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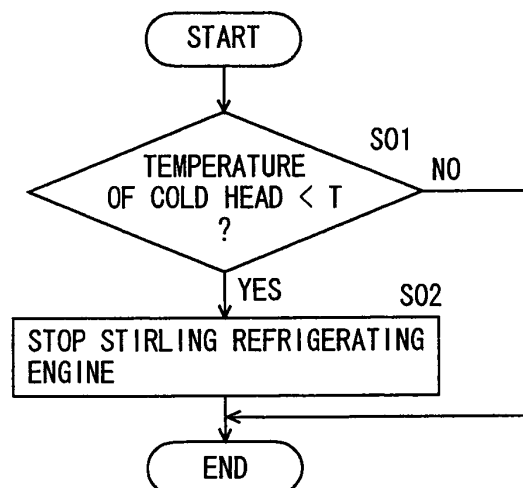
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(54) **REFRIGERATOR**

(57) A refrigerator for cooling a space inside thereof with a Stirling refrigerating engine includes state detection means (S01) for detecting an excessive cooling critical state of the Stirling refrigerating engine and excessive

sive cooling prevention means (S02) for preventing excessive cooling of the Stirling refrigerating engine based on detection of the excessive cooling critical state by the state detection means. Excessive cooling of the Stirling refrigerating engine can thus be prevented.

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Description

Technical Field

[0001] The present invention relates to a refrigerator, and more particularly to a refrigerator for cooling a space inside thereof with a Stirling refrigerating engine.

Background Art

[0002] Detrimental effects of CFCs on global environment have recently been pointed out, and a refrigerator including a Stirling refrigerating engine has been attracting attention as a refrigerator free from CFCs. In the refrigerator, cold heat of a cold head of the Stirling refrigerating engine is transmitted to a low-temperature side evaporator through a secondary coolant and cold air generated by the low-temperature side evaporator is supplied to a space inside the refrigerator (see, for example, Japanese Patent Laying-Open No. 2002-221384 (Patent Document 1)).

Patent Document 1: Japanese Patent Laying-Open No. 2002-221384

Disclosure of the Invention

Problems to be Solved by the Invention

[0003] In conventional refrigerating equipment, however, if cooling capability of the Stirling refrigerating engine is great, the secondary coolant is frozen and the cold heat of the cold head of the Stirling refrigerating engine is no longer transmitted to the low-temperature side evaporator, namely, the space inside the refrigerator is not cooled.

[0004] In addition, the Stirling refrigerating engine has such a characteristic that it cannot increase output when a temperature of the cold head is high. Accordingly, quick cooling of the space inside is desired, even when the temperature of the cold head is high, such as at the time of power-on of the refrigerator or switching to a quick-freeze operation mode.

[0005] The present invention was made to solve the above-described problems, and one object of the present invention is to provide a refrigerator capable of preventing excessive cooling of a Stirling refrigerating engine before the Stirling refrigerating engine is excessively cooled.

[0006] Another object of the present invention is to provide a refrigerator achieving improved efficiency in cooling a space inside thereof.

Means for Solving the Problems

[0007] In order to achieve the above described object, according to one aspect of the present invention, a refrigerator for cooling a space inside the refrigerator with a Stirling refrigerating engine includes: a state detection portion detecting an excessive cooling critical state of the

Stirling refrigerating engine; and an excessive cooling prevention portion preventing excessive cooling of the Stirling refrigerating engine based on detection of the excessive cooling critical state by the state detection portion.

[0008] According to the present invention, a refrigerator capable of avoiding excessive cooling of a Stirling refrigerating engine before the Stirling refrigerating engine is excessively cooled can be provided.

[0009] Preferably, the refrigerator further includes: a door state detection portion detecting an open/close state of a door of a cooling chamber of the refrigerator; a cooling fan supplying cold air cooled by the Stirling refrigerating engine into the space inside; and a cooling fan control portion stopping the cooling fan while a door open state is detected by the door state detection portion, and the state detection portion detects that a prescribed time period has elapsed since detection of the door open state by the door state detection portion.

[0010] According to the present invention, lapse of the prescribed time period since the door was opened is detected. As the cooling fan is stopped while the door is open, air around a low-temperature side cooler is stagnant during that time period. Accordingly, if the Stirling refrigerating engine continues to operate, the temperature of the secondary coolant is lowered. Thus, a state before the secondary coolant is frozen can be detected based on a time period during which the cooling fan remains stopped.

[0011] Preferably, the refrigerator further includes: a first cooling chamber and a second cooling chamber partitioned by a heat insulator and each having the door; the first cooling chamber being supplied with cold air cooled by the Stirling refrigerating engine by the cooling fan; an air passage for guiding the cold air cooled by the Stirling refrigerating engine to the second cooling chamber; a shut-off portion provided in the air passage, for shutting off the cold air cooled by the Stirling refrigerating engine; and a blowing fan sending the cold air cooled by the Stirling refrigerating engine to the air passage, and when the door state detection portion detects a closed state of the door of the first cooling chamber and an open state of the door of the second cooling chamber, the excessive cooling prevention portion causes the shut-off portion to shut off the air passage and cancels stopped state of the cooling fan and drives the cooling fan, and when the door state detection portion detects an open state of the door of the first cooling chamber and a closed state of the door of the second cooling chamber, the excessive cooling prevention portion causes the shut-off portion to cancel shut-off of the air passage and drives the blowing fan.

[0012] According to the present invention, when the closed state of the door of the first cooling chamber and the open state of the door of the second cooling chamber are detected, the air passage is shut off and the cooling fan is driven. When the open state of the door of the first cooling chamber and the closed state of the door of the second cooling chamber are detected, shut-off of the air

passage is canceled and the blowing fan is driven. Accordingly, if the door of the second cooling chamber is opened while the door of the first cooling chamber is closed, the air cooled by the Stirling refrigerating engine is supplied to the first cooling chamber, and if the door of the first cooling chamber is opened while the door of the second cooling chamber is closed, the air cooled by the Stirling refrigerating engine is supplied to the second cooling chamber. Whichever door of the first door and the second door may be opened, convection of the air cooled by the Stirling refrigerating engine is achieved, and therefore, excessive cooling of the Stirling refrigerating engine can be prevented. In addition, as the cold air sent to the cooling chamber of which door is open can be decreased, leakage to the outside of the cold air in the space inside can be prevented.

[0013] Preferably, the refrigerator further includes a low-temperature side evaporator receiving cold heat from a low-temperature portion formed on the Stirling refrigerating engine through a secondary coolant. The state detection portion includes a temperature detection portion, the low-temperature side evaporator, or a low-temperature side condenser paired with the low-temperature side evaporator (a secondary coolant circulation circuit circulating the secondary coolant between the low-temperature side evaporator and the low-temperature side condenser), and detects that the temperature detected by the temperature detection portion is lower than a prescribed temperature.

[0014] According to the present invention, it is detected that the temperature of the low-temperature portion or the secondary coolant circulation circuit (represented by the low-temperature side evaporator or the low-temperature side condenser) is lower than the prescribed temperature. Accordingly, excessive cooling of the Stirling refrigerating engine can be detected.

[0015] Preferably, a freezing prevention portion carries out, prior to stop control for stopping the Stirling refrigerating engine, excessive cooling prevention control different from the stop control, for preventing excessive cooling of the Stirling refrigerating engine.

[0016] According to the present invention, in order to prevent excessive cooling of the Stirling refrigerating engine, excessive cooling prevention control different from stop control for stopping the Stirling refrigerating engine is carried out before the stop control, so that excessive cooling of the Stirling refrigerating engine is prevented. Accordingly, if excessive cooling of the Stirling refrigerating engine can successfully be prevented by excessive cooling prevention control, the stop control of the Stirling refrigerating engine is not necessary. Consequently, stop of the Stirling refrigerating engine can be avoided as much as possible. Reliability of the refrigerator can thus be improved.

[0017] Preferably, the prescribed temperature includes a first temperature higher than a temperature at which the Stirling refrigerating engine is excessively

cooled and a second temperature higher than the temperature at which the Stirling refrigerating engine is excessively cooled and lower than the first temperature, and when the state detection portion detects that the temperature detected by the temperature detection portion is lower than the first temperature, the excessive cooling prevention portion carries out the excessive cooling prevention control, and when the state detection portion detects that the temperature detected by the temperature detection portion is lower than the second temperature, the excessive cooling prevention portion carries out the stop control.

[0018] According to the present invention, initially, when the temperature detected by the temperature detection portion is lower than the first temperature that is higher than the temperature at which the Stirling refrigerating engine is excessively cooled, excessive cooling prevention control is carried out, and if the temperature detected by the temperature detection portion is lower than the second temperature that is higher than the temperature at which the Stirling refrigerating engine is excessively cooled and lower than the first temperature, stop control is carried out. Accordingly, if excessive cooling prevention control prevents the temperature detected by the temperature detection portion from becoming lower than the second temperature and excessive cooling of the Stirling refrigerating engine can successfully be prevented, stop control of the Stirling refrigerating engine is not necessary. Consequently, stop of the Stirling refrigerating engine can be avoided as much as possible.

[0019] Preferably, the refrigerator further includes an abnormality in temperature detection sensing portion sensing abnormality in detection of a temperature by the temperature detection portion when the temperature detection portion detects a temperature.

[0020] According to the present invention, as the abnormality in detection of a temperature is sensed at the time of detection of a temperature, erroneous detection of a temperature can be prevented. Therefore, stop of the Stirling refrigerating engine based on erroneous detection that the temperature detected by the temperature detection portion is lower than the first temperature can be avoided.

[0021] Preferably, the refrigerator further includes a cooling fan supplying cold air cooled by the low-temperature side evaporator into the space inside, and the excessive cooling prevention portion drives the cooling fan or increases a fan level of the cooling fan.

[0022] According to the present invention, as the cooling fan is driven or the fan level of the cooling fan is increased, convection of the air around the low-temperature side evaporator is achieved. Accordingly, as the air newly sent to the low-temperature side evaporator provides heat to the secondary coolant, the temperature of the secondary coolant is raised. Consequently, excessive cooling of the Stirling refrigerating engine can be prevented. In addition, as convection of the air in the space inside is achieved by means of the cooling fan,

the air in the space inside can efficiently be cooled by the Stirling refrigerating engine. Consequently, COP (Coefficient of Performance) of the Stirling refrigerating engine can be improved.

[0023] Preferably, when the state detection portion detects that the temperature detected by the temperature detection portion is lower than the first temperature, the excessive cooling prevention portion drives the cooling fan or increases a fan level of the cooling fan, and when the state detection portion detects that the temperature detected by the temperature detection portion is lower than the first temperature after a prescribed time period has elapsed since drive of the cooling fan or increase in the fan level of the cooling fan, the excessive cooling prevention portion controls the Stirling refrigerating engine so as to lower cooling capability.

[0024] According to the present invention, if the temperature of the secondary coolant is not raised and the temperature detected by the temperature detection portion is lower than the first temperature in spite of heat provided to the secondary coolant, the excessive cooling prevention portion controls the Stirling refrigerating engine so as to lower its cooling capability. As cooling of the secondary coolant is thus suppressed, the temperature of the secondary coolant is raised. Consequently, excessive cooling of the Stirling refrigerating engine can be prevented.

[0025] Preferably, the excessive cooling prevention portion includes a revolution number control portion controlling the number of revolutions of the cooling fan, and when the state detection portion detects that the temperature detected by the temperature detection portion is lower than the first temperature, the excessive cooling prevention portion drives the cooling fan with the number of revolutions of the cooling fan being set to maximum revolution capability, and when the state detection portion detects that the temperature detected by the temperature detection portion is lower than the first temperature after a prescribed time period has elapsed since drive of the cooling fan with the number of revolutions of the cooling fan being set to maximum revolution capability of the cooling fan, the excessive cooling prevention portion controls the Stirling refrigerating engine so as to lower cooling capability.

[0026] According to the present invention, as the cooling fan is driven with the number of revolutions thereof being set to maximum revolution capability, excessive cooling of the Stirling refrigerating engine can further be prevented, as compared with a case where the number of revolutions is not set to the maximum. In addition, by setting the number of revolutions to the maximum, further convection of the air in the space inside is achieved by means of the cooling fan, and therefore, COP of the Stirling refrigerating engine can further be improved.

[0027] If the temperature of the secondary coolant is not raised and the temperature detected by the temperature detection portion is lower than the first temperature in spite of heat provided to the secondary coolant, control

for lowering the cooling capability of the Stirling refrigerating engine is carried out. As cooling of the secondary coolant is thus suppressed, the temperature of the secondary coolant is raised. Consequently, excessive cooling of the Stirling refrigerating engine can be prevented. Such freezing prevention control is preferably carried out while the door is closed. This is because, if the cooling fan is driven or the fan level of the cooling fan is increased while the door is open, the air in the space inside leaks to the outside, and when the door is subsequently closed, the cooling capability of the Stirling refrigerating engine should be increased in order to cool the air in the space inside again.

Brief Description of the Drawings

[0028]

Fig. 1 is a schematic cross-sectional view of one embodiment of a refrigerator according to the present invention.

Fig. 2 schematically shows a flow of cold air in the refrigerator in the present embodiment.

Fig. 3 is a functional block diagram showing a freezing prevention function of a refrigerator in a first embodiment.

Fig. 4 is a flowchart showing a flow of freezing prevention processing performed in the refrigerator in the first embodiment.

Fig. 5 is a flowchart showing a flow of modified freezing prevention processing performed in the refrigerator in the first embodiment.

Fig. 6 is a functional block diagram showing a freezing prevention function of a refrigerator in a second embodiment.

Fig. 7 is a flowchart showing a flow of freezing prevention processing performed in the refrigerator in the second embodiment.

Fig. 8 is a flowchart showing a flow of modified freezing prevention processing performed in the refrigerator in the second embodiment.

Fig. 9 is a functional block diagram showing a freezing prevention function of a refrigerator in a third embodiment.

Fig. 10 is a flowchart showing a flow of freezing prevention processing performed in the refrigerator in the third embodiment.

Description of the Reference Character Signs

[0029] 1 refrigerator; 2 cooling fan; 10 housing; 11 second cooling chamber; 12 first cooling chamber; 14 upper door; 15 lower door; 17 packing; 18 shelf; 19 machine room; 20, 21 duct; 20A, 20B cold air outlet; 22 cooling fan; 30 Stirling refrigerating engine; 40 low-temperature side circulation circuit; 41 low-temperature side condenser; 42 low-temperature side evaporator; 50 high-temperature side natural circulation circuit; 51 high-temperature

side evaporator; 52 high-temperature side condenser; 61 damper; 62 blowing fan; 81 temperature sensor; 82 upper door opening/closing detection switch; 83 lower door opening/closing detection switch; 84 door opening/closing detection switch; 90 control portion; and 91 display portion.

Best Modes for Carrying Out the Invention

[0030] An embodiment of the present invention will be described hereinafter with reference to the drawings. In the description below, the same elements have the same reference characters allotted. Their label and function are also identical. Therefore, detailed description thereof will not be repeated.

<First Embodiment>

[0031] Fig. 1 is a schematic cross-sectional view of one embodiment of a refrigerator according to the present invention. Fig. 2 schematically shows a flow of cold air in the refrigerator in the present embodiment. Referring to Figs. 1 and 2, a refrigerator 1 for storing food includes a housing 10 of a heat-insulating structure. Housing 10 is vertically partitioned into two cooling chambers 11 and 12. Each of cooling chambers 11 and 12 has an opening on the front side of housing 10 (on the left side in Fig. 1), and the opening is shut by an upper door 14 and a lower door 15 that are freely opened/closed. Upper door 14 and lower door 15 include a heat insulator, and a packing 17 surrounding the opening of cooling chamber 11, 12 is attached to the back surface of the door. Shelves 18 adapted to types of stored food are provided in cooling chambers 11 and 12 as appropriate.

[0032] A cooling system and a heat dissipation system mainly constituted of a Stirling refrigerating engine 30 are arranged from an upper surface through a rear surface to a lower surface of housing 10. A machine room 19 is provided in a part of the upper rear surface of housing 10, and Stirling refrigerating engine 30 is located in machine room 19.

[0033] A part of Stirling refrigerating engine 30 turns into a low-temperature portion (hereinafter, referred to as a cold head) when it is driven. A low-temperature side condenser 41 is attached to the cold head. In addition, a low-temperature side evaporator 42 is located in the rear of cooling chamber 12. Low-temperature side condenser 41 and low-temperature side evaporator 42 are connected to each other through a coolant pipe, to together form a low-temperature side circulation circuit (secondary coolant circulation circuit) 40. A natural coolant such as CO₂ is sealed in low-temperature side circulation circuit 40, and heat is supplied/received between low-temperature side evaporator 42 and low-temperature side condenser 41.

[0034] Ducts 20 and 21 for distributing cold air obtained in low-temperature side evaporator 42 to cooling chambers 11 and 12 are provided in housing 10. Duct 20 has

a cold air outlet 20A communicating to cooling chamber (first cooling chamber) 12 at an appropriate position. In duct 20, a cooling fan 22 is located at an appropriate position. Cooling fan 22 forcibly sends the cold air in duct 20 into cooling chamber 12. In addition, when cooling fan 22 is driven, convection of the air around low-temperature side evaporator 42 is achieved. Thus, different air at a relatively high temperature is supplied to low-temperature side evaporator 42.

[0035] Duct 21 has a cold air outlet 21A communicating to cooling chamber (second cooling chamber) 11 at an appropriate position. In duct 21, a blowing fan 62 is located at an appropriate position. Blowing fan 62 sends air to duct 21, and forcibly sends the cold air in duct 21 into cooling chamber 11. In addition, a damper 61 that is freely opened and closed is located at one end of duct 21 on the side of low-temperature side evaporator 42. When damper 61 is closed, duct 21 and duct 20 are disconnected from each other. Accordingly, the cold air in duct 20 is shut off by damper 61, and it is prevented from moving into duct 21. When damper 61 is open, duct 21 and duct 20 communicate with each other. Therefore, when blowing fan 62 is driven while damper 61 is open, the cold air in duct 20 flows into duct 21 and the cold air is forcibly sent into cooling chamber 11.

[0036] Meanwhile, while damper 61 is open, blowing fan 62 may be driven without driving cooling fan 22. In this state as well, the cold air in duct 20 flows into duct 21, and the cold air is forcibly sent into cooling chamber 11. In addition, when blowing fan 62 is driven, convection of the air around low-temperature side evaporator 42 is achieved. Thus, different air at a relatively high temperature is supplied to low-temperature side evaporator 42.

[0037] In addition, while damper 61 is open, cooling fan 22 and blowing fan 62 may be driven. In this state, some cold air in duct 20 is sent into cooling chamber 12 by means of cooling fan 22 and some cold air in duct 20 is sent into cooling chamber 11 via duct 21 by means of blowing fan 62. In this case as well, convection of the air around low-temperature side evaporator 42 is achieved and different air at a relatively high temperature is supplied to low-temperature side evaporator 42.

[0038] Though not shown, a duct recovering air from cooling chambers 11 and 12 is also provided in housing 10. The duct has an outlet below low-temperature side evaporator 42, and supplies the air to be cooled to low-temperature side evaporator 42 as shown with a dashed arrow in Fig. 1.

[0039] Another part of Stirling refrigerating engine 30 turns into a warm head (high-temperature portion) when it is driven. A high-temperature side evaporator 51 is attached to the warm head. In addition, a high-temperature side condenser 52 dissipating heat to an environment outside the refrigerator and a blowing fan 53 are provided on the upper surface of housing 10. High-temperature side evaporator 51 and high-temperature side condenser 52 are connected to each other through a coolant pipe, to together form a high-temperature side natural circula-

tion circuit 50. Water (including an aqueous solution) or a hydrocarbon-based natural coolant is sealed in high-temperature side natural circulation circuit 50, and the coolant naturally circulates through high-temperature side natural circulation circuit 50.

[0040] An operation of refrigerator 1 structured as above will now be described. When Stirling refrigerating engine 30 is driven in refrigerator 1 structured as above, the temperature of the cold head is lowered. Therefore, low-temperature side condenser 41 is cooled, and the secondary coolant (hereinafter, abbreviated as the coolant) inside is condensed.

[0041] The coolant condensed in low-temperature side condenser 41 flows into low-temperature side evaporator 42 through low-temperature side circulation circuit 40. The coolant that flowed into low temperature side evaporator 42 is evaporated by heat of air current that passes outside low-temperature side evaporator 42, thereby lowering a surface temperature of low-temperature side evaporator 42. Therefore, the air that passes through low-temperature side evaporator 42 becomes cold, and the cold air is blown into cooling chamber 11 through cold air outlet 20A of duct 20 and through cold air outlet 21 A of duct 21. The temperature of cooling chambers 11 and 12 is thus lowered. Thereafter, the air in cooling chambers 11 and 12 returns to low-temperature side evaporator 42 through a not-shown duct.

[0042] The coolant evaporated in low-temperature side evaporator 42 returns to low-temperature side condenser 41 through low-temperature side circulation circuit 40, where heat is removed and the coolant again condenses. Then, the heat exchange operation as above is repeated.

[0043] Meanwhile, heat generated by drive of Stirling refrigerating engine 30 or heat recovered from the space inside by the cold head is dissipated from the warm head as exhaust heat. Therefore, high-temperature side evaporator 51 is heated and the coolant inside evaporates.

[0044] The coolant turned to vapor phase due to heat generated in high-temperature side evaporator 51 flows into high-temperature side condenser 52 provided in the upper portion, through high-temperature side natural circulation circuit 50. Heat of the coolant that has flowed into high-temperature side condenser 52 is removed by the air current introduced into high-temperature side condenser 52 from the outside by means of blowing fan 53 and the coolant condenses. The coolant that has condensed in high-temperature side condenser 52 returns to high-temperature side evaporator 51 through high-temperature side natural circulation circuit 50, where the coolant receives heat and again evaporates. Then, the heat exchange operation as above is repeated.

[0045] Fig. 3 is a functional block diagram showing a freezing prevention function of the refrigerator in a first embodiment. Referring to Fig. 3, refrigerator 1 includes a control portion 90 for overall control of the refrigerator and a temperature sensor 81 connected thereto. Control portion 90 is connected to Stirling refrigerating engine

30, cooling fan 22, damper 61, and blowing fan 62.

[0046] Temperature sensor 81 detects a temperature of low-temperature side evaporator 42 or the low-temperature side circulation circuit (represented by low-temperature side condenser 41 or the cold head of Stirling refrigerating engine 30). In the present embodiment, the temperature of the coolant within low-temperature side circulation circuit 40 should only be detected directly, however, the temperature of low-temperature side evaporator 42, low-temperature side condenser 41 or the cold head of Stirling refrigerating engine 30 is detected, instead of direct detection. Therefore, temperature sensor 81 may detect a temperature of any of low-temperature side evaporator 42, low-temperature side condenser 41, and the cold head of Stirling refrigerating engine 30, however, preferably, temperature sensor 81 detects the temperature of low-temperature side condenser 41 and further preferably it detects the temperature of the cold head.

[0047] Control portion 90 controls drive of Stirling refrigerating engine 30. The Stirling refrigerating engine can be driven with varied load. The Stirling refrigerating engine attains high cooling capability in drive with greater load, and attains low cooling capability in drive with lower load. Control portion 90 controls the fan level of cooling fan 22 and blowing fan 62. In addition, control portion 90 may control switching between drive and stop of cooling fan 22 and blowing fan 62. Moreover, control portion 90 controls switching between an open state and a closed state of damper 61.

[0048] Fig. 4 is a flowchart showing a flow of freezing prevention processing performed in the refrigerator in the first embodiment. Referring to Fig. 4, control portion 90 of refrigerator 1 receives input of the temperature of the cold head of Stirling refrigerating engine 30 from temperature sensor 81. Control portion 90 determines whether the temperature of the cold head is lower than a prescribed temperature T (step S01). If YES, the process proceeds to step S02, and if NO, the process ends. Prescribed value T is predetermined based on a freezing point of the coolant within low-temperature side circulation circuit 40, and set to a temperature higher than the freezing temperature of the coolant by approximately 3°C. The temperature of the coolant does not necessarily match with the temperature of the cold head, however, it is never lower than the temperature of the cold head. If a temperature difference D between the temperature of the coolant and the temperature of the cold head is known, the prescribed temperature should be set to at least a value obtained by subtracting temperature difference D from the freezing point of the coolant.

[0049] When temperature sensor 81 detects the temperature of low-temperature side evaporator 42 or low-temperature side condenser 41, the temperature of low-temperature side evaporator 42 or low-temperature side condenser 41 does not necessarily match with the temperature of the coolant, however, the temperature of the coolant is never higher than the temperature of low-tem-

perature side evaporator 42 or low-temperature side condenser 41. If a temperature difference D_1 between the temperature of the coolant and the temperature of low-temperature side evaporator 42 or low-temperature side condenser 41 is known, the prescribed temperature should be set to at least a value obtained by adding temperature difference D_1 to the freezing point of the coolant.

[0050] In step S02, the Stirling refrigerating engine is stopped. Thus, the coolant is no longer cooled and it does not freeze.

[0051] In step S02, the Stirling refrigerating engine is stopped, however, the Stirling refrigerating engine may be driven with lower load. In this case, though the coolant is cooled, the coolant can be prevented from freezing if the Stirling refrigerating engine is driven under such a load as maintaining the temperature of the coolant at the current level.

<Variation of Freezing Prevention Processing>

[0052] Fig. 5 is a flowchart showing a flow of modified freezing prevention processing performed in the refrigerator in the first embodiment. Referring to Fig. 5, control portion 90 of refrigerator 1 receives input of the temperature of the cold head of Stirling refrigerating engine 30 from temperature sensor 81. Control portion 90 determines whether the temperature of the cold head is lower than prescribed temperature T (step S11). If YES, the process proceeds to step S12, and if NO, the process proceeds to step S20.

[0053] In step S12, whether cooling fan 22 has been stopped or not is determined. If cooling fan 22 has been stopped, the process proceeds to step S13. If cooling fan has not been stopped, the process proceeds to step S14. In step S13, cooling fan 22 is driven. When cooling fan 22 is driven, convection of the air around low-temperature side evaporator 42 is achieved and the air at a relatively high temperature is supplied to low-temperature side evaporator 22. Thus, lowering in the temperature of the coolant is prevented. Meanwhile, if the process proceeds to step S14, cooling fan 22 is driven, and it is driven with its fan level being increased. Thus, further active convection of the air around low-temperature side evaporator 42 is achieved and lowering in the temperature of the coolant is prevented.

[0054] In step S15, whether a prescribed time period has elapsed or not is determined. If YES, the process proceeds to step S16, and if NO, the process returns to step S11. In step S16, whether blowing fan 62 has been stopped or not is determined. If blowing fan 62 has been stopped, the process proceeds to step S17. If blowing fan 62 has not been stopped, the process proceeds to step S19. In step S17, the damper is opened, and in next step S18, blowing fan 62 is driven. When blowing fan 62 is driven, convection of the air around low-temperature side evaporator 42 is achieved and the air at a relatively high temperature is supplied to low-temperature side evaporator 42. Thus, lowering in the temperature of the

coolant is further prevented. Meanwhile, if the process proceeds to step S19, blowing fan 62 is driven and it is driven with its fan level being increased. Thus, further active convection of the air around low-temperature side evaporator 42 is achieved and lowering in the temperature of the coolant is prevented.

[0055] After step S18 or step S19, the process returns to step S11. In step S11, whether or not the temperature of the cold head is lower than prescribed temperature T is again determined. If the temperature of the cold head is not lower than prescribed temperature T , the process proceeds to step S20. On the other hand, if the temperature of the cold head is lower than prescribed temperature T , the process proceeds to step S12. Namely, the processing in step S12 to step S19 described above is performed until the temperature of the cold head is equal to or higher than prescribed temperature T . In step S20, cooling fan 22, damper 61 and blowing fan 62 are driven in a normal operation mode.

[0056] Thus, according to the variation of the first embodiment, the cooling fan or both of the cooling fan and the blowing fan is/are driven. Accordingly, convection of the air around low-temperature side evaporator 42 is achieved and lowering in the temperature of the coolant can be prevented. The coolant can thus be prevented from freezing.

[0057] It is noted that control for stopping Stirling refrigerating engine 30 described above or for driving Stirling refrigerating engine 30 with its cooling capability being lowered and control for driving the cooling fan or both of the cooling fan and the blowing fan may be carried out together. Thus, freezing of the coolant can further be prevented.

[0058] As described above, when the temperature of low-temperature side evaporator 42, low-temperature side condenser 41 or the cold head of Stirling refrigerating engine 30 is lower than prescribed temperature T , refrigerator 1 in the first embodiment lowers the cooling capability of the Stirling refrigerating engine or stops the Stirling refrigerating engine. Accordingly, cooling of the coolant is suppressed and the coolant can be prevented from freezing.

[0059] In addition, if the temperature of low-temperature side evaporator 42, low-temperature side condenser 41 or the cold head of Stirling refrigerating engine 30 is lower than prescribed temperature T , cooling fan 22 is driven or the fan level thereof is increased. Therefore, convection of the air around low-temperature side evaporator 42 is achieved and the coolant can be prevented from freezing.

[0060] In the first embodiment, for example, prescribed temperature T is set to a temperature higher than the freezing point of the coolant by approximately 3°C . Prescribed temperature T , however, may naturally be set to other temperatures, so long as it is higher than the freezing point of the coolant.

[0061] Here, a lowest temperature in a coolant temperature range that is possible during operation in a rated

state of Stirling refrigerating engine 30 is adopted as prescribed temperature T, so that the temperature of the coolant can be prevented from attaining a temperature lower than the coolant temperature range that is possible during the rated operation of Stirling refrigerating engine 30.

[0062] Thus, as excessive cooling of the coolant resulting from operation of Stirling refrigerating engine 30 is avoided and excessive cooling of the cold head can be prevented, Stirling refrigerating engine 30 can be prevented from entering an overload state beyond the rated state. Consequently, deterioration of Stirling refrigerating engine 30 can be prevented.

<Second Embodiment>

[0063] A refrigerator in a second embodiment will now be described. The refrigerator in the second embodiment is the same as the refrigerator in the first embodiment in the structure except for the freezing prevention function. In the following, the freezing prevention function in the second embodiment will be described.

[0064] Fig. 6 is a functional block diagram showing the freezing prevention function of the refrigerator in the second embodiment. Referring to Fig. 6, refrigerator 1 includes control portion 90 for overall control of the refrigerator and an upper door opening/closing detection switch 82 and a lower door opening/closing detection switch 83 connected thereto. Control portion 90 is connected to Stirling refrigerating engine 30, cooling fan 22, damper 61, and blowing fan 62.

[0065] Upper door opening/closing detection switch 82 detects whether upper door 14 is open or closed. Lower door opening/closing detection switch 83 detects whether lower door 15 is open or closed.

[0066] Fig. 7 is a flowchart showing a flow of freezing prevention processing performed in the refrigerator in the second embodiment. Referring to Fig. 7, control portion 90 of refrigerator 1 receives input of an open/close state of upper door 14 and lower door 15 from upper door opening/closing detection switch 82 or lower door opening/closing detection switch 83. Control portion 90 determines whether any of upper door 14 and lower door 15 is open (step S21). If any of upper door 14 and lower door 15 is open, the process proceeds to step S22, and otherwise, the process ends.

[0067] In step S22, cooling fan 22 is stopped. Thus, forced flow-out of the cold air in cooling chambers 11, 12, of which door is open, to the outside can be prevented. In next step S23, whether a prescribed time period has elapsed or not is determined. The elapsed time here may refer to any of a time counted from the time point of detection of the open state of any of upper door 14 or lower door 15 in step S21 or a time counted from the time point of stop of the cooling fan. If the prescribed time period has elapsed, the process proceeds to step S24, and if the prescribed time period has not elapsed, the process returns to step S21. By stopping the cooling fan, convec-

tion of the air around low-temperature side evaporator 42 is stopped. Thus, the temperature of the coolant is lowered. The prescribed time period is shorter than a time period from the time point when lowering in the temperature of the coolant started to the time point when the temperature of the coolant reaches the freezing point. The prescribed time period may be a single predetermined time period or may be a time period predetermined for each load of the Stirling refrigerating engine. Alternatively, the prescribed time period may be a time period predetermined for each temperature in the space inside and each load of the Stirling refrigerating engine.

[0068] In next step S24, the Stirling refrigerating engine is stopped. Thus, the coolant is no longer cooled and can be prevented from freezing.

[0069] In step S24, the Stirling refrigerating engine is stopped, however, the Stirling refrigerating engine may be driven with lower load. In this case, though the coolant is cooled, the coolant can be prevented from freezing if the Stirling refrigerating engine is driven under such a load as maintaining the temperature of the coolant at the current level.

<First Variation of Freezing Prevention Processing>

[0070] Fig. 8 is a flowchart showing a flow of modified freezing prevention processing performed in the refrigerator in the second embodiment. Referring to Fig. 8, control portion 90 determines whether upper door 14 is open or not (step S31). If upper door 14 is open, the process proceeds to step S32, and otherwise, the process proceeds to step S38.

[0071] In step S32, blowing fan 62 is stopped and in step S33, cooling fan 22 is stopped. Thus, forced flow-out of the cold air in cooling chamber 11 to the outside can be prevented even if upper door 14 is open. Then, whether a prescribed time period has elapsed or not is determined (step S34). If the prescribed time period has elapsed, the process proceeds to step S35, and otherwise, the process returns to step S31. In other words, if the prescribed time period has elapsed with upper door 14 remaining open, the process proceeds to step S35, however, if upper door 14 is closed before the prescribed time period elapses, the process proceeds to step S38. By stopping cooling fan 22 in step S33, convection of the air around low-temperature side evaporator 42 is stopped. Thus, the temperature of the coolant is lowered. If cooling fan 22 is left stopped, the temperature of the coolant is lowered and reaches the freezing point. Therefore, the prescribed time period should be shorter than a time period required until the temperature of the coolant reaches the freezing point. The prescribed time period may be a single predetermined time period or may be a time period predetermined for each load of the Stirling refrigerating engine. Alternatively, the prescribed time period may be a time period predetermined for each temperature in the space inside and each load of the Stirling refrigerating engine.

[0072] In step S35, damper 61 is closed, and in step S36, cooling fan 22 is driven. Thus, the cold air around low-temperature side evaporator 42 is sent into cooling chamber 12 but not into cooling chamber 11, because damper 61 is closed. Therefore, convection of the air around low-temperature side evaporator 42 is achieved and the air at a relatively high temperature is supplied to low-temperature side evaporator 42. Thus, the temperature of the coolant is prevented from lowering. Consequently, the coolant is prevented from freezing. In addition, as the cold air around low-temperature side evaporator 42 is not sent into cooling chamber 11, forced flow-out of the cold air in cooling chamber 11 from the opened upper door can be prevented.

[0073] In step S37, whether upper door 14 is closed or not is determined. If upper door 14 is closed, the process proceeds to step S38, and otherwise, the process returns to step S35. The cold air around low-temperature side evaporator 42 is sent into cooling chamber 12 until upper door 14 is closed, and thus the coolant is prevented from freezing.

[0074] In step S38, cooling fan 22, damper 61 and blowing fan 62 are driven in a normal operation mode.

[0075] In next step S39, control portion 90 determines whether lower door 15 is open or not. If lower door 15 is open, the process proceeds to step S40, and otherwise, the process ends.

[0076] In step S40, blowing fan 62 is stopped and in step S41, cooling fan 22 is stopped. Thus, forced flow-out of the cold air in cooling chamber 12 to the outside can be prevented even if lower door 15 is open. In addition, convection of the air around low-temperature side evaporator 42 is stopped. Then, whether a prescribed time period has elapsed or not is determined (step S42). If the prescribed time period has elapsed, the process proceeds to step S43, and otherwise, the process returns to step S39. In other words, if the prescribed time period has elapsed with lower door 15 remaining open, the process proceeds to step S43, however, if lower door 15 is closed before the prescribed time period elapses, the process ends. The prescribed time period here is the same as in step S34.

[0077] In step S43, damper 61 is opened, and in step S44, blowing fan 62 is driven. Thus, the cold air around low-temperature side evaporator 42 is sent into cooling chamber 11 but not into cooling chamber 12. Therefore, convection of the air around low-temperature side evaporator 42 is achieved and the air at a relatively high temperature is supplied to low-temperature side evaporator 42. Thus, the temperature of the coolant is prevented from lowering, and consequently, the coolant is prevented from freezing. In addition, as an amount of cold air around low-temperature side evaporator 42 that is sent into cooling chamber 12 is small, forced flow-out of the cold air in cooling chamber 12 from the opened lower door can be suppressed.

[0078] In step S45, whether lower door 15 is closed or not is determined. If lower door 15 is closed, the process

proceeds to step S46, and otherwise, the process returns to step S43. Then, the cold air around low-temperature side evaporator 42 is sent into cooling chamber 11 until lower door 15 is closed, and thus the coolant is prevented from freezing.

[0079] In step S46, cooling fan 22, damper 61 and blowing fan 62 are driven in a normal operation mode.

[0080] When the open state of any of upper door 14 and lower door 15 continues for a prescribed time period, refrigerator 1 in the second embodiment lowers the cooling capability of the Stirling refrigerating engine or stops the Stirling refrigerating engine. Accordingly, cooling of the coolant is suppressed and the coolant can be prevented from freezing.

[0081] In addition, if the open state of any of upper door 14 or lower door 15 continues for a prescribed time period, cooling fan 22 is driven or the fan level thereof is increased. Therefore, convection of the air around low-temperature side evaporator 42 is achieved and the coolant can be prevented from freezing.

[0082] Moreover, if the open state of lower door 15 continues for a prescribed time period, damper 61 is closed and cooling fan 22 is driven. If the open state of the upper door continues for a prescribed time period, damper 61 is opened and blowing fan 62 is driven. Accordingly, whichever of upper door 14 and lower door 15 may be opened, the coolant can be prevented from freezing and leakage to the outside of the cold air in the space inside can be prevented.

[0083] The invention of the subject application is applicable to quick-freeze operation for quickly passing a largest ice crystal generation zone (-3°C to -7°C) in freezing food, in which cooling fan 22 is once stopped to set the cold air around low-temperature side evaporator 42 to an extremely low temperature and thereafter cooling fan 22 is driven.

[0084] In the second embodiment, in order to prevent flow-out of the cold air when upper door 14 or lower door 15 is open, cooling fan 22 is stopped, and after a prescribed time period has elapsed, Stirling refrigerating engine 30 is stopped.

[0085] The present invention, however, is not limited as such, and cooling fan 22 and Stirling refrigerating engine 30 may be stopped when upper door 14 or lower door 15 is opened. If the temperature of the cold head of Stirling refrigerating engine 30 is controlled to rapidly lower in order to prevent temperature increase in the space inside refrigerator 1, accidental freezing of the coolant may occur due to delay in control for stopping Stirling refrigerating engine 30.

[0086] In order to avoid this, even when the door of refrigerator 1 is open, Stirling refrigerating engine 30 is stopped without carrying out control for lowering the temperature of the cold head of Stirling refrigerating engine 30 for preventing temperature increase in refrigerator 1, and thus the coolant can be prevented from freezing.

[0087] In addition, in the second embodiment, cooling fan 22 is stopped when upper door 14 or lower door 15

is opened, and after a prescribed time period has elapsed, Stirling refrigerating engine 30 is stopped.

[0088] The present invention, however, is not limited as such. Cooling fan 22 may be stopped when upper door 14 or lower door 15 is opened, and Stirling refrigerating engine 30 may be stopped when the temperature of the cold head of Stirling refrigerating engine 30 attains to a prescribed temperature.

[0089] Freezing of the coolant due to lowering in the temperature of the cold head of Stirling refrigerating engine 30 can thus be prevented. Alternatively, electric power input to Stirling refrigerating engine 30 may be decreased in a stepped manner from the time point when the door is opened to the time point when Stirling refrigerating engine 30 is stopped. Thus, even when the door is open, increase in the temperature in the space inside refrigerator 1 due to flow-out of the cold air can be suppressed, and at the same time, the coolant can be prevented from freezing.

[0090] In addition, preferably, if Stirling refrigerating engine 30 is once stopped when upper door 14 or lower door 15 is opened and thereafter upper door 14 and lower door 15 are closed, Stirling refrigerating engine 30 is operated immediately or after a prescribed time period (for example, after 5 seconds). Thus, the temperature in the space inside refrigerator 1 that has increased due to flow-out of the cold air can quickly be lowered.

[0091] Moreover, preferably, if Stirling refrigerating engine 30 is once stopped when upper door 14 or lower door 15 is opened and thereafter the temperature of the cold head of Stirling refrigerating engine 30 increases to a prescribed temperature, Stirling refrigerating engine 30 is operated. Thus, excessive increase in the temperature in the space inside refrigerator 1 can be prevented.

[0092] In the second embodiment, cooling fan 22 is stopped when upper door 14 or lower door 15 is opened. The present invention, however, is not limited as such, and cooling fan 22 may operate at lower number of revolutions. Thus, as heat is supplied to the coolant from air in refrigerator 1, of which temperature is higher than that of the coolant, the temperature of the coolant gradually increases and the coolant can be prevented from freezing.

[0093] In the second embodiment, Stirling refrigerating engine 30 is stopped when upper door 14 or lower door 15 is opened. The present invention, however, is not limited as such, and electric power input to Stirling refrigerating engine 30 may be decreased. Thus, as quantity of heat removed from the coolant is decreased, the temperature of the coolant increases and the coolant can be prevented from freezing.

[0094] In the second embodiment, the prescribed time period is set to a time period shorter than a time period from the time point when cooling fan 22 is stopped to the time point when the temperature of the coolant reaches the freezing point. The present invention, however, is not limited as such, and the prescribed time period may be set to a time period from the time point when cooling fan

22 is stopped to the time point when the temperature of the coolant reaches a prescribed temperature. The prescribed temperature may be higher than the freezing point of the coolant.

[0095] Thus, the temperature of the coolant can be prevented from reaching the prescribed temperature. Here, a lowest temperature in a coolant temperature range that is possible during rated operation of Stirling refrigerating engine 30 is adopted as the prescribed temperature, so that the temperature of the coolant can be prevented from attaining a temperature lower than the coolant temperature range that is possible during rated operation of Stirling refrigerating engine 30.

[0096] Thus, excessive cooling of the coolant resulting from operation of Stirling refrigerating engine 30 is avoided and excessive cooling of the cold head can be prevented, and therefore, Stirling refrigerating engine 30 can be prevented from entering an overload state beyond the rated state. Consequently, deterioration of Stirling refrigerating engine 30 can be prevented.

<Third Embodiment>

[0097] A refrigerator in a third embodiment will now be described. The refrigerator in the third embodiment is the same as the refrigerator in the first embodiment in the structure except for the freezing prevention function. In the following, the freezing prevention function in the third embodiment will be described.

[0098] Fig. 9 is a functional block diagram showing the freezing prevention function of the refrigerator in the third embodiment. Referring to Fig. 9, refrigerator 1 includes control portion 90 for overall control of refrigerator 1, temperature sensor 81, upper door opening/closing detection switch 82, and lower door opening/closing detection switch 83 connected thereto. Control portion 90 is connected to Stirling refrigerating engine 30, cooling fan 22, damper 61, blowing fan 62, and a display portion 91.

[0099] Display portion 91 displays information on an operation status of the refrigerator. For example, display portion 91 displays indication that Stirling refrigerating engine 30 is abnormal, indication that temperature sensor 81 is abnormal, indication that upper door 14 or lower door 15 is open, or indication that the normal operation is performed. In addition, abnormality may be notified with voice and sound in accordance with display on display portion 91.

[0100] Fig. 10 is a flowchart showing a flow of freezing prevention processing performed in the refrigerator in the third embodiment. Referring to Fig. 10, control portion 90 of refrigerator 1 detects whether temperature sensor 81 is abnormal or not. Control portion 90 determines whether a thermistor of temperature sensor 81 is abnormal or not (step S71). If the thermistor is abnormal, the process proceeds to step S72, and if the thermistor is not abnormal, the process proceeds to step S74. In step S72, display portion 91 displays indication that the thermistor is abnormal. Then, Stirling refrigerating engine 30 is

stopped (step S73). Thereafter, the process ends.

[0101] As described above, if the thermistor is abnormal, Stirling refrigerating engine 30 is stopped regardless of the temperature of the coolant. Thus, the coolant is no longer cooled by Stirling refrigerating engine 30, and the coolant can be prevented from freezing. In addition, detection of a temperature lower than an actual temperature due to malfunction of the thermistor in S83 which will be described later and resultant inadvertent stop of Stirling refrigerating engine 30 in S86 can be prevented. Moreover, detection of a temperature higher than an actual temperature in S83 which will be described later due to malfunction of the thermistor, and resultant failure in stopping Stirling refrigerating engine 30 in spite of freezing of the coolant because the coolant has reached the freezing temperature, can be prevented.

[0102] Further, control portion 90 of refrigerator 1 receives input of the temperature of the cold head of Stirling refrigerating engine 30 from temperature sensor 81. Control portion 90 determines whether the temperature of the cold head is lower than a temperature T_1 (step S74). If the temperature of the cold head is lower than temperature T_1 , the process proceeds to step S75. If the temperature of the cold head is not lower than temperature T_1 , the process returns to step S71. For example, temperature T_1 is higher than the freezing temperature of the coolant by approximately 3°C.

[0103] Control portion 90 of refrigerator 1 receives input of an open/close state of upper door 14 and lower door 15 from upper door opening/closing detection switch 82 or lower door opening/closing detection switch 83. Control portion 90 determines whether any of upper door 14 and lower door 15 is open (step S75). If any of upper door 14 and lower door 15 is open, the process proceeds to step S76, and otherwise, the process proceeds to step S77.

[0104] In step S76, control portion 90 gives notification of warning that upper door 14 or lower door 15 is open on display portion 91. Thereafter, the process returns to S71.

[0105] In step S77, whether or not the number of revolutions of cooling fan 22 has been set to the maximum tolerable number of revolutions of cooling fan 22 is determined. If the maximum tolerable number of revolutions has not been set, the process proceeds to step S78, and if the maximum tolerable number of revolutions has been set, the process proceeds to step S81.

[0106] In step S78, the number of revolutions of cooling fan 22 is set to the maximum tolerable number of revolutions of cooling fan 22. Thus, as compared with the case where the number of revolutions of cooling fan 22 is smaller than the maximum tolerable number of revolutions, further active convection of the air around low-temperature side evaporator 42 is achieved and lowering in the temperature of the coolant can be suppressed. Then, whether a prescribed time period has elapsed since the number of revolutions of cooling fan 22 was set to the maximum tolerable number of revolutions is deter-

mined (step S79). If the prescribed time period has not elapsed, S79 is repeated. If the prescribed time period has elapsed, the process proceeds to step S82.

[0107] Preferably, the prescribed time period is not shorter than a time period required for the temperature of the coolant to increase at least by such temperature variation that temperature sensor 81 is capable of detecting temperature increase when the number of revolutions of cooling fan 22 is set to the maximum tolerable number of revolutions during normal operation. For example, if temperature detection error of temperature sensor 81 is $\pm 0.5^\circ\text{C}$, a time period not shorter than a time period required for the temperature of the coolant to increase by at least 1°C should be set as the prescribed time period.

[0108] In addition, preferably, the prescribed time period is shorter than a time period until the temperature of the cold head lowers from temperature T_1 to a temperature T_2 which will be described later when the number of revolutions of cooling fan 22 is set to the maximum tolerable number of revolutions during abnormal operation.

[0109] In step S81, electric power input to Stirling refrigerating engine 30 is decreased by a prescribed amount. The cooling capability of Stirling refrigerating engine 30 is thus lowered. Therefore, a quantity of heat removed from the coolant can be decreased and temperature lowering of the coolant can be suppressed.

[0110] In step S82, control portion 90 again determines whether the temperature of the cold head is lower than temperature T_1 . If the temperature of the cold head is not lower than temperature T_1 , the process proceeds to step S83. If the temperature of the cold head is lower than temperature T_1 , the process proceeds to step S84.

[0111] Namely, if the process proceeds to step S83, by setting the number of revolutions of cooling fan 22 to the maximum tolerable number of revolutions in step S78 or decreasing electric power input to Stirling refrigerating engine 30 in step S81, the temperature of the cold head returns from an abnormal value lower than temperature T_1 to a normal value not lower than temperature T_1 . If the process proceeds to step S84, the temperature of the cold head remains at abnormal value.

[0112] In step S83, the operation mode of Stirling refrigerating engine 30, cooling fan 22, damper 61, and blowing fan 62 is switched to the normal operation mode. Thereafter, the process returns to step S71.

[0113] In step S84, control portion 90 determines whether the temperature of the cold head is lower than temperature T_2 . If the temperature of the cold head is not lower than temperature T_2 , the process returns to step S81. If the temperature of the cold head is lower than temperature T_2 , the process proceeds to step S85. For example, temperature T_2 is higher than the freezing temperature of the coolant by approximately 1°C .

[0114] In step S85, control portion 90 displays indication that Stirling refrigerating engine 30 is abnormal on display portion 91. Then, in step S86, control portion 90 stops Stirling refrigerating engine 30. Thereafter, the

process ends.

[0115] In the present embodiment, the number of revolutions of cooling fan 22 is set to the maximum tolerable number of revolutions in step S78, however, the number of revolutions of cooling fan 22 may be increased in a stepped manner. Then, if the temperature of the cold head is not lower than temperature T_1 after a prescribed time period elapsed, the operation returns to the normal operation.

[0116] Thus, if the temperature of the cold head is not lower than temperature T_1 before the number of revolutions of cooling fan 22 reaches the maximum tolerable number of revolutions, it is not necessary to increase the number of revolutions of cooling fan 22 more than necessary and power consumption can be suppressed. In addition, as the temperature variation of the coolant is gradual, the temperature of the coolant can be controlled more accurately than when the temperature variation of the coolant is sudden.

[0117] In a mechanism for cooling the space inside refrigerator 1 using the coolant, the coolant may freeze. If the operation of Stirling refrigerating engine 30 is continued with the coolant remaining frozen, the temperature of the cold head suddenly lowers and Stirling refrigerating engine 30 may fail.

[0118] Therefore, if the temperature of low-temperature side circulation circuit 40 reaches a temperature around the freezing temperature of the coolant as a result of detection of the temperature of low-temperature side circulation circuit 40 of Stirling refrigerating engine 30, Stirling refrigerating engine 30 should be stopped. If Stirling refrigerating engine 30 is suddenly stopped, however, reliability of refrigerator 1 as a product is remarkably harmed, which is not preferred.

[0119] As described above, refrigerator 1 in the third embodiment carries out, prior to stop control for stopping Stirling refrigerating engine 30 for preventing the coolant from freezing, freezing prevention control for preventing freezing of the coolant that is different from stop control, such as control for setting the number of revolutions of cooling fan 22 to the maximum tolerable number of revolutions or control for decreasing electric power input to Stirling refrigerating engine 30, to thereby prevent the coolant from freezing.

[0120] Therefore, if the coolant can be prevented from freezing as a result of freezing prevention control, stop control of Stirling refrigerating engine 30 is not necessary. Consequently, stop of the Stirling refrigerating engine can be avoided as much as possible. Reliability of the refrigerator as the product can thus be improved.

[0121] In addition, in detecting a temperature by means of temperature sensor 81, for example, abnormality in detection of the temperature, such as abnormality of the thermistor of temperature sensor 81, is sensed. Therefore, erroneous detection of the temperature by temperature sensor 81 can be prevented. Thus, stop of Stirling refrigerating engine 30 in step S86 based on erroneous detection in step S84 that the temperature of

the cold head is lower than temperature T_2 can be avoided.

[0122] In addition, if the temperature of the cold head is lower than temperature T_1 which is higher than the freezing temperature of the coolant, freezing prevention control is carried out. Meanwhile, if the temperature of the cold head is lower than temperature T_2 which is higher than the freezing temperature of the coolant and lower than T_1 , stop control of Stirling refrigerating engine 30 is carried out. Accordingly, if freezing prevention control is able to prevent the temperature of the cold head from becoming lower than temperature T_2 and to prevent the coolant from freezing, stop control of Stirling refrigerating engine 30 is not necessary. Consequently, stop of Stirling refrigerating engine 30 can be avoided as much as possible.

[0123] In addition, as the fan level of cooling fan 22 is increased, convection of the air around low-temperature side evaporator 42 is achieved. Accordingly, as the air newly sent to low-temperature side evaporator 42 provides heat to the coolant, the temperature of the coolant is raised. Consequently, the coolant can be prevented from freezing.

[0124] Moreover, as convection of the air in the space inside is achieved by means of cooling fan 22, the air in the space inside can efficiently be cooled by low-temperature side evaporator 42. Consequently, COP (Coefficient of Performance) of Stirling refrigerating engine 30 can be improved.

[0125] Here, COP represents heating or cooling capability of a heating apparatus or a cooling apparatus per power consumption, and it is calculated as a ratio between a quantity of heat provided to a non-heated object or a quantity of heat removed from a non-cooled object and a value obtained by converting an amount of energy consumed for heating or cooling to a heat quantity. In the present embodiment, the cooling apparatus is refrigerator 1, and the non-cooled object is the air in refrigerator 1 cooled by the coolant cooled by the cold head of Stirling refrigerating engine 30. Here, COP can be found in the expression $COP = Q_{OUT}/Q_{IN}$, where Q_{OUT} represents a quantity of heat removed from the non-cooled object and Q_{IN} represents a value obtained by converting the amount of consumed energy to heat quantity.

[0126] Namely, as the heat quantity is efficiently removed from the air convected by means of cooling fan 22 by the coolant cooled by Stirling refrigerating engine 30, heat quantity Q_{OUT} removed from the air increases relative to value Q_{IN} obtained by converting the consumed electric power to heat quantity, and COP thus improves.

[0127] If the temperature of the coolant is not raised and the temperature of the cold head is lower than temperature T_1 in spite of the fact that the heat quantity is provided to the coolant as a result of removal of heat quantity from the air, the cooling capability of Stirling refrigerating engine 30 is lowered, that is, control for decreasing electric power input to Stirling refrigerating en-

gine 30 is carried out.

[0128] Accordingly, as cooling of the coolant by Stirling refrigerating engine 30 is suppressed, the temperature of the coolant is raised. Consequently, the coolant is prevented from freezing.

[0129] In addition, as cooling fan 22 is driven with the number of revolutions of cooling fan 22 being set to the maximum tolerable number of revolutions, freezing of the coolant can further be prevented as compared with the case where the number of revolutions is not set to the maximum tolerable number of revolutions. Moreover, by setting the number of revolutions to the maximum tolerable number of revolutions, further convection of the air in the space inside is achieved by means of cooling fan 22, and therefore, COP of Stirling refrigerating engine 30 can further be improved.

[0130] If the temperature of the coolant is not raised and the temperature of the cold head is lower than temperature T_1 in spite of the fact that the fan level of cooling fan 22 is increased and the heat quantity is provided to the coolant, control for decreasing electric power input to Stirling refrigerating engine 30 is carried out. As cooling of the coolant can thus be suppressed, the temperature of the coolant is increased. Consequently, the coolant can be prevented from freezing.

[0131] In addition, as warning about freezing of the coolant due to abnormality of Stirling refrigerating engine 30 is notified before the coolant freezes, one can be urged to take emergency measures for addressing freezing of the coolant, for example, by opening and closing the door.

[0132] In the third embodiment, for example, temperature T_1 is higher than the freezing point of the coolant by approximately 3°C and temperature T_2 is higher than the freezing point of the coolant by approximately 1°C. It goes without saying, however, that any other temperature may be set as temperatures T_1 and T_2 , so long as it is higher than the freezing point of the coolant and relation of $T_1 > T_2$ is satisfied.

[0133] Here, a lowest temperature in a coolant temperature range that is possible during operation in a rated state of Stirling refrigerating engine 30 is adopted as temperature T_2 , and a temperature lower than a highest temperature in the aforementioned temperature range and higher than temperature T_2 by several degrees is adopted as temperature T_1 , so that the temperature of the coolant can be prevented from attaining a temperature lower than the coolant temperature range that is possible during rated operation of Stirling refrigerating engine 30.

[0134] Thus, excessive cooling of the coolant resulting from operation of Stirling refrigerating engine 30 is avoided and excessive cooling of the cold head can be prevented. Therefore, Stirling refrigerating engine 30 can be prevented from entering an overload state beyond the rated state. Consequently, deterioration of Stirling refrigerating engine 30 can be prevented.

[0135] In the first to third embodiments, refrigerator 1 has been described, however, the invention may be understood as a method of controlling refrigerator 1 or Stirling refrigerating engine 30 performing the processing

shown in Figs. 4, 5, 7, 8, and 10, a program for controlling refrigerator 1 or Stirling refrigerating engine 30 performing the processing shown in Figs. 4, 5, 7, 8, and 10, and Stirling refrigerating engine 30 provided in refrigerator 1.

[0136] Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

Claims

1. A refrigerator (1) for cooling a space inside the refrigerator with a Stirling refrigerating engine (30), comprising:

state detection means (81, S01, S11, S21, S31, S37, S39, S45, S74, S75, S82, S84) for detecting an excessive cooling critical state of said Stirling refrigerating engine; and
excessive cooling prevention means (S02) for preventing excessive cooling of said Stirling refrigerating engine based on detection of said excessive cooling critical state by said state detection means.

2. The refrigerator according to claim 1, further comprising:

door state detection means (82, 83) for detecting an open/close state of a door (14, 15) of a cooling chamber (11, 12) of said refrigerator;
a cooling fan (22) supplying cold air cooled by said Stirling refrigerating engine into the space inside; and
cooling fan control means (S22) for stopping said cooling fan while a door open state is detected by said door state detection means; and
said state detection means detecting that a prescribed time period has elapsed since detection of the door open state by said door state detection means (S23).

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

a first cooling chamber (12) and a second cooling chamber (11) partitioned by a heat insulator and each having the door; said first cooling chamber being supplied with cold air cooled by said Stirling refrigerating engine by said cooling fan;
an air passage (20, 21, 21 A) for guiding the cold air cooled by said Stirling refrigerating engine to said second cooling chamber;

- shut-off means (61) provided in said air passage, for shutting off the cold air cooled by said Stirling refrigerating engine; and
a blowing fan (62) sending the cold air cooled by said Stirling refrigerating engine to said air passage; wherein
when said door state detection means detects a closed state of the door of said first cooling chamber and an open state of the door of said second cooling chamber (S31), said excessive cooling prevention means causes said shut-off means to shut off said air passage (S35) and cancels stopped state of said cooling fan and drives said cooling fan (S36), and when said door state detection means detects an open state of the door of said first cooling chamber and a closed state of the door of said second cooling chamber (S39), said excessive cooling prevention means causes said shut-off means to cancel shut-off of said air passage (S43) and drives said blowing fan (S44).
4. The refrigerator according to claim 1, further comprising a low-temperature side evaporator (42) receiving cold heat from a low-temperature portion formed in said Stirling refrigerating engine through a secondary coolant; wherein
said state detection means includes temperature detection means (81) for detecting a temperature of said low-temperature portion, said low-temperature side evaporator, or a low-temperature side condenser (41) paired with said low-temperature side evaporator, and detects that the temperature detected by said temperature detection means is lower than a prescribed temperature (S01, S11, S74, S82, S84).
5. The refrigerator according to claim 4, wherein
said excessive cooling prevention means carries out, prior to stop control (S24, S86) for controlling and stopping said Stirling refrigerating engine, excessive cooling prevention control (S22, S78, S81) different from said stop control, for preventing excessive cooling of said Stirling refrigerating engine.
6. The refrigerator according to claim 5, wherein
said prescribed temperature includes a first temperature (T_1) higher than a temperature at which said Stirling refrigerating engine is excessively cooled and a second temperature (T_2) higher than the temperature at which said Stirling refrigerating engine is excessively cooled and lower than said first temperature, and
when said state detection means detects that the temperature detected by said temperature detection means is lower than said first temperature, said excessive cooling prevention means carries out said excessive cooling prevention control, and when said coolant state detection means detects that the temperature detected by said temperature detection means is lower than said second temperature, said excessive cooling prevention means carries out said stop control.
7. The refrigerator according to claim 4, further comprising:
abnormality in temperature detection sensing means (81) for sensing abnormality in detection of a temperature by said temperature detection means, when said temperature detection means detects a temperature.
8. The refrigerator according to claim 4, further comprising:
a cooling fan (22) supplying cold air cooled by said low-temperature side evaporator into the space inside; wherein
said excessive cooling prevention means drives said cooling fan (S13, S36) or increases a fan level of said cooling fan (S14, S78).
9. The refrigerator according to claim 8, wherein
when said state detection means detects that the temperature detected by said temperature detection means is lower than said first temperature (S74), said excessive cooling prevention means drives said cooling fan or increases a fan level of said cooling fan (S78), and when said state detection means detects that the temperature detected by said temperature detection means is lower than said first temperature (S82) after a prescribed time period has elapsed since drive of said cooling fan or increase in the fan level of said cooling fan (S79), said excessive cooling prevention means controls said Stirling refrigerating engine to lower cooling capability (S81).
10. The refrigerator according to claim 8, wherein
said excessive cooling prevention means includes revolution number control means (90) for controlling number of revolutions of said cooling fan, and
when said state detection means detects that the temperature detected by said temperature detection means is lower than said first temperature, said excessive cooling prevention means drives said cooling fan with the number of revolutions of said cooling fan being set to maximum revolution capability (S78), and when said state detection means detects that the temperature detected by said temperature detection means is lower than said first temperature (S82) after a prescribed time period has elapsed since drive of said cooling fan at the maximum number of revolutions (S79), said excessive cooling prevention means controls said Stirling refrigerating engine to lower cooling capability (S81).

FIG. 1

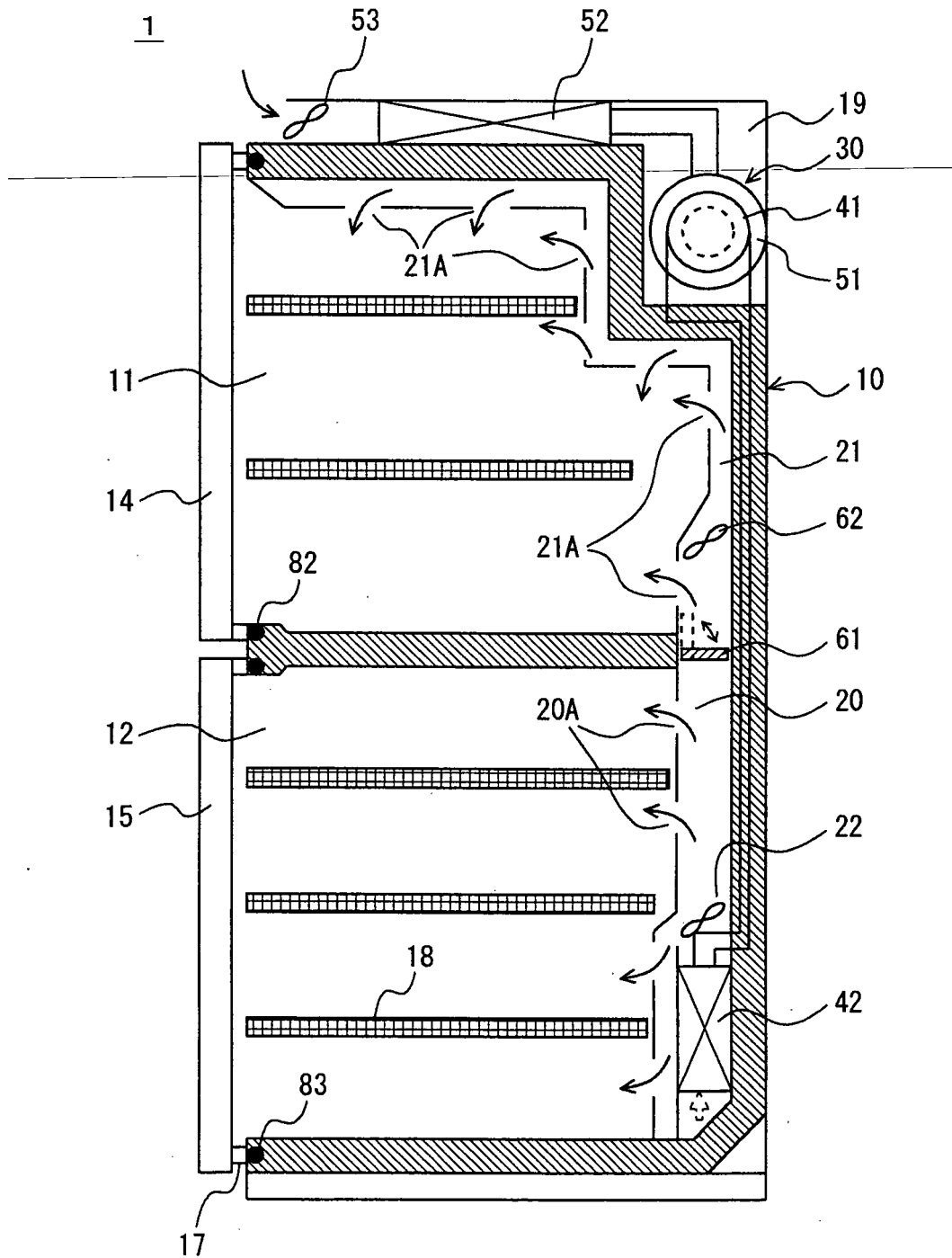


FIG. 2

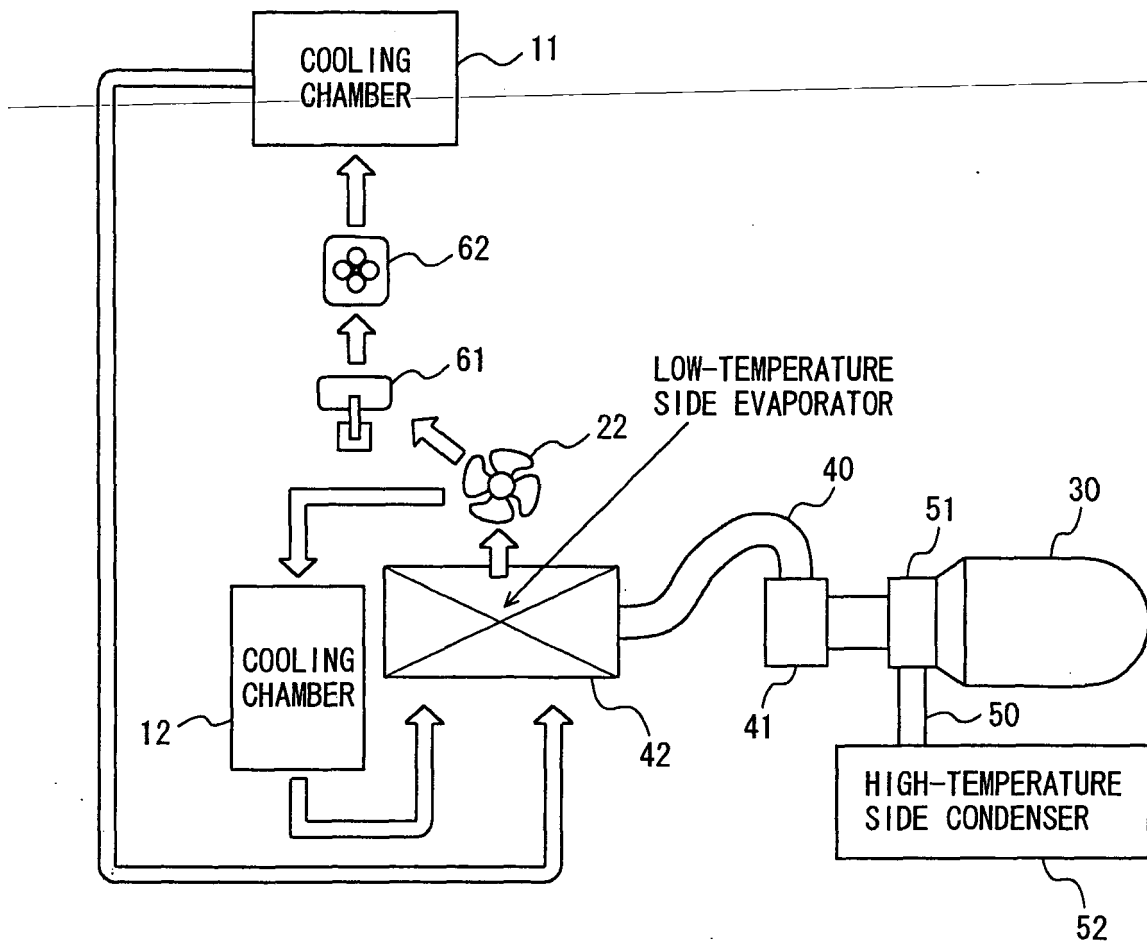


FIG. 3

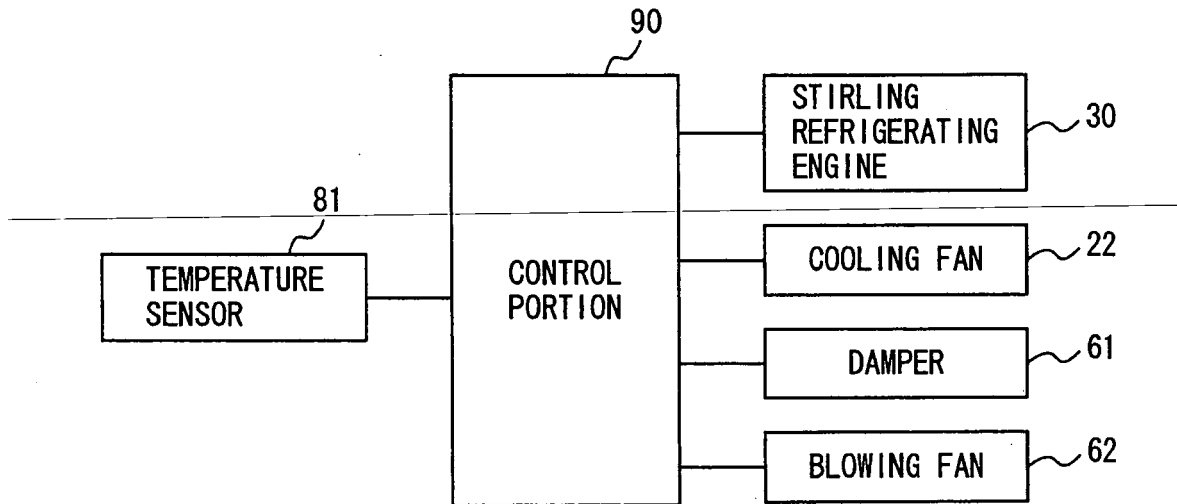


FIG. 4

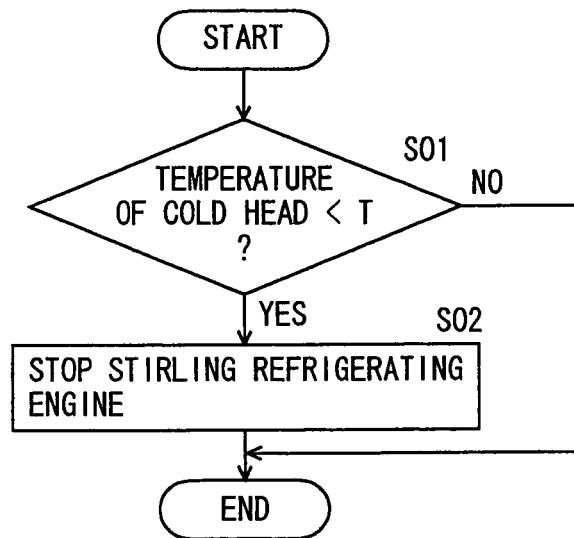


FIG. 5

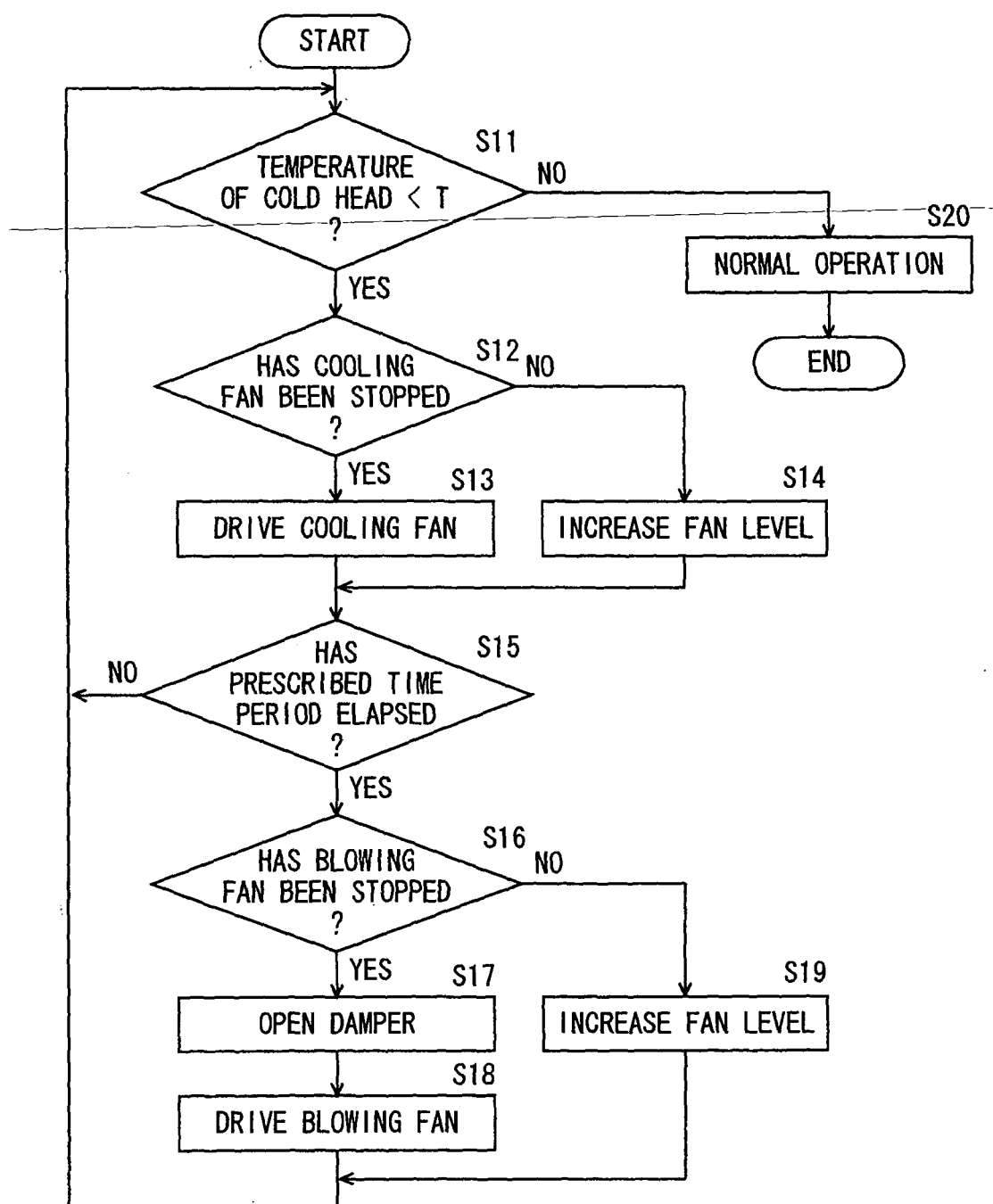


FIG. 6

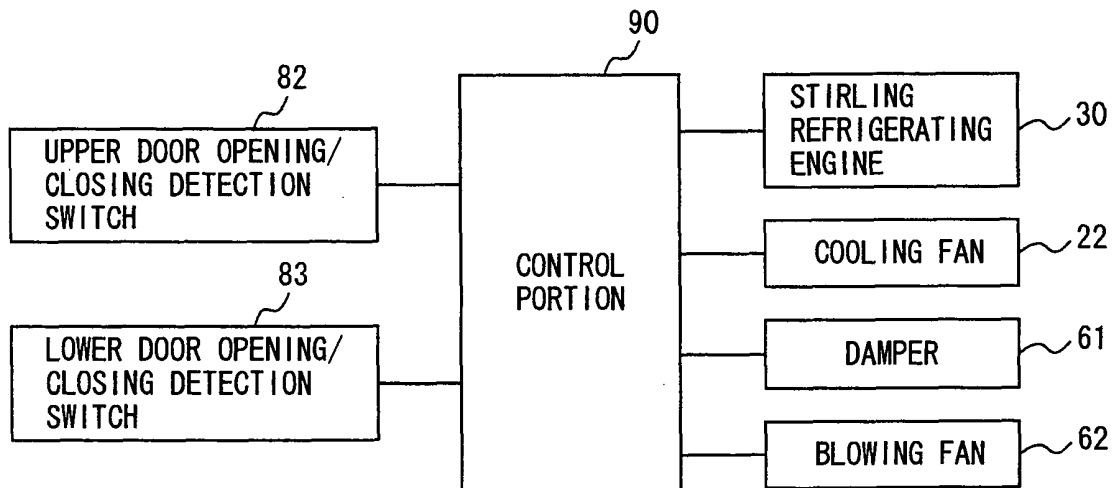


FIG. 7

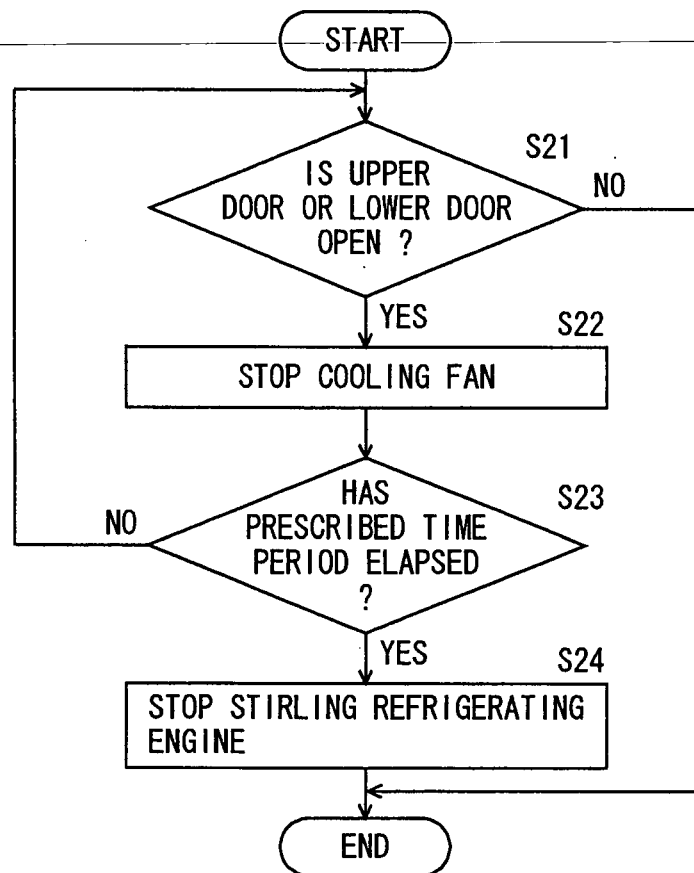


FIG. 8

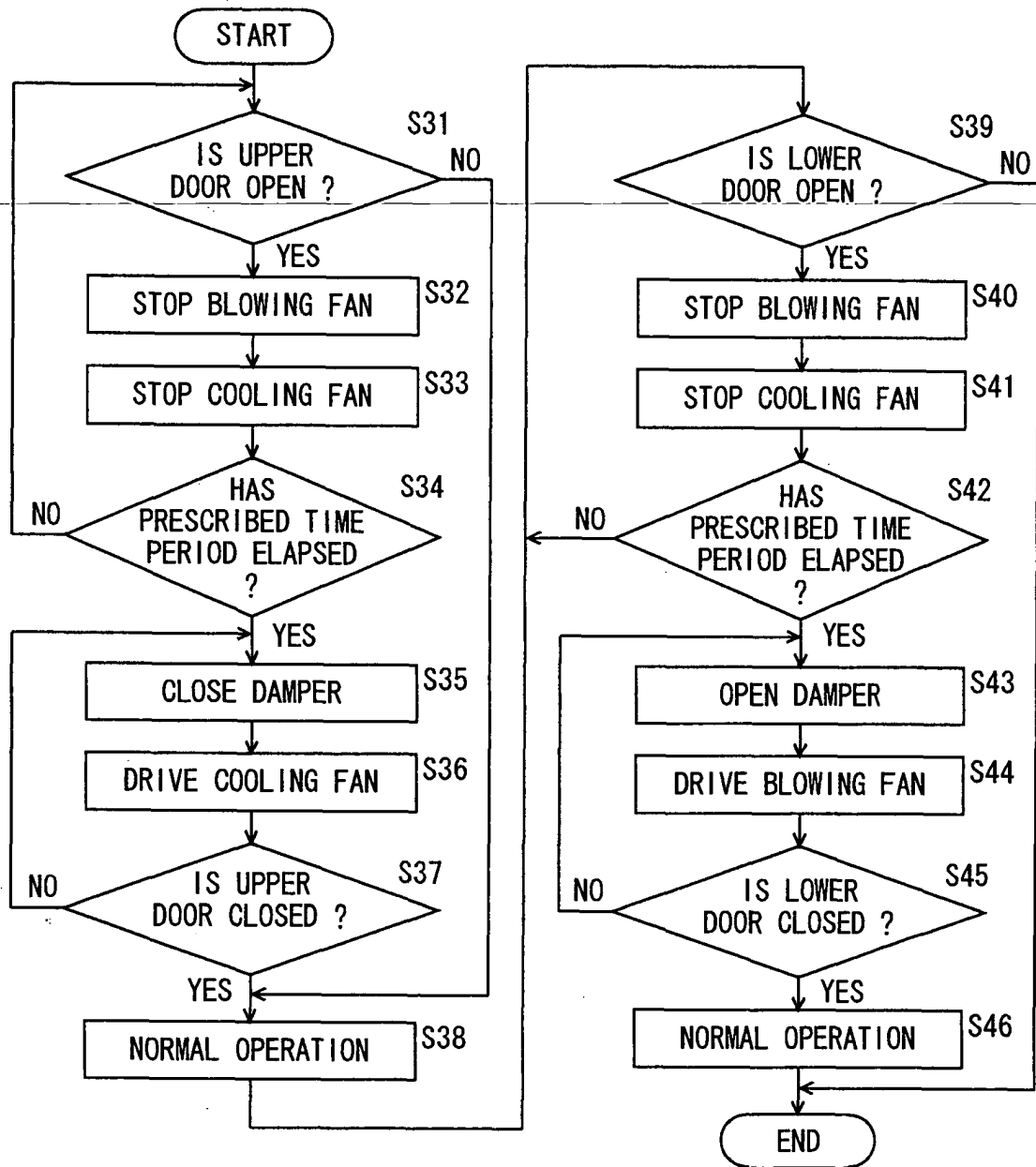


FIG. 9

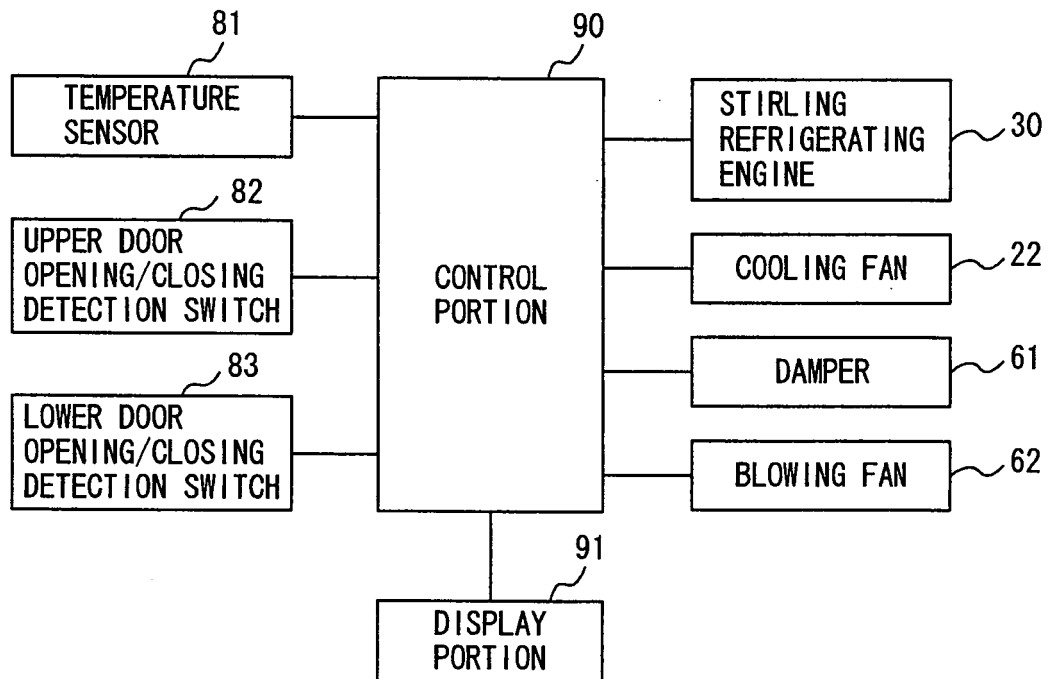
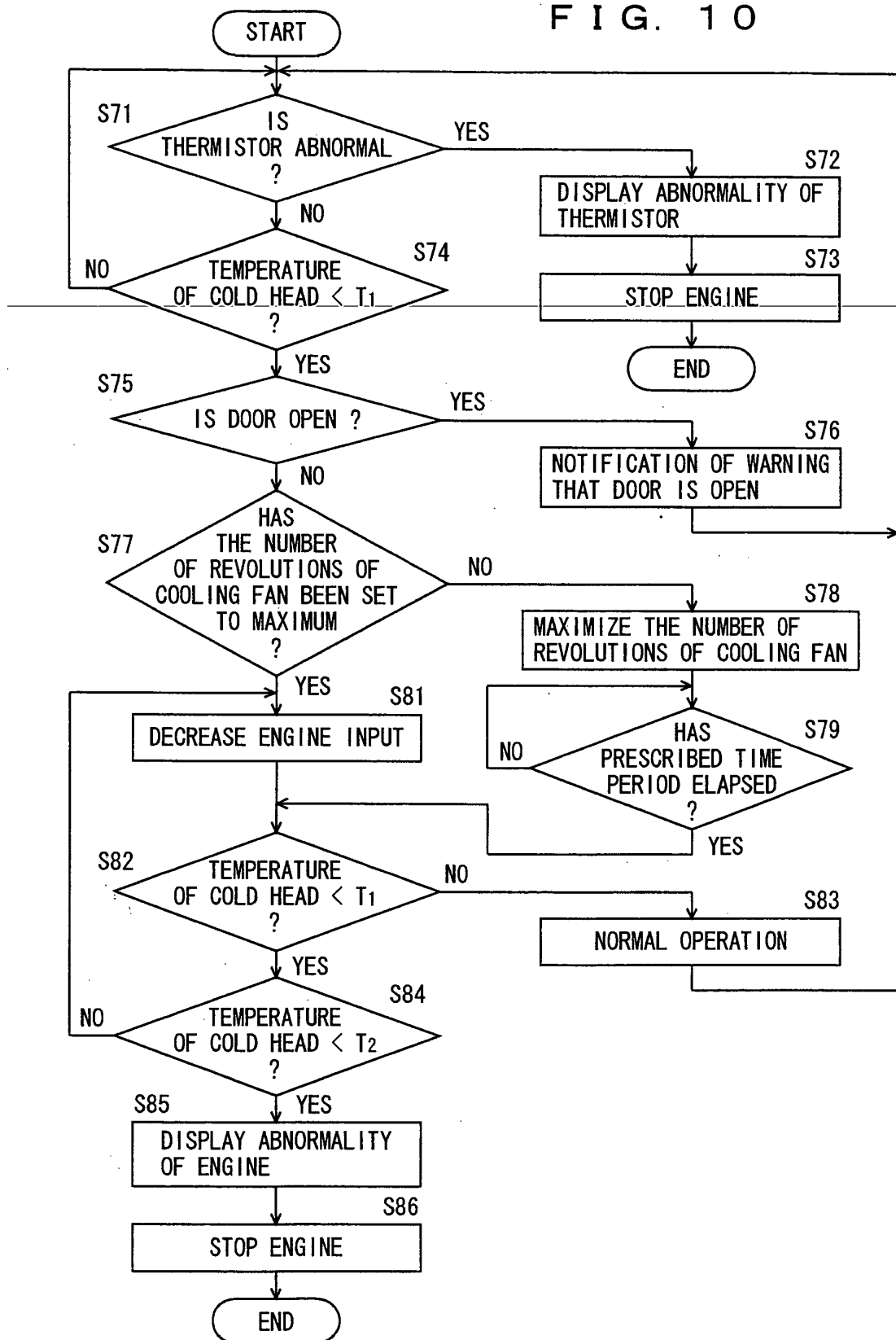


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/016912

A. CLASSIFICATION OF SUBJECT MATTER

F25D11/00(2006.01) , **F25D16/00**(2006.01) , **F25D17/08**(2006.01)

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)

F25D11/00(2006.01) , **F25D16/00**(2006.01) , **F25D17/08**(2006.01)

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

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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.
X Y	JP 2000-18747 A (Sanyo Electric Co., Ltd.), 18 January, 2000 (18.01.00), Par. Nos. [0047], [0049] to [0050]; Figs. 1 to 4 (Family: none)	1, 4, 7 2-3, 5-6, 8-10
Y	JP 2003-314937 A (Sharp Corp.), 06 November, 2003 (06.11.03), Par. Nos. [0037] to [0042], [0064] to [0066]; Figs. 1 to 3 (Family: none)	2-3, 5-6, 8-10
Y	JP 9-236369 A (Matsushita Refrigeration Co.), 09 September, 1997 (09.09.97), Par. No. [0047]; Fig. 1 (Family: none)	2-3, 8-10

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

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Date of the actual completion of the international search
06 December, 2005 (06.12.05)Date of mailing of the international search report
13 December, 2005 (13.12.05)Name and mailing address of the ISA/
Japanese Patent Office

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2002221384 A [0002] [0002]