



Single-Phase Induction Motor and Refrigerator using the Single-Phase Induction Motor

This invention relates to single-phase induction motor, a method of controlling the single-phase induction motor used for a compressor, and a refrigerator or air conditioner or and other electric apparatus using it.

In the accompanying drawings, Fig. 13 is a circuit diagram of a conventional compressor drive apparatus used for such devices as an air conditioner disclosed in Unexamined Japanese Patent Publication SHO 64-29682. The circuitry is configured with a compressor (motor) 1, a capacitor 2 for low load, a capacitor 3 for high load, a change-over switch 4, and a starting relay 5. The change-over switch switches from one capacitor to the other. The starting relay operates only on starting compressor 1 to connect contacts 5a.

The operation of such a conventional compressor drive apparatus is described with reference to Fig. 14.

On the starting the compressor 1, capacitor terminal voltage is low, causing contact 5a of starting relay 5 to be closed, upon which capacitors 2 and 3 are connected in parallel with the auxiliary winding of compressor 1 to obtain a large starting torque (the torque curve shown in Fig. 14 with use of the starting capacitor). The compressor therefore starts despite high initial load.



As the rate of compressor rotation increases, the capacitor terminal voltage also rises. At the operating point of relay 5 shown in Fig. 14, contacts 5a are opened. Then, the operation capacitor only operates (see the torque curve in Fig. 14 for using the operation capacitor). At this time, change-over switch 4 switches between the capacitors over depending on the load on the compressor 1. When the load on the compressor is low, capacitor 2 is used as the operation capacitor while capacitor 3 is used as the starting capacitor. Conversely, when the load is high, capacitor 3 is used as the operating capacitor while the capacitor 2 is used as the starting capacitor. Switching in this way allows the compressor to drive with sufficient starting torque and high operating efficiency.

The configuration of a conventional compressor drive apparatus has posed the problems as follows:

1. When there is a significant difference in the amount of torque on starting of the compressor and during regular operation, capacitor 2 is used as the operation capacitor while capacitor 3 is used as the starting capacitor. However, the capacity of capacitor 3 is much too high when it is used as the operation capacitor at high load which gives low efficiency.

2. Similarly, excess capacity of capacitor 3 invariably



causes greater errors in the absolute value of capacity,
further resulting in unstable operation of starting relay
5.

3. A large current charging the operation capacitor
5 runs through the contacts of change-over switch 4
everytime when capacitors 2 and 3 are switched over.
Moreover, large current generates arc, significantly
degrading contact life. Strengthening of contacts
requires high cost.

10 Accordingly, it is a primary object of this
invention to overcome these problems associated with the
techniques in the prior art. According to the present
invention, there is provided a single-phase induction
motor which includes a main winding, an auxiliary winding
15 installed at electrically different angle from the main
winding, a plurality of operation capacitors connected to
the auxiliary winding, a relay that connects and
disconnects the operation capacitors, and a controller
that closes the relay only when power to the motor is cut
20 off.

The invention also provides a method of controlling
a single-phase induction motor having a main winding, an
auxiliary winding installed at electrically different
angle from the main winding, a plurality of operation
25 capacitors connected to the auxiliary winding, a relay



for connecting and disconnecting the operation capacitors, and a controller for controlling the relay, wherein the controller closes the relay only when power to the motor is cut off.

5 The invention can be used with a compressor, e.g. for a refrigerator. It can start the compressor with large starting torque using all capacitors and can select an optimal capacitor depending on the load.

10 In one embodiment it is possible to power off the compressor at the occurrence of an abnormality and generate maximum starting torque using all capacitors at restart.

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

Fig. 1 is a circuit diagram showing a single-phase induction motor in accordance with Embodiment 1 of the present invention;

20 Fig. 2 depicts a cross sectional view of a refrigerator containing the single-phase induction motor in accordance with Embodiment 1 of the present invention;

Fig. 3 is a flowchart setting out the controlling operation of the refrigerator in accordance with Embodiment 1 of the invention;

25 Fig. 4 is a flowchart setting out the controlling



operation of the refrigerator in accordance with
Embodiment 1 of the invention;

Fig. 5 is a flowchart setting out the controlling
operation of the refrigerator in accordance with
5 Embodiment 1 of the invention;

Fig. 6 is a circuit diagram showing the single-phase
induction motor in accordance with Embodiment 2 of the
invention;

Fig. 7 is a flowchart setting out the controlling
10 operation of the refrigerator in accordance with
Embodiment 2 of the invention;

Fig. 8 is a flowchart setting out the controlling
operation of the refrigerator in accordance with
Embodiment 2 of the invention;

Fig. 9 shows output voltage of the current detector
15 in accordance with Embodiment 2 of the invention;

Fig. 10 is a flowchart setting out the controlling
operation of the refrigerator in accordance with
Embodiment 2 of the invention;

Fig. 11 is a flowchart showing the controlling
20 operation of the refrigerator in accordance with
Embodiment 5 of this invention;

Fig. 12 is a flowchart showing the controlling
operation of the refrigerator in accordance with
25 Embodiment 6 of this invention;

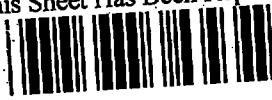


Fig. 13 is a circuit diagram of a conventional compressor drive apparatus; and

Fig. 14 shows the characteristics of a conventional single-phase induction motor.

5 Embodiment 1

Embodiment 1 will set forth the basic operation of a refrigerator containing a compressor drive apparatus to which a single-phase induction motor of the present invention is applied. The single-phase induction motor has three capacitors, one starting capacitor and two operation capacitors, all of which are controlled by a controller. On starting the compressor, all three capacitors are employed to get the maximum starting torque. Then, to ensure higher operation efficiency, either or both operation capacitors are employed depending upon the operating load of the compressor.

Because a large current running through contacts generates arc, especially at the time of connecting the operation capacitors, the contacts are set to be closed only when the compressor is in the stopped state.

Referring now to Fig. 1, a compressor 1 contains a motor. The compressor 1 includes a main winding 1a and an auxiliary winding 1b. A positive temperature coefficient (PTC) thermistor 5 connects a starting capacitor 6 with auxiliary winding 1b of the compressor



at the start of its operation. A first operation capacitor 7 is connected in parallel with the PTC thermistor and starting capacitor, and keeps on operating as the load enters a steady state. Connected in parallel with the first operation capacitor via contacts 4a of a relay 4, a second operation capacitor 8 is added when load becomes high. A controller 10 controls the operation of compressor 1. A temperature sensor 11 detects temperature of a cooler (not shown). A relay 12 powers compressor 1 on or off via contacts 12a. An electric discharge resistance 13 discharges the second operation capacitor when relay contacts 4a are open.

Fig. 2 shows a cross sectional view of the refrigerator equipped with the compressor drive apparatus of the present invention. In Fig. 2, a main refrigerator body 100 has a freezer compartment 101 placed above a refrigerator compartment 102. A fan 103 for circulating cooling air is made up of vanes and a motor. A damper 104 is driven by an electric motor and regulates the amount of cooling air flow into the refrigerator compartment 102 to keep it at appropriate temperature. A cooler (evaporator) 105 is provided in the freezer compartment. A heater 106 is provided to defrost cooler 105.

Compressor 1 is installed at the bottom of the main



body. Temperature sensor 11 is set near cooler 105 to act as a defrost thermometer.

With reference to the flowchart in Fig. 3, the second controlling operation of the refrigerator will be discussed first.

At step 200, temperature data is read from the freezer compartment and refrigerator compartment and temperature sensor 11 as a defrost thermistor. Then, at step 201 it is checked whether the cooler is being defrosted. Defrosting is started by a separate sub-routine (not shown) in response to automatic detection or an operator's request. Continuation or termination of defrosting is determined based on the temperature read by temperature sensor 11 of cooler 105. A heater 106 is set off to end defrosting and on to continue defrosting in steps 203 and 204. Then operation proceeds to step 213 to regulate the refrigerator compartment temperature using the damper 104. If at step 201 defrosting is not being performed, whether the compressor is needed to run is determined at step 205 by the freezer compartment temperature. When the freezer compartment temperature is high, so that the compressor is needed, and operation of the compressor is allowed (see the operation inhibit flag K below), compressor 1 and fan motor 103 are set to start in step 206 if they are not in operation, a start



prevention timer is cleared. A compressor operation flag F is set to 1 at step 208 to indicate that the compressor is running. When the freezer compartment temperature is or becomes low, compressor 1 and fan motor 103 are
5 stopped at step 209 and an operation inhibit flag K is set to 1, the compressor operation flag F is cleared to zero, and start prevention timer TM is set for 10 minutes. The setting of the operation inhibit flag K for 10 minutes prevents too frequent operation of the
10 compressor. After 10 minutes, the operation inhibit flag K is zero cleared at step 212.

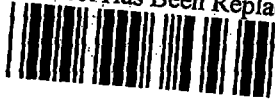
In steps 213 to 215 the damper driven by an electric motor is operated to maintain the refrigerator at an appropriate temperature.

15 The above procedure is periodically repeated, e.g. every minute, to keep the refrigerator under control.

The detailed operation of the compressor drive apparatus (and thus particularly steps 205, 206, 208, and 209 of Fig.3) will be further described with reference to
20 the flowchart in Fig. 4.

In Fig. 4, in step 21 it is determined whether the compressor 1 is in the stopped state (the compressor operation flag being set to 0). If it is, and an operation is requested based on the temperature (at step
25 22), whether or not the compressor is ready to start must

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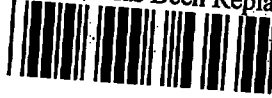


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be determined first by checking the operation inhibit flag K at step 23. When it is in the ready state, relay contacts 4a are closed to connect all three capacitors 6, 7, and 8 in parallel ready for starting the compressor.

5 The operation flag of compressor 1 is also set to 1. Then after one second, relay contacts 12a are closed at step 27 to supply power to start the compressor. Thus the relay 4a is operated while the circuit is powered-down.

10 Thus starting capacitor 6 and operation capacitors 7 and 8 connected in parallel with the auxiliary winding of compressor 1 will help obtain high starting torque, thereby enabling compressor 1 to start despite high initial load. At the same time, current also runs
15 through PTC thermistor 5. When its resistance grows infinitely large at the Curie point, starting capacitor 6 will be electrically disconnected from the auxiliary winding. This leaves the two operation capacitors 7 and 8 connected. After a certain time, which is dependent on
20 whether a defrost operation is occurring or not, the capacitor 8 needs to be disconnected. So at step 28, time from the start of compressor 1 is counted. Then in steps 29 to 33 relay contacts 4a will open after two minutes (T1) on account of high compressor load in case
25 defrosting has been complete or after 2 seconds (T2) in



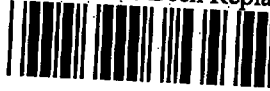
other cases, to operate compressor 1 with operation capacitor 7 only. When the operation flag of compressor 1 is determined as 1 at step 21 (i.g. the compressor is already operating), and if the operation is still requested based on the temperature at step 26, then at step 27 relay contacts 12a are maintained closed to supply power to the compressor and operation is as above.

When at step 26 the compressor is operating but an operation request is not present, relay contacts 12a are opened at step 34 to disconnect power from the compressor and the operation flag of compressor 1 is set to 0. After one second (S35), relay contacts 4a are opened at step 36 so as not to waste power of relay coil 4. It is better to open relay contacts 4a after capacitors 7 and 8 are discharged to avoid contact troubles. It is for this reason that relay contacts 4a are opened after relay contacts 12a are opened.

However, as shown in the flowchart in Fig. 5, it is possible to open relay contacts 4a first by changing the step 34 with 36.

Controlling the torque of compressor 1 according to operating status of the refrigerator allows the compressor to operate with high efficiency as well as large starting torque.

Moreover, large current will not run through relay



contacts 4a nor will arc be generated because relay contacts 4a are closed only when compressor 1 is in stopped state. They are not closed while compressor 1 is connected to power source, e.g., capacitor 7 is being charged.

Embodiment 2

A second Embodiment of the invention is similar to the above but has an additional troubleshooting capability. If the compressor begins to stall and then stops operating for some reason, an abnormality is quickly detected and the compressor is powered off. When an operation request is reissued, all capacitors are connected so as to obtain maximum starting torque according to this invention.

In Fig. 6, the configuration for Embodiment 2 is identical to that of Embodiment 1 except a current detector 9 (hereinafter referred to as the CT) and a protective device 14 for compressor 1. The CT detects current that runs compressor 1.

At CT 9, output voltage is generated based on the current that runs compressor 1 as indicated in Fig. 9. Depending upon the output voltage, controller 10 stores the status of the compressor by (1) operating, (2) stalling or locked, or (3) stopped or disconnected.

Then at step 37 in Fig. 7, whether or not compressor



1 is operating normally with relay contacts 12a being closed is determined by the current detected at CT 9. If any abnormality is detected, a further check is made at step 38 to determine if the abnormality is attributed to stalling or locked condition. If it is determined to be caused by stalling or locked condition, relay contacts 12a are opened, the operation flag of compressor is set from 1 to 0 and the operation inhibit flag K is set to 1. After one second, relay contacts 4a are opened (steps 34 to 36). If stalling or locked condition is not the cause of abnormality, the circuit must be disconnected at somewhere including compressor 1, or compressor 1 is being stopped for some reason since relay contacts 12a are closed. In this case, the discontinuation flag D is set to 1 at step 39. Then at steps 34 to 36, power to compressor 1 is cut off. This power off will be carried out prior to the power off by protective device 14.

In Fig. 7, after relay contacts 12a are opened at step 34, at step 36 the relay contacts 4a are opened for the reasons given in Embodiment 1. However, as shown in Fig. 8, it is possible to open relay contacts 4a before relay contacts 12a.

When compressor 1 stalls or becomes locked for some reason during operation, controller 10 detects the abnormality according to the current detected at CT 9 and



cuts power off compressor 1 and relay contacts 4a are
opened. At the restart of the operation, controller 10
first closes relay contacts 4a again and then relay
contacts 12a. Thus, being re-connected with all
5 capacitors, compressor 1 is allowed to re-start operation
with large starting torque.

If CT 9 is unavailable and controlling operation by
CT 9 shown in Fig. 7 or 8 is not performed, protective
device 14 eventually disconnects the compressor from
10 power source in an event of stalling or locked condition.
If the event of stalling or locked condition happens
after relay contacts 4a are opened, relay contacts 4a
remain open when the protective device connects the
compressor to power source again after a recovery
15 operation. Therefore, only starting capacitor 6 and
operation capacitor 7 are activated at starting time,
thereby getting insufficient starting torque.

Embodiment 3

Instead of current detector CT 9 set forth in the
20 above Embodiment, a shunt resistance or vibration sensor
can be used and will prove equally effective to detect
the operating status of compressor 1.

Embodiment 4

Referring now to Fig. 10, at plug-in time of the
25 refrigerator to a power source outlet, the temperature of

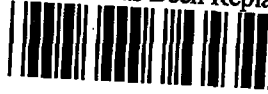


the evaporator 105 is detected by temperature sensor 11.
If the temperature remains below A degrees centigrade for
an hour, then relay contacts 4a are opened (steps 40 to
45), producing the same effect as in Embodiment 1, in
5 which the combined use of capacitors 7 and 8 at high and
low load is determined by the time period. The judgement
of plug-in time at step 40 can be made by the plug-in
Flag P. The plug-in flag is set to 1 by controller 10
only at the plug-in time of the refrigerator to a power
10 source outlet and set to 0 at step 46 when the
temperature remains below A degrees centigrade for an
hour. According to this embodiment, the refrigerator can
continue one hour operation with high torque to make sure
the sufficient cooling at the plug-in time of the
15 refrigerator.

Embodiment 5

In the above it is possible that a failure of the CT
9 could result in the controller incorrectly determining
that the compressor is stalling and cutting power to the
20 compressor. To avoid such a misjudgment from being made,
in this embodiment the CT 9 is checked and power is
supplied to the compressor as long as operation is
requested when a failure is detected at the CT, to keep
the refrigerator cool.

25 Embodiment 5 will be set forth below referring to



the configuration in Fig. 6 and the flowchart given in Fig. 11. At step 50, failure detection is periodically conducted at CT 9. Failure occurrence is determined if controller 10 receives an ON signal despite the fact that the current is not running. If compressor 1 is in the stopped state with its operation flag being set to 0 at step 21, whether or not an operation is requested is checked at step 22. If yes relay contacts 4a are closed and the operation flag of compressor 1 is set to 1 at step 24. After one second (S25), relay contacts 12a are closed to supply power to compressor 1 at step 27.

On the other hand, if the compressor is in the operating state with its operation flag being set to 1 at step 21, whether or not an operation is requested is checked at step 26. When an operation is requested, and if any abnormality has been detected at CT 9 at step 51, power is kept supplied to both the compressor and motor fan until all operation requests for compressor 1 have been met because the stalling judgement cannot be made correctly.

At step 51, if it turns out that CT 9 is operating normally, stalling is checked at step 52. If stalling is detected at step 53, relay contacts 12a are opened and the operation flag of compressor 1 is set to 0. After one second, relay contacts 4a are opened to power off



compressor 1 (steps 34 to 36).

5 If a failure is detected at CT 9 at step 51, an error indication may be made. Even if compressor 1 is kept powered on after it starts stalling, it is possible to determine that the abnormality has occurred not to compressor 1 but to CT 9.

10 In Embodiment 5, even when a failure is detected at CT 9, power will be kept supplied to compressor 1 until all operation requests for compressor 1 have been met to cool inside the refrigerator without making a judgement of stalling. A failure at CT 9 thus will not halt refrigerator operation.

15 The operation described in Fig. 11 can be carried out either separately from or jointly in a series with operation in Fig. 7 or Fig. 8.

Embodiment 6

20 Embodiment 6 will be described below referring to flowchart in Fig. 12. If compressor 1 starts stalling while its operation flag is being set to 1, power supply to compressor 1 is once stopped, counting the number of continuous stallings as one (S54). When power is supplied again after 10 minutes, and if compressor starts stalling again, power to compressor 1 is stopped again, counting the number of continuous stallings as two (S55).
25 At this time, controller 10 determines that high load is

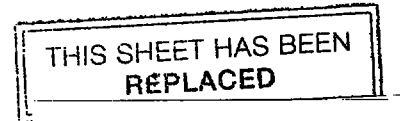


being applied. Therefore, when compressor 1 is restarted
10 minutes later, operation with high torque is extended
to 30 minutes. If stalling continues to occur, when
compressor 1 restarts after 10 minutes, its operation
5 with high torque will be extended by half an hour each
time as stalling occurs, up to two hours (S56).

The number of continuous stallings is reset when
compressor 1 terminates its operation normally. Thus the
operation with high torque at the next time compressor 1
10 restarts returns to normal time length (steps 57 and 58).

If continuous stalling occurs more than twice, the
operation with high torque at the restart of compressor 1
after 10 minutes can be extended by half an hour up to
two hours, thereby preventing compressor 1 from
15 continuously stalling at the start of its operation.

Having thus described several particular embodiments
of the invention, various alterations, modifications, and
improvement will readily occur to those skilled in the
art within the scope of the invention as defined by the
20 following claims.



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CLAIMS

1. A single-phase induction motor, comprising.

a main winding,

an auxiliary winding installed at electrically

5 different angle from the main winding,

a plurality of operation capacitors connected to the
auxiliary winding,

a relay that connects and disconnects the operation
capacitors, and

10 a controller that closes the relay only when power
to the motor is cut off.

2. A single-phase induction motor according to claim 1
wherein

15 the plurality of operation capacitors are connected
in parallel with a starting capacitor which is connected
to the auxiliary winding via a switch means.

3. A single-phase induction motor according to claim 1
or 2, wherein the relay disconnects at least one of the
operation capacitors after load has been lowered after
20 the motor has been started.

4. A single-phase induction motor according to claim 3,
comprising a first operation capacitor connected to the
auxiliary winding and a second operation capacitor
connected to the auxiliary winding via the relay, wherein
25 the second operation capacitor is employed as an



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additional capacitor when the motor operates with high load.

5. A single-phase induction motor according to any one of claims 1 to 4, further comprising:

5 a current detector that detects electrical current running in the motor, wherein the controller is operable to cut power off the motor and open the relay when the detector detects stalling.

6. A single-phase induction motor according to any one
10 of the preceding claims wherein the relay is disconnected a predetermined time after power to the motor is cut off.

7. A refrigerator comprising compressor drive apparatus including the single-phase motor of any one of claims 1 to 6, wherein all operation capacitors are connected at
15 the start of the motor.

8. A refrigerator according to claim 7, wherein the relay that connects and disconnects the operation capacitors is opened when the load on the compressor drive apparatus is lowered.

20 9. A refrigerator according to claim 7 or 8, wherein the relay that connects and disconnects the operation capacitors is opened when the temperature in the refrigerator compartments or refrigerator evaporator falls below a predetermined level.

25 10. A refrigerator according to claim 7, 8, or 9,



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comprising means for performing a defrosting operation
and wherein a time period from the time the operation
capacitors are connected by the relay after a defrosting
operation is completed to the time the operation
5 capacitors are disconnected is set longer than during
normal operation.

11. A refrigerator according to any one of claims 7 to
10 when dependent from claim 5, further including means
for detecting an abnormality at the current detector, and
10 wherein the controller does not perform compressor
stalling detection when an abnormality has occurred to
the current detector.

12. A refrigerator according to claim 11, further
includes a set means that sets a time period between the
15 connection and the disconnection of the operation
capacitors by the relay longer each time the compressor
stalls.

13. A method of controlling a single-phase induction
motor having a main winding, an auxiliary winding
20 installed at electrically different angle from the main
winding, a plurality of operation capacitors connected to
the auxiliary winding, a relay for connecting and
disconnecting the operation capacitors, and a controller
for controlling the relay, wherein the controller closes
25 the relay only when power to the motor is cut off.



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14. A method according to claim 13 wherein the relay disconnects at least one of the operation capacitors after the load has been lowered after the motor has been started.

5 15. A method according to claim 14 for use with a motor comprising a first operation capacitor connected to the auxiliary winding and a second operation capacitor connected to the auxiliary winding via the relay, wherein the second operation capacitor is connected as an
10 additional capacitor when the motor operates with high load.

16. A method according to any one of claims 13 to 16 comprising detecting electrical current running in the motor, and cutting power to the motor and opening the
15 relay when the detector detects stalling.

17. A method according to any one of claims 13 to 16 wherein the relay is disconnected a predetermined time after power to the motor is cut-off.

18. A method according to any one of claims 13 to 17
20 comprising connecting all operation capacitors to the motor at the start of the motor.

19. A method according to any one of claims 13 to 18, wherein the motor is used as a compressor drive for a refrigerator and wherein the relay that connects and
25 disconnects the operation capacitors is opened when the



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temperature in the refrigerator compartments or of refrigerator evaporator falls below a predetermined level.

20. A method according to claim 19 wherein a time period from the time the operation capacitors are connected by the relay after a defrosting operation is completed to the time the operation capacitors are disconnected is set longer than during a normal operation.

21. A method according to any one of claims 17 to 20 when dependent from claim 17, further comprising detecting an abnormality in the current detection, and suspending compressor stalling detection when an abnormality is detected.

22. A method according to claim 21 comprising setting a time period between the connection to the disconnection of the operation capacitors by the relay longer each time the compressor stalls.

23. A single phase induction motor constructed and arranged to operate substantially as hereinbefore described with reference to and as illustrated in Figures 1 to 12 of the accompanying drawings.

24. A method of controlling a single phase induction motor substantially as herein before described with reference to and as illustrated in Figures 1 to 12 of the accompanying drawings.



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25. A refrigerator including a compressor driven by a motor constructed in accordance with claim 23 or controlled in accordance with claim 24.

26. A refrigerator substantially as herein described with reference to Figures 1-12 or the accompanying drawings.

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27. A method of controlling a refrigerator, said method being substantially as herein described with reference to Figures 1-12 of the accompanying drawings.