a speed command signal S from the main control part, and PWM signals are outputted to the invertor circuit 42 from the PWM formation part 48 so that the compressor motor 28 rotates at a rotation speed ωref matched to the speed command signal S. On the basis of this the invertor circuit 42 outputs drive currents of three phases to the three phases of stator windings 40 of the compressor motor 28.

(3) Power Calculation Method

[0056] Next, the power calculation method will be explained.
[0057] The power is calculated using the dq axis. In a case where the permanent magnets of the rotor are of a surface type, because control is carried out so that the efficiency is a maximum when Id = 0, power only arises in the q-axis direction. Therefore, the instantaneous power Wi of the compressor motor 28 is obtained from the product of the detected q-axis current Iq(t) and the reference q-axis voltage Vq(t). That is, it can be calculated as

$$Wi(t) = Iq(t) \times Vq(t). \quad ...(5)$$

[0058] The instantaneous power Wi(t) is fed to the main control part 33. As shown in Fig. 8, the instantaneous power Wi(t) matches the measured input value of the compressor motor 28.
[0059] Because the compressor input is decided on the basis of the load on the refrigerating cycle, the AC voltage does not affect it.

(4) Behavior when Flammable Coolant has Leaked

[0060] Here, the behavior of the instantaneous power value Wi(t) when flammable coolant has leaked while a refrigerating cycle using flammable coolant is running will be discussed.
[0061] Fig. 3 shows power changes of when flammable coolant has leaked from the low-pressure side of the refrigerating cycle.
[0062] When a coolant leakage location arises on the low-pressure side of the refrigerating cycle (in F-cooling [2] in Fig. 3), because the cycle in operation has a negative pressure, it sucks in air and the power increases. When the value of this increase in the instantaneous power value Wi(t) for determination rises above a predetermined value (hereinafter called the reference increase value G2), a low-pressure side leak is inferred.
[0063] When a coolant leakage location arises on the high-pressure side of the refrigerating cycle (in R-cooling [2] in Fig. 4), the internal pressure of the cycle in operation decreases and the power decreases. When the value of this decrease in the instantaneous power value Wi(t) for determination rises above a predetermined value (hereinafter called the reference decrease value G1), a high-pressure leak is inferred.

(5) First Coolant Leakage Determining Method

[0064] Next, a coolant leakage determining method will be explained.
[0065] The main control part 33 monitors the instantaneous power value Wi(t) fed to it and performs a coolant leakage determination.

(5-1) High-Pressure Side Coolant Leakage

[0066] After a few minutes from when the compressor 15 starts up, a reference power value Wi(t0) is stored. Thereafter the actual power value Wi(t) and the reference power value Wi(t0) are compared at fixed intervals. And when the power value for determination Wi(t) decreases to more than the reference decrease value G1 below the reference power value Wi(t0), a high-pressure leak is inferred. That is, when

$$Wi(t0) - Wi(t) > G1. \quad ...(6)$$

[0067] At the time of a high-pressure leak, because flammable coolant escapes, the load on the compressor 15 falls and the power falls dramatically. After a high-pressure leak determination, for example the compressor 15 is stopped.

[0068] The reference decrease value respective to the reference power value is set by experiment so that when the cycle is normal the power value for determination does not fall below the reference power value by more than the reference decrease value but at the time of a coolant leak the leak can be detected.

(5-2) Low-Pressure Side Coolant Leak

[0069] After a few minutes from when the rotation speed of the compressor 15 reaches a designated rotation speed, the reference power value Wi(t0) is stored. For example, a new reference power value Wi(t0) is set when the refrigerating cycle has switched over from the freezing temperature section 31 to the refrigerating temperature section 30.

[0070] Thereafter, the power value for determination Wi(t) and the reference power value Wi(t0) are compared at fixed intervals. And when the power value for determination Wi(t) rises above the reference power value Wi(t0) by more than the reference increase value G2, a low-pressure leak determination is made. That is, when

$$Wi(t) - Wi(t0) > G2. \quad ...(7)$$

[0071] At the time of a low-pressure leak determination, because air is sucked in, the input increases dramatically. The ratio with respect to the reference power value Wi(t0) is set by experiment so that when the cycle is normal the power value for determination does not rise above the reference power value by more than the reference increase value but at the time of a coolant leak the leak can surely be detected. After a high-pressure leak determination, for example the driving of high-voltage parts is stopped.

(6) Second Coolant Leakage Determination Method

[0072] In a case where the rotor has embedded permanent magnets, besides the magnet torque a reluctance torque due to a difference between an inductance in the q-axis direction and an inductance in the d-axis direction arises, and the two torques combined are greater than the magnet torque alone.

[0073] A method whereby the current phase is advanced with respect to the induced voltage (q-axis direction) so as to drive the compressor motor at the point at which this combined torque is a maximum is used. And because a negative Id in this case is made to flow to advance the current phase and achieve the maximum torque, a power also arises on the d-axis.

[0074] The method for calculating the instantaneous power value Wi(t) of the compressor motor 28 in this case is as follows.

$$Wi(t) = Iq(t) \times Vq(t) + Id(t) \times Vq(t) \quad ...(8)$$

[0075] Using this instantaneous power value Wi(t), a determination is made in the same way as in the first coolant leakage determination method.

(7) Third Coolant Leakage Determination Method

[0076] In the first and second coolant leakage determination methods, because the power is the instantaneous power value Wi(t), variation arises in the course of one revolution of the compressor 15.

[0077] In this third method, an average value of the instantaneous power value wi(t) over one revolution or multiple revolutions is calculated and compared with the reference power value Wi(t0), and a determination is made in the same way as in the first coolant leakage determination method.

(8) Control Method for After a Coolant Leakage Determination (8-1) First Control Method

[0078] When a coolant leak is determined as described above (hereinafter called a first-stage determination), the main control part 33 forcibly stops the driving of high-voltage parts such as the deodorizing device 35 and the defrosting heater 36 to ensure safety.

[0079] Then, after making the coolant leak determination in the first-stage determination, the main control part 33 makes a second-stage determination. In this second-stage determination, a fixed time (for example twelve hours) after the first-stage determination, or after a set number of alternate coolings (for example three) has elapsed, if the freezer compartment temperature detected by the R sensor 34 has fallen below a set temperature it is inferred that there was no coolant leak and the main control part 33 discontinues the stopping of the high-voltage parts, and if it is above the set temperature it is inferred that there was a coolant leak.

[0080] The reason for carrying out this two-stage determination is that when a lot of foodstuffs or foodstuffs having a high heat capacity are placed in the refrigerator, the interior temperature rises and the load on the compressor 15 becomes large, and when in this state a coolant leak is mistakenly mis-determined in the first stage, if at the second stage the interior temperature has fallen it can be determined that there is no coolant leak, so that coolant leaks can be detected stably. (8-2) Second Control Method

[0081] When from the main control part 33 making a coolant leak determination the number of door openings and closings detected by the door switches 4b to 7b exceeds a predetermined number (for example three) or the time for which a door is open exceeds a predetermined time (for example three minutes), it may be inferred that even if flammable coolant has leaked it will have flowed to outside and its concentration will have been amply diluted, and the time to the determination by the R sensor 34 may be made short, and in this case it is possible to shorten the time taken for the refrigerator to return to normal operation.

(8-3) Third Control Method

[0082] Conversely to the second control method, when the number of door openings and closings detected by the door switches 4b to 7b rises above a predetermined number, because the interior cooling capacity of the refrigerator may have deteriorated due to a door being opened, the time to the determination by the R sensor 34 may be made longer (for example extended by one hour); in this case, mis-detections caused by temperature rises due to door openings can be prevented and coolant leaks can be more certainly detected.

(8-4) Fourth Control Method

[0083] When the defrosting heater 26 is a pipe heater or is of an explosion-proof construction with a low heating temperature, even when a coolant leakage determination is made, by defrosting of the freezer compartment evaporator 12 being carried out without control being stopped until the determination by the R sensor 34, the influence of deterioration of the interior cooling capacity caused by frosting impairment of the evaporator can be removed, and coolant leak detection can be made more certain. In this case, to prevent mis-detection by the temperature detection of the R sensor 34 due to temperature increase after defrosting, the detection may be made a predetermined time after defrosting is completed (for example six hours after).

(9) Variation

[0084] Besides the freezer compartment temperature detected with the R sensor 34, the temperature detected with a temperature sensor may alternatively be that of any other location where the cooling performance of the refrigerator 1 can be inferred, such as the refrigerator compartment temperature, the freezer compartment evaporator temperature, the refrigerator compartment evaporator temperature, a switching compartment temperature, or an ice-making compartment temperature.

(INDUSTRIAL APPLICABILITY)

[0085] A coolant leakage detecting device according to the invention can be used for a compressor for a household refrigerator or air-conditioner.

Claims

1. A coolant leakage detecting device, **characterized in that** it has:

a refrigerator cycle having at least a compressor driven by a three-phase brushless DC motor, a condenser and an evaporator;
an invertor circuit for supplying three-phase drive currents to stator windings of the brushless DC motor;
a PWM circuit for supplying PWM signals to the invertor circuit;
drive current detecting means for detecting the three-phase drive currents;
dq converting means for converting the detected three-phase drive currents into a d-axis current, which is a current component corresponding to the flux of the rotor of the brushless DC motor, and a q-axis current, which is a current component corresponding to the torque of the brushless DC motor;
control means for outputting a reference q-axis current and a reference d-axis current on the basis of the converted d-axis current and q-axis current and a speed command signal inputted from outside;
voltage converting means for converting the reference q-axis current and the reference d-axis current into a reference q-axis voltage and a reference d-axis voltage;
three-phase converting means for converting the converted reference q-axis voltage and reference d-axis voltage into three-phase voltages and outputting them to the PWM circuit;
power value calculating means for calculating a power value from the product of the detected q-axis current and the reference q-axis voltage; and
determining means for sampling a reference power value from the power value calculated by the power value calculating means, sampling a power value for determination a predetermined time after sampling the reference power value, and determining that a coolant leak has occurred when the difference between the reference power value and the power value for determination is above a predetermined value.

2. A coolant leakage detecting device according to claim 1, **characterized in that** both a magnet torque and a reluctance torque are used for the rotation of the rotor of the brushless DC motor and a negative d-axis current is made to flow so that a maximum torque is obtained, and the power calculating means calculates the power value from a value obtained by adding the product of the detected d-axis current and the reference d-axis voltage to the product of the detected q-axis current and the reference q-axis voltage.

3. A coolant leakage detecting device according to claim 1, **characterized in that** after sampling the reference power value the determining means samples multiple power values at intervals of a fixed time and averages these multiple sampled power values to obtain the power value for determination.

4. A refrigerator in which is used a coolant leakage detecting device according to at least one of claims 1 to 3.

5. A refrigerator according to claim 4, **characterized in that** when it has determined that a coolant leak has occurred the determining means temporarily stops high-voltage parts of the refrigerator while cooling is continued, and after a predetermined time has elapsed from when it determined the coolant leak it cancels the stoppage of the high-voltage parts in accordance with the detected temperature of a temperature sensor mounted in the refrigerator.

6. A refrigerator according to claim 5, **characterized in that** the predetermined time is altered in correspondence with the number of times a door of the refrigerator is opened and closed.

FIG. 1

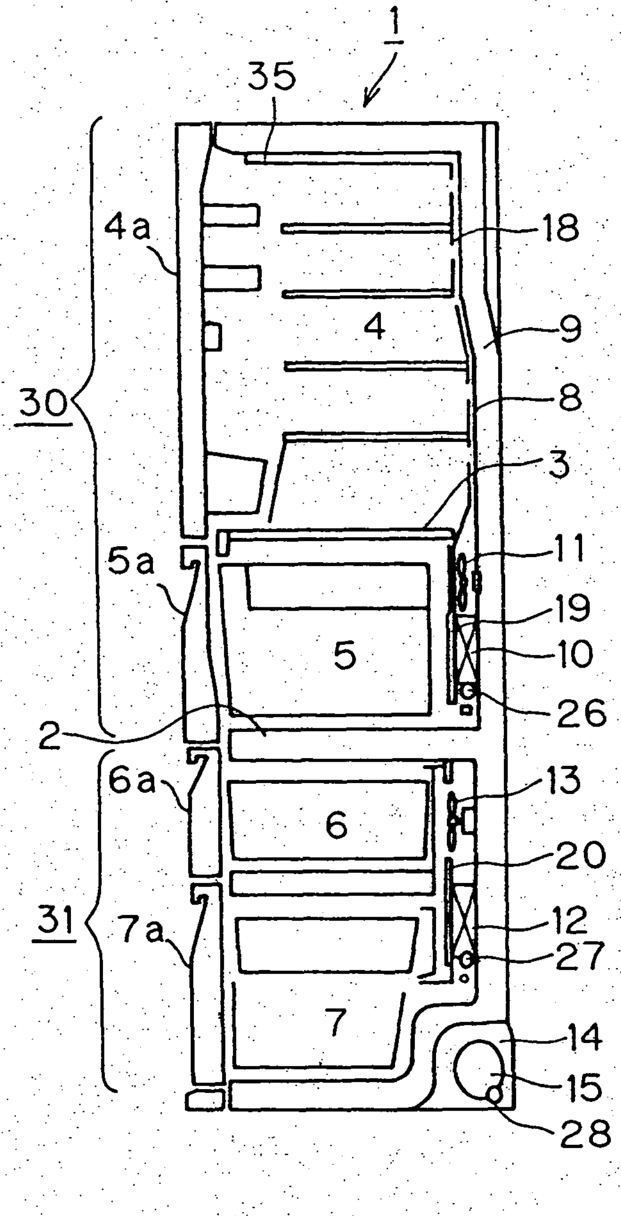


FIG. 2

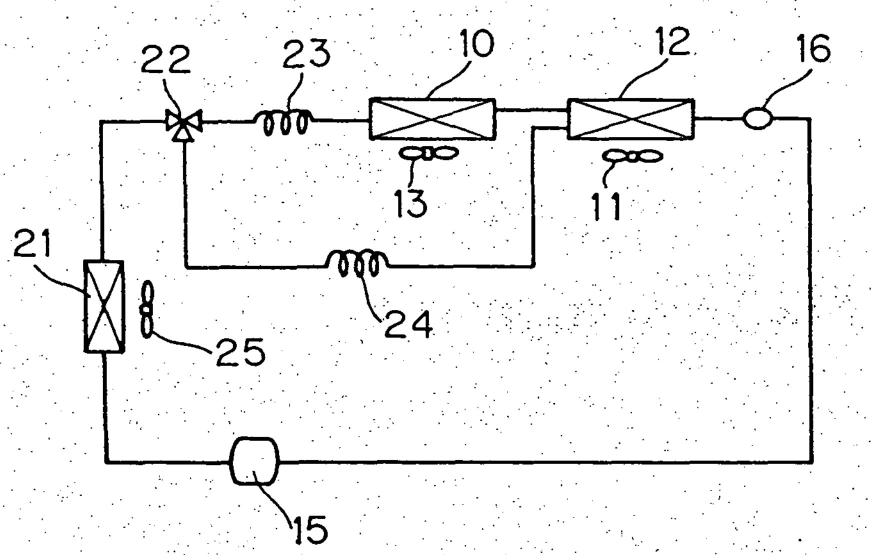
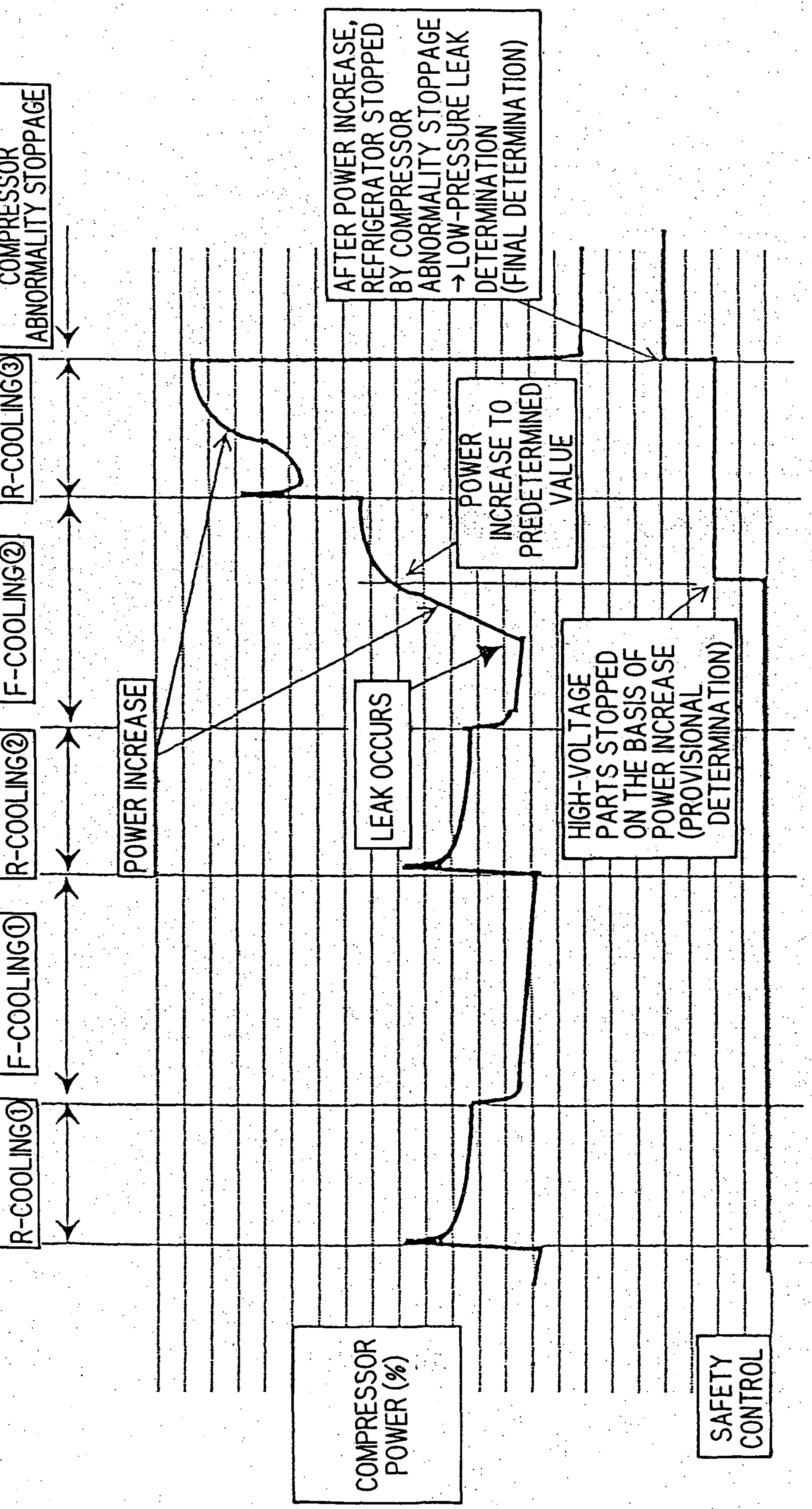


FIG. 3


COMPRESSOR POWER (%)
SAFETY CONTROL
R-COOLING①
F-COOLING①
R-COOLING②
F-COOLING②
R-COOLING③
COMPRESSOR ABNORMALITY STOPPAGE
POWER INCREASE
LEAK OCCURS
POWER INCREASE TO PREDETERMINED VALUE
HIGH-VOLTAGE PARTS STOPPED ON THE BASIS OF POWER INCREASE (PROVISIONAL DETERMINATION)
AFTER POWER INCREASE, REFRIGERATOR STOPPED BY COMPRESSOR ABNORMALITY STOPPAGE →LOW-PRESSURE LEAK DETERMINATION (FINAL DETERMINATION)

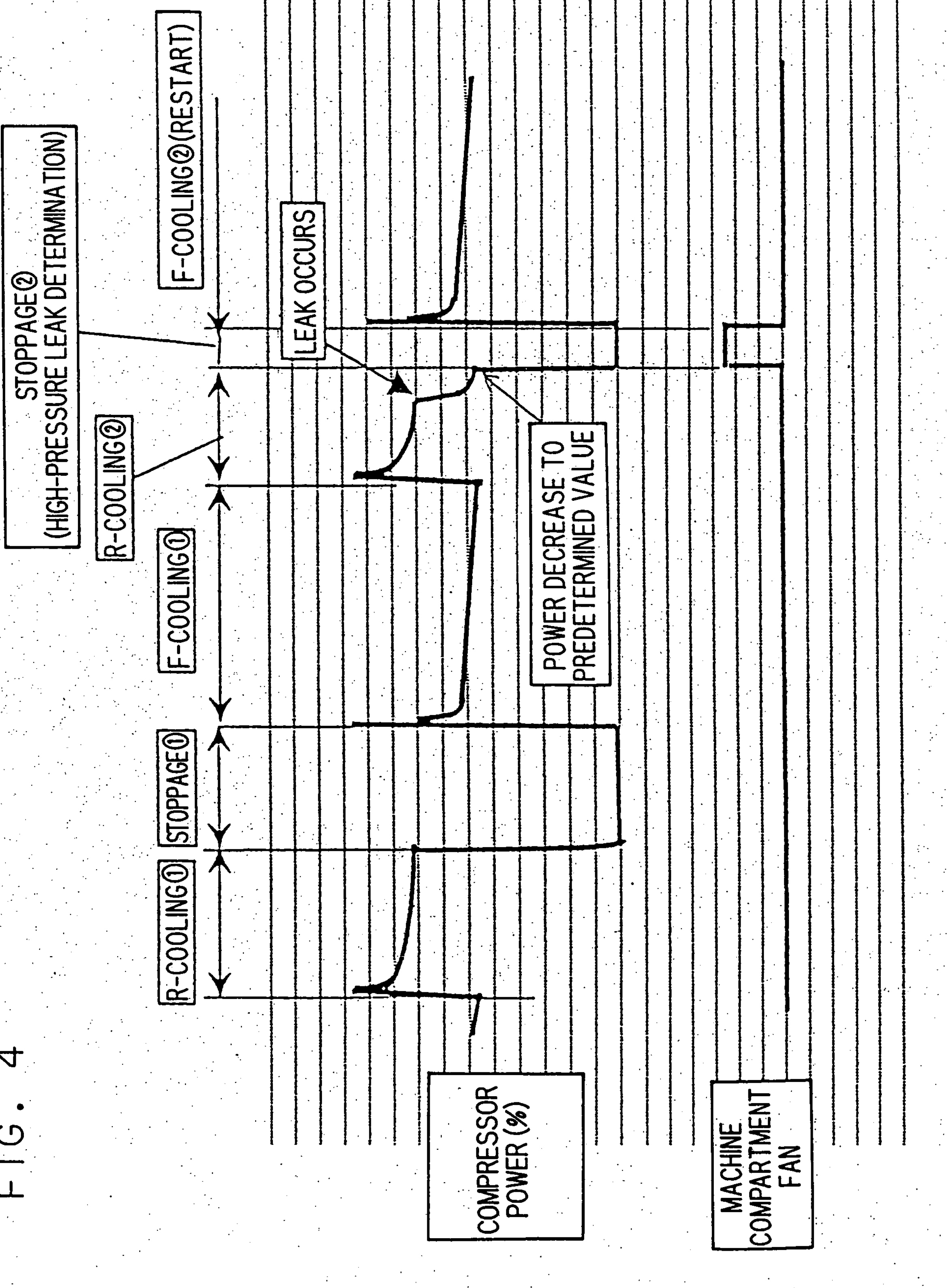

STOPPAGE②
(HIGH-PRESSURE LEAK DETERMINATION)
F-COOLING②(RESTART)
R-COOLING②
LEAK OCCURS
F-COOLING①
POWER DECREASE TO
PREDETERMINED VALUE
R-COOLING①
STOPPAGE①
COMPRESSOR
POWER (%)
MACHINE
COMPARTMENT
FAN

FIG. 4

FIG. 5

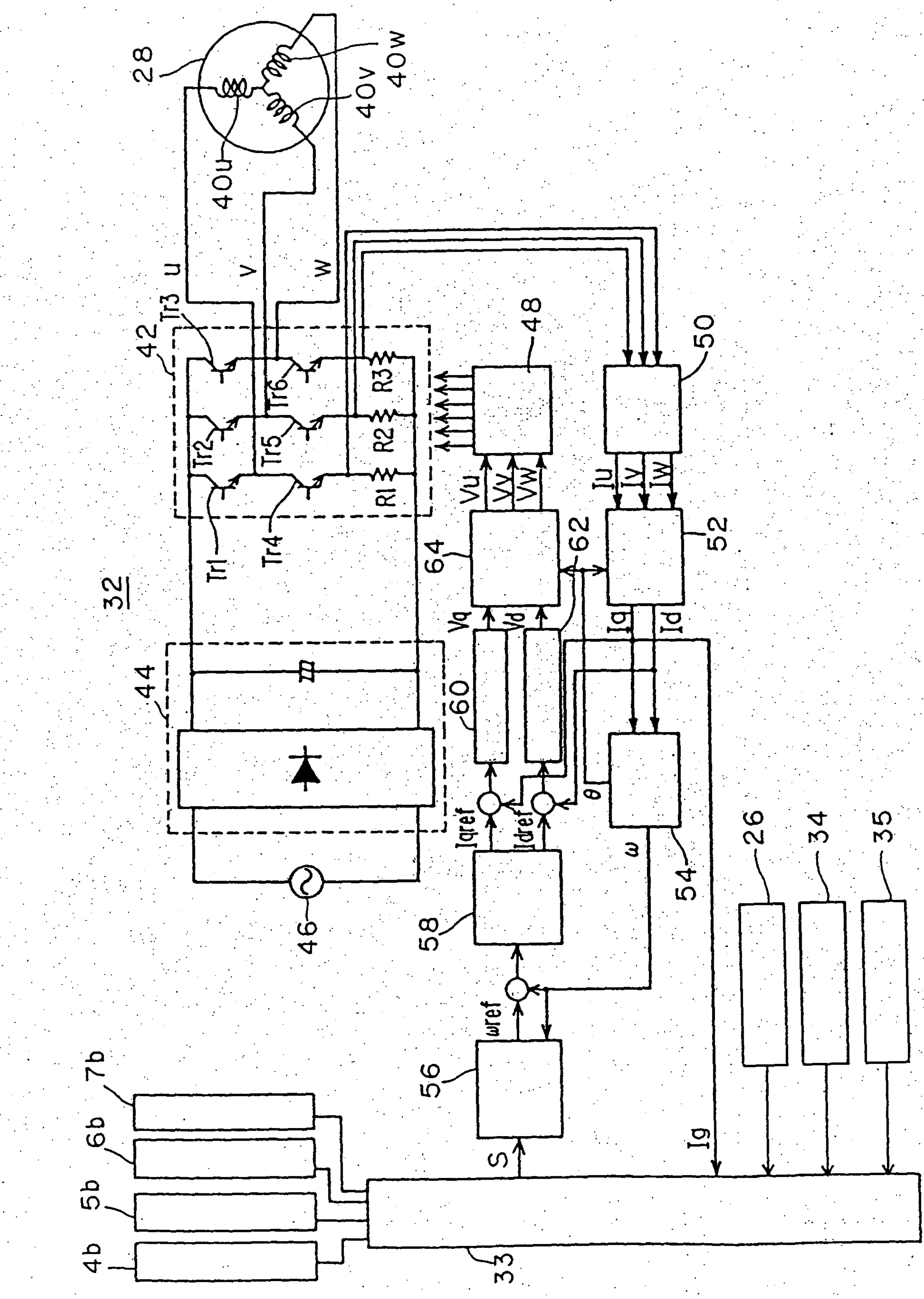
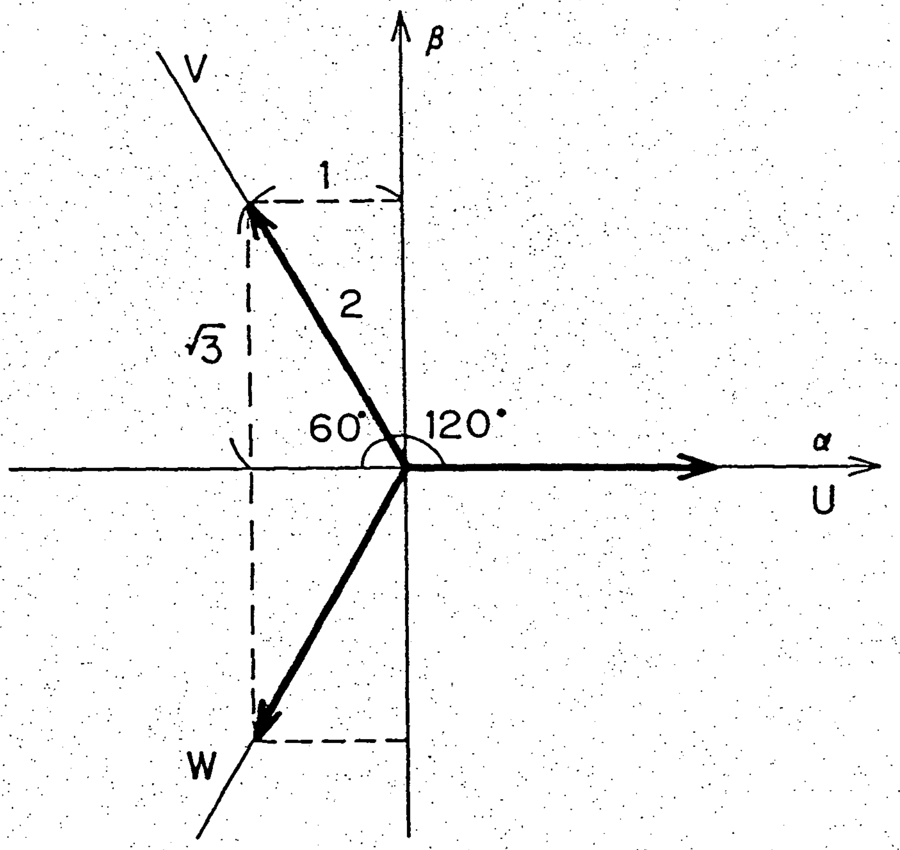
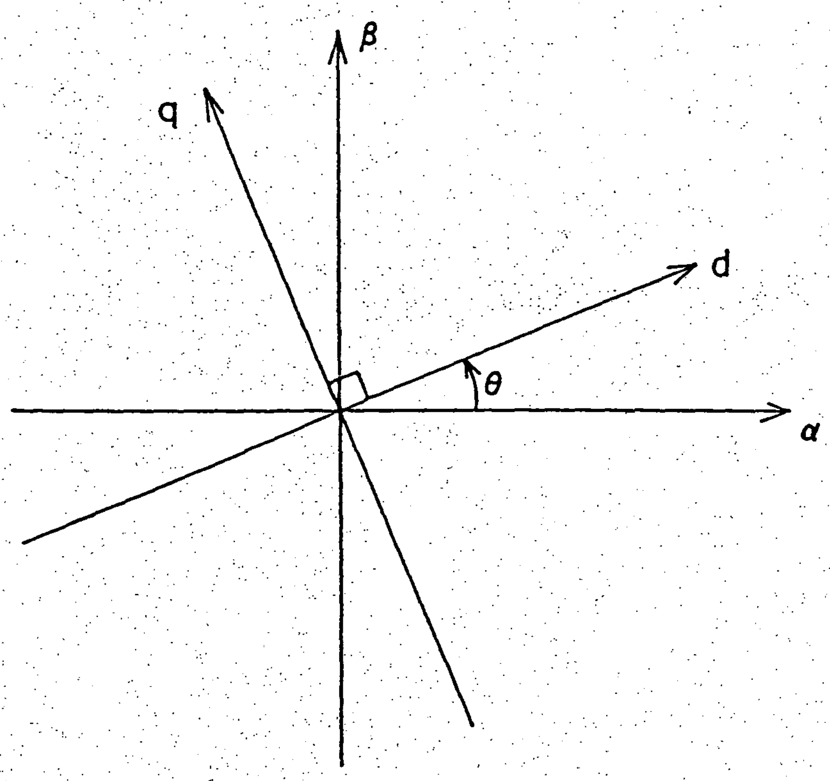

28
40u
40v
40w
u
v
w
Tr1
Tr2
Tr3
Tr4
Tr5
Tr6
R1
R2
R3
42
32
44
46
48
50
Vu
Vv
Vw
Iu
Iv
Iw
64
62
52
Vq
Vd
Iq
Id
60
θ
Iqref
Idref
54
ω
58
ωref
56
S
Ig
26
34
35
7b
6b
5b
4b
33

FIG. 6



UVW→αβ CONVERSION

FIG. 7



αβ→dq CONVERSION

FIG. 8

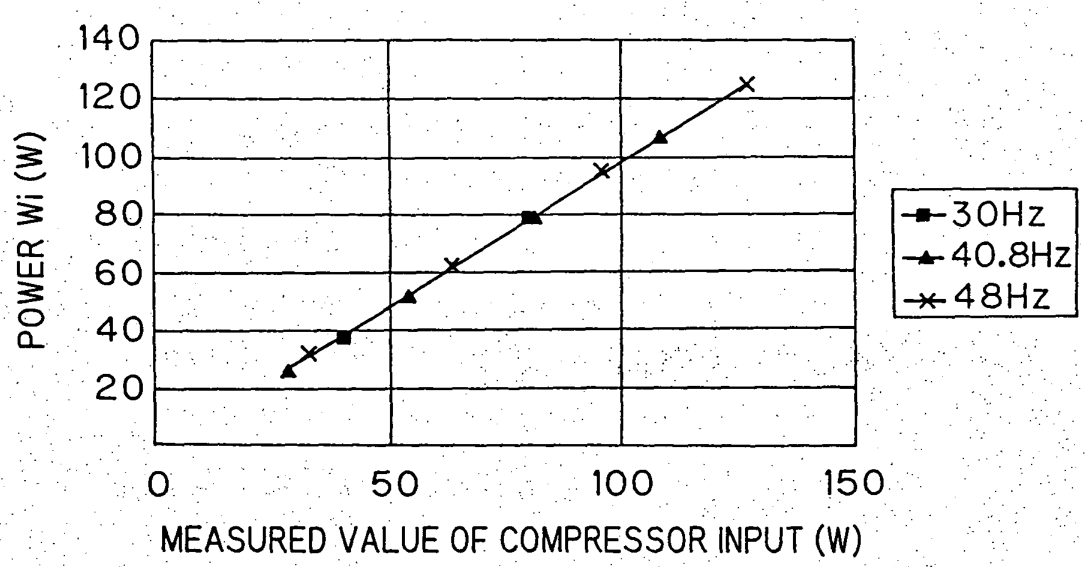
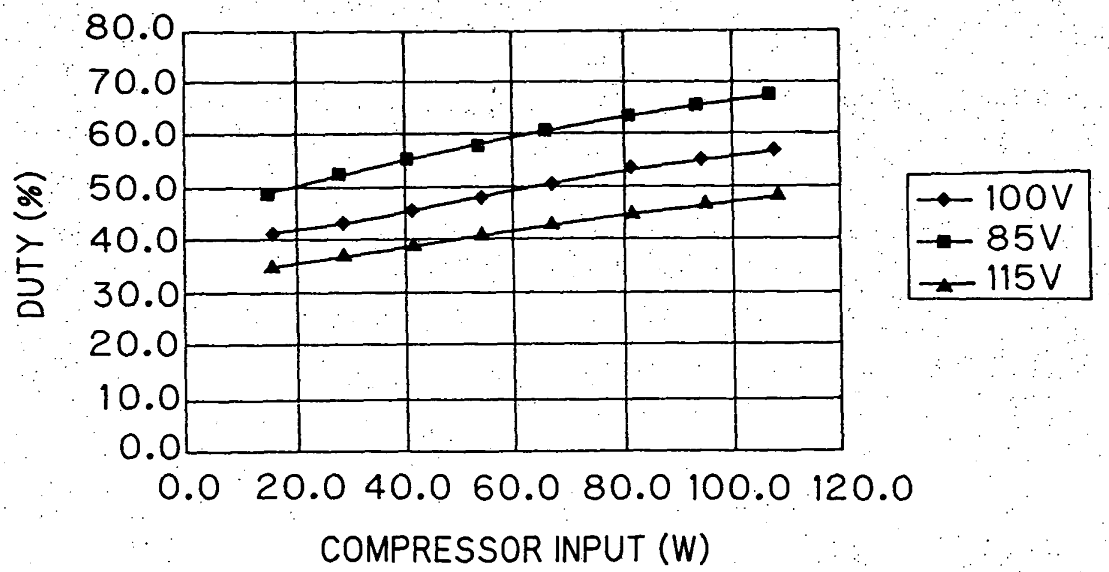

140
120
100
80
60
40
20
POWER Wi (W)
0
50
100
150
MEASURED VALUE OF COMPRESSOR INPUT (W)
30Hz
40.8Hz
48Hz

FIG. 9


80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
DUTY (%)
0.0
20.0
40.0
60.0
80.0
100.0
120.0
COMPRESSOR INPUT (W)
100V
85V
115V

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2004/003451

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[7] F25B49/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[7] F25B49/02, H02P6/24

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2004
Kokai Jitsuyo Shinan Koho	1971-2004	Toroku Jitsuyo Shinan Koho	1994-2004

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	JP 2003-106730 A (Toshiba Corp.), 09 April, 2003 (09.04.03),	
Y	Par. Nos. [0001], [0042]; Figs. 2, 8	1-5
Y	Par. Nos. [0068] to [0075]; Fig. 1	5
A	Par. Nos. [0068] to [0075]; Fig. 1 & WO 03/027587 A1	6
Y	JP 2003-88168 A (Matsushita Electric Industrial Co., Ltd.), 20 March, 2003 (20.03.03), Par. Nos. [0033] to [0041]; Fig. 1 (Family: none)	1-5

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 June, 2004 (11.06.04)	29 June, 2004 (29.06.04)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2004/003451

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 7-294075 A (Aichi Tokei Denki Kabushiki Kaisha), 10 November, 1995 (10.11.95), Par. Nos. [0023] to [0027] (Family: none)	3-5

Form PCT/ISA/210 (continuation of second sheet) (January 2004)