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Egawa et al.

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(54) AIR CONDITIONING SYSTEMS AND METHODS FOR OPERATING THE SAME

(76) Inventors: **Satoru Egawa**, Kariya-shi (JP); **Ken Suitou**, Kariya-shi (JP); **Yasuharu Odachi**, Kariya-shi (JP); **Shoichi Ieoka**, Kariya-shi (JP); **Hiroyuki Gennami**, Kariya-shi (JP); **Kazuhiro Kuroki**, Kariya-shi (JP)

Correspondence Address:
WOODCOCK WASHBURN LLP
ONE LIBERTY PLACE, 46TH FLOOR
1650 MARKET STREET
PHILADELPHIA, PA 19103 (US)

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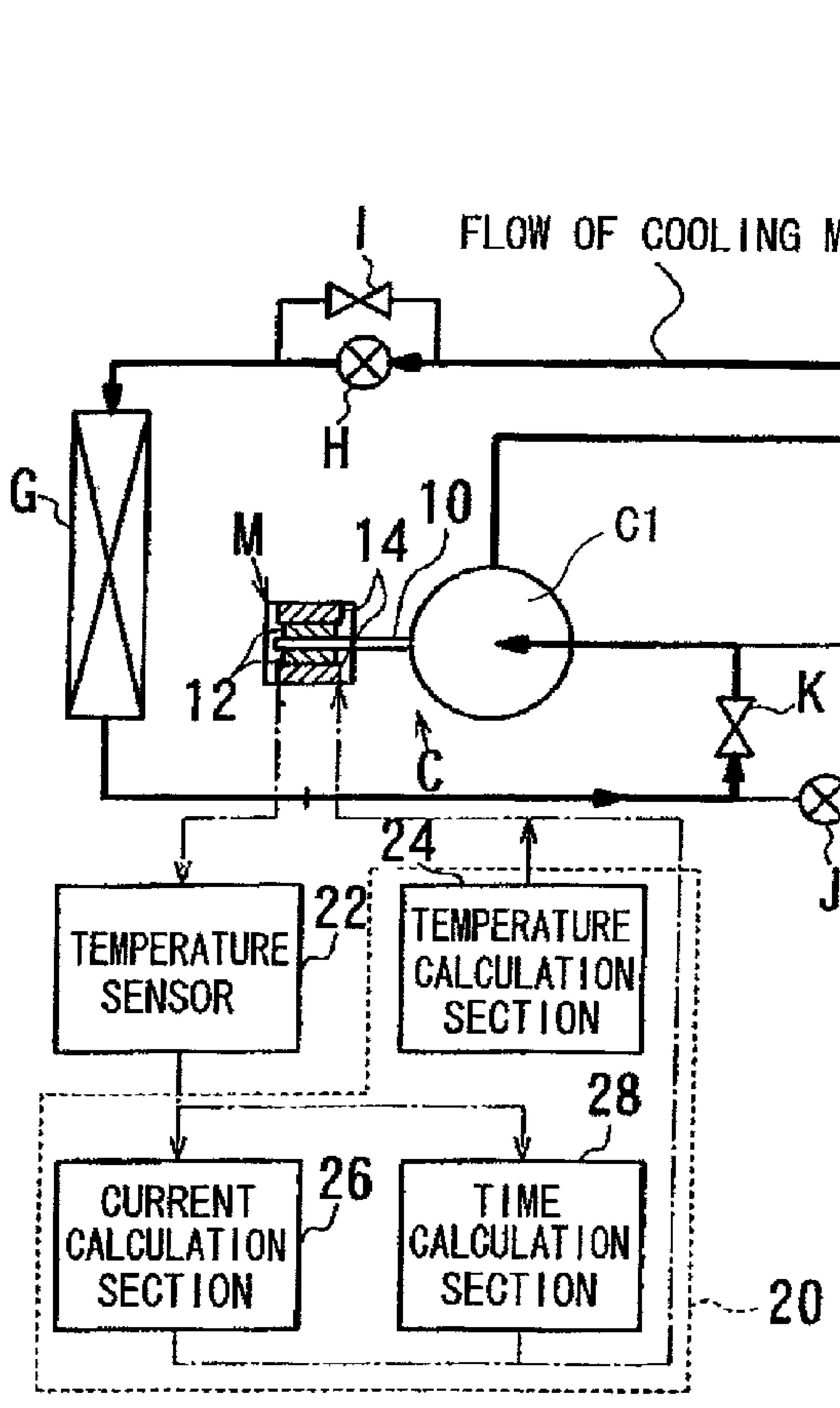
(57) **ABSTRACT**

Air conditioning systems (**1**) may include an air conditioning circuit (**2**) and an electrically driven compressor (C). The compressor may have a motor (M) that includes a rotor (**12**) and a stator (**14**). The rotor may be rotated by a magnetic force generated when current is supplied to the stator. A temperature sensor (**22**) may detect the temperature of the rotor or the ambient temperature when the rotor is started to be rotated. A current calculator (**26**) may calculate a demagnetization limit current of the rotor at the detected temperature. The calculated demagnetization limit current may be used for determining a current that will be supplied to the stator for a predetermined period. In the alternative, the supplied current may increase as the rotor temperature increases during the initial operation. Preferably, the current may be less than the demagnetization limit current and may be greater than a minimum current that is required to rotate the rotor.



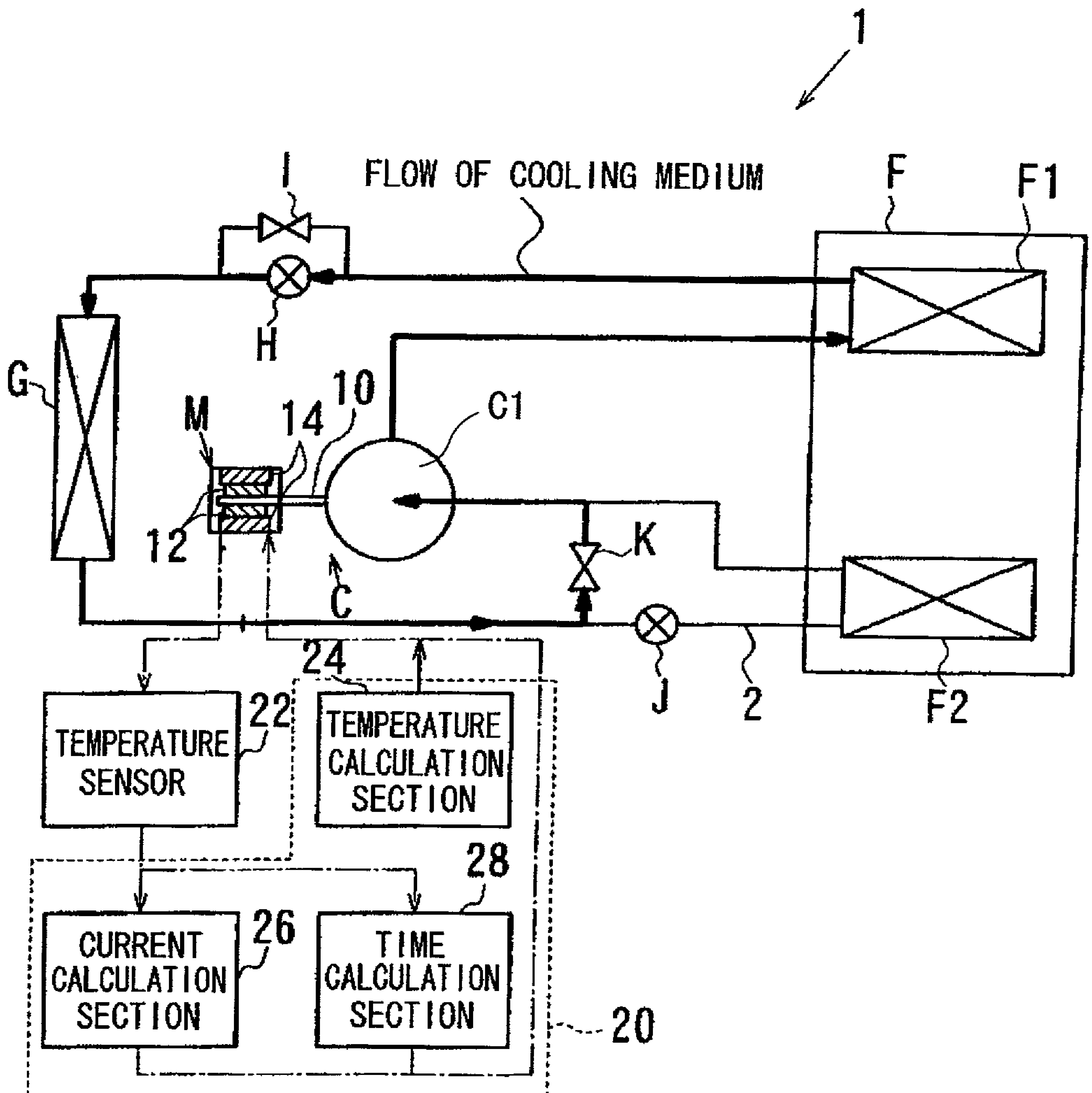

1
FLOW OF COOLING MEDIUM
I
F
F1
H
G
M
14
10
C1
12
K
C
24
J
2
F2
22
TEMPERATURE SENSOR
TEMPERATURE CALCULATION SECTION
28
26
CURRENT CALCULATION SECTION
TIME CALCULATION SECTION
20

FIG. 1

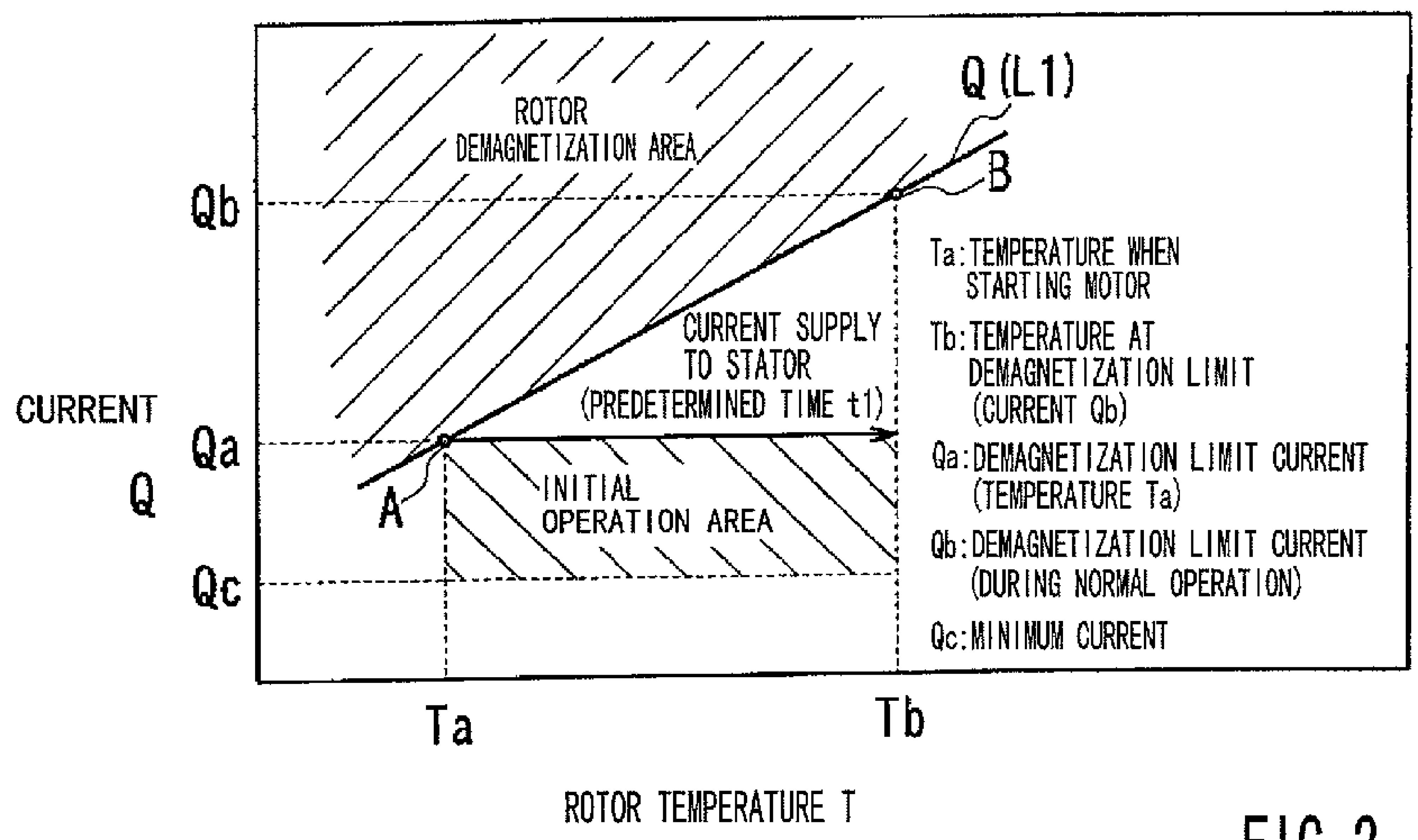

Q (L1)
ROTOR
DEMAGNETIZATION AREA
B
Qb
Ta:TEMPERATURE WHEN
STARTING MOTOR
CURRENT SUPPLY
TO STATOR
(PREDETERMINED TIME t1)
Tb:TEMPERATURE AT
DEMAGNETIZATION LIMIT
(CURRENT Qb)
CURRENT
Qa
Q
A
INITIAL
OPERATION AREA
Qa:DEMAGNETIZATION LIMIT CURRENT
(TEMPERATURE Ta)
Qc
Qb:DEMAGNETIZATION LIMIT CURRENT
(DURING NORMAL OPERATION)
Qc:MINIMUM CURRENT
Ta
Tb
ROTOR TEMPERATURE T

FIG. 2

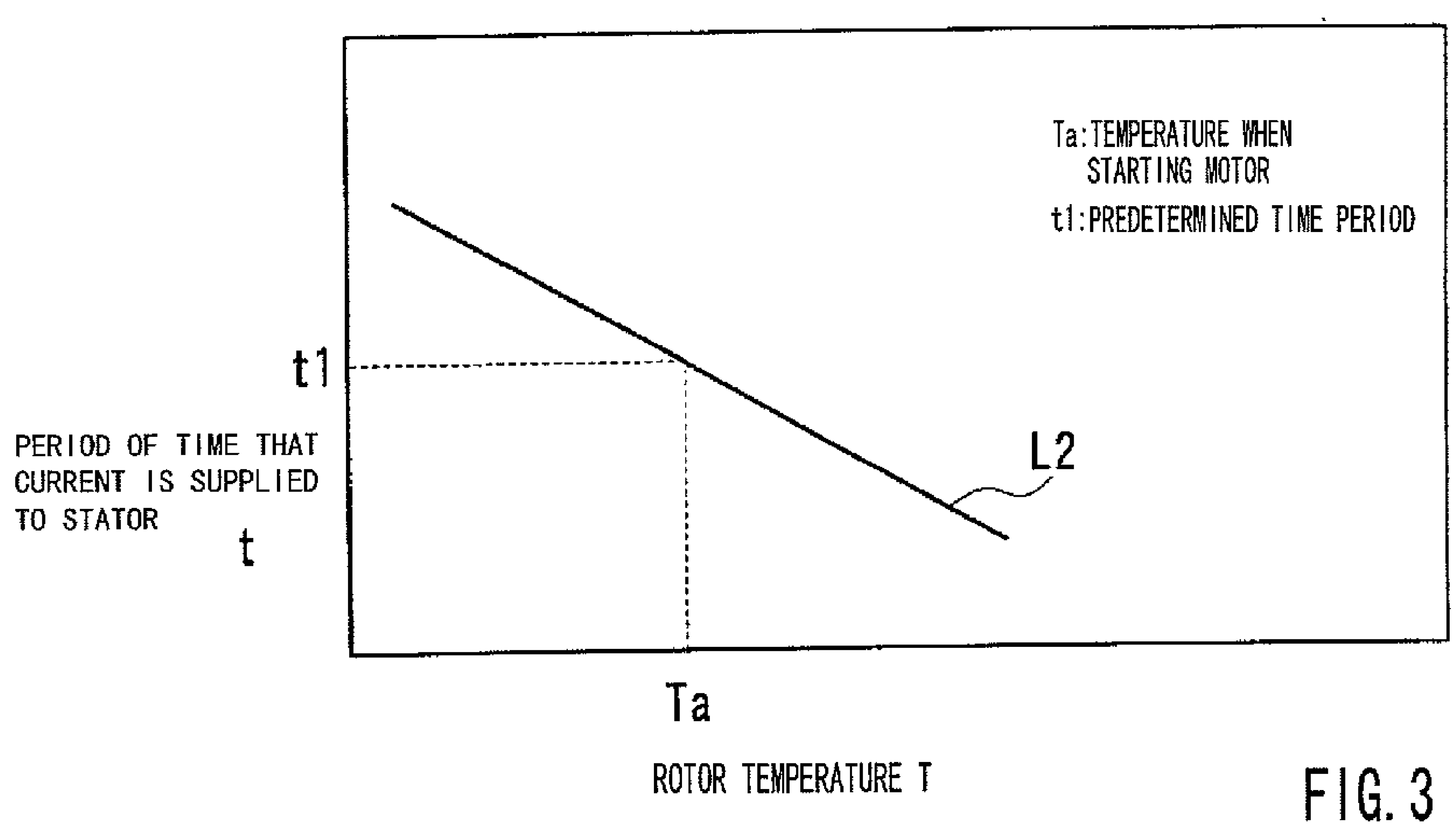

Ta:TEMPERATURE WHEN
STARTING MOTOR
t1:PREDETERMINED TIME PERIOD
t1
PERIOD OF TIME THAT
CURRENT IS SUPPLIED
TO STATOR
t
L2
Ta
ROTOR TEMPERATURE T

FIG. 3

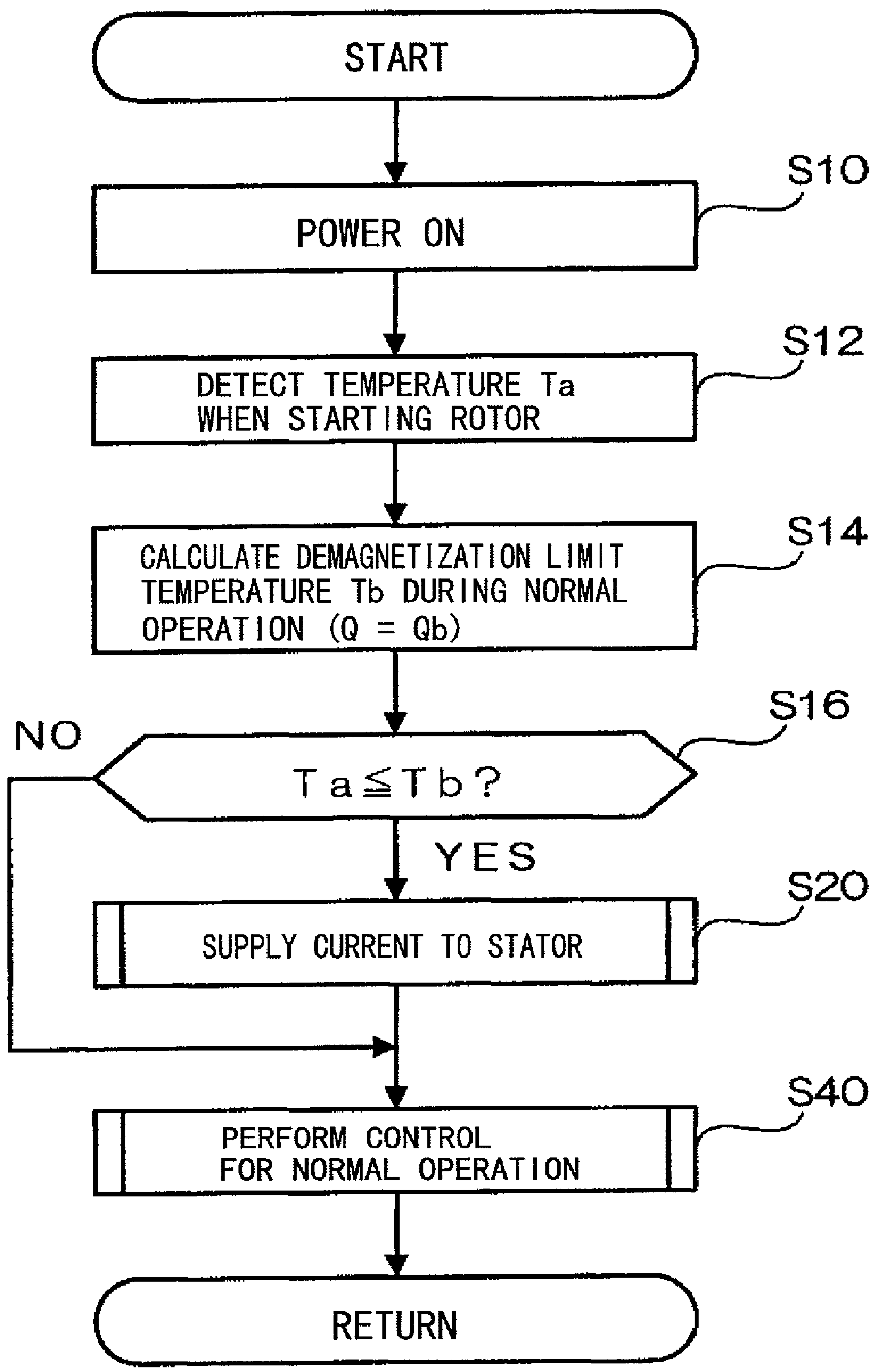

START
POWER ON
S10
DETECT TEMPERATURE Ta
WHEN STARTING ROTOR
S12
CALCULATE DEMAGNETIZATION LIMIT
TEMPERATURE Tb DURING NORMAL
OPERATION (Q = Qb)
S14
Ta≦Tb?
S16
NO
YES
SUPPLY CURRENT TO STATOR
S20
PERFORM CONTROL
FOR NORMAL OPERATION
S40
RETURN

FIG. 4

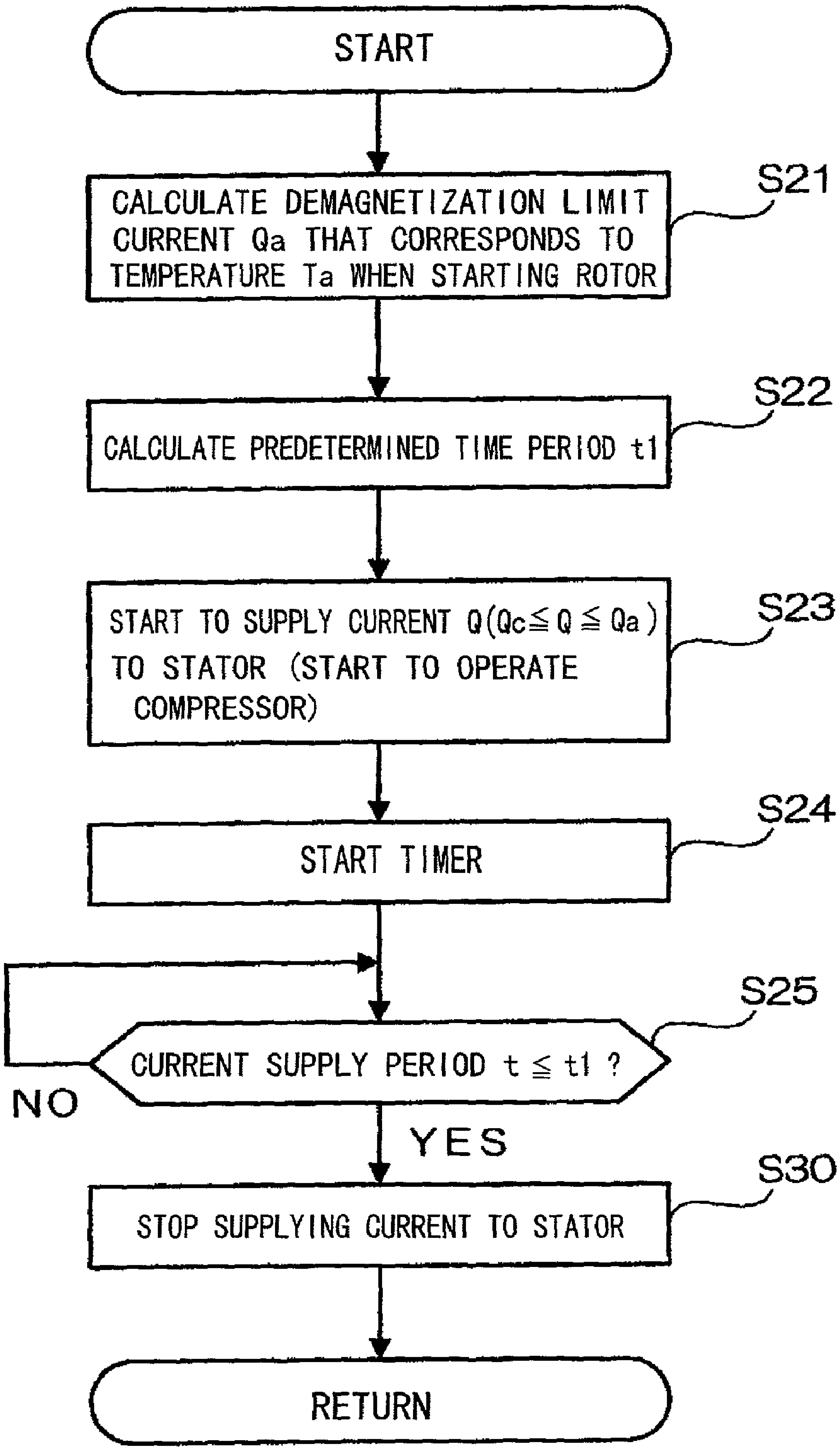

START
CALCULATE DEMAGNETIZATION LIMIT CURRENT Qa THAT CORRESPONDS TO TEMPERATURE Ta WHEN STARTING ROTOR
S21
CALCULATE PREDETERMINED TIME PERIOD t1
S22
START TO SUPPLY CURRENT Q(Qc≦Q≦Qa) TO STATOR (START TO OPERATE COMPRESSOR)
S23
START TIMER
S24
CURRENT SUPPLY PERIOD t≦t1 ?
S25
NO
YES
STOP SUPPLYING CURRENT TO STATOR
S30
RETURN

FIG. 5

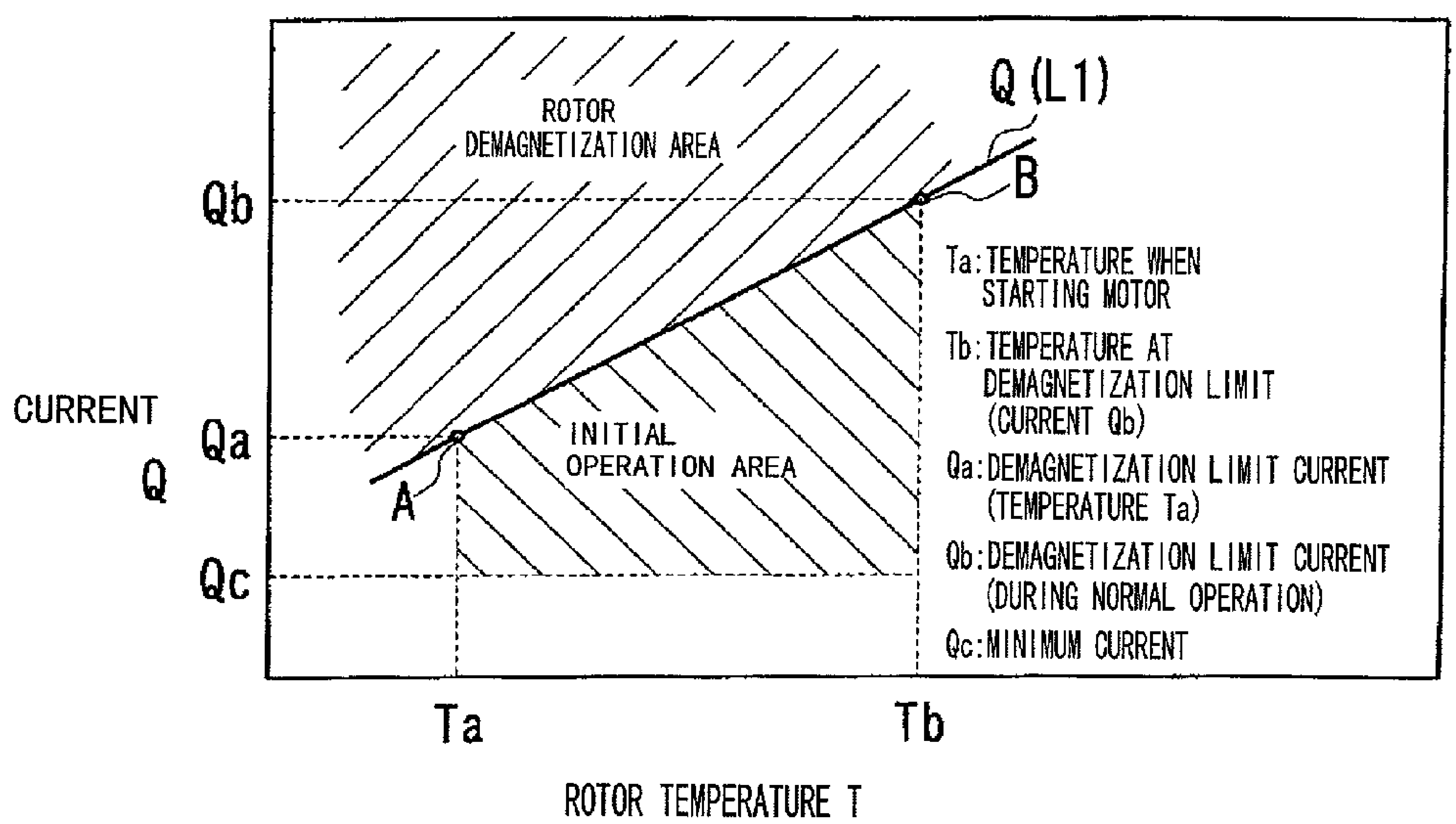

Q (L1)
ROTOR
DEMAGNETIZATION AREA
Qb
B
Ta: TEMPERATURE WHEN STARTING MOTOR
Tb: TEMPERATURE AT DEMAGNETIZATION LIMIT (CURRENT Qb)
CURRENT
Q
Qa
INITIAL
OPERATION AREA
Qa: DEMAGNETIZATION LIMIT CURRENT (TEMPERATURE Ta)
A
Qc
Qb: DEMAGNETIZATION LIMIT CURRENT (DURING NORMAL OPERATION)
Qc: MINIMUM CURRENT
Ta
Tb
ROTOR TEMPERATURE T

FIG. 6

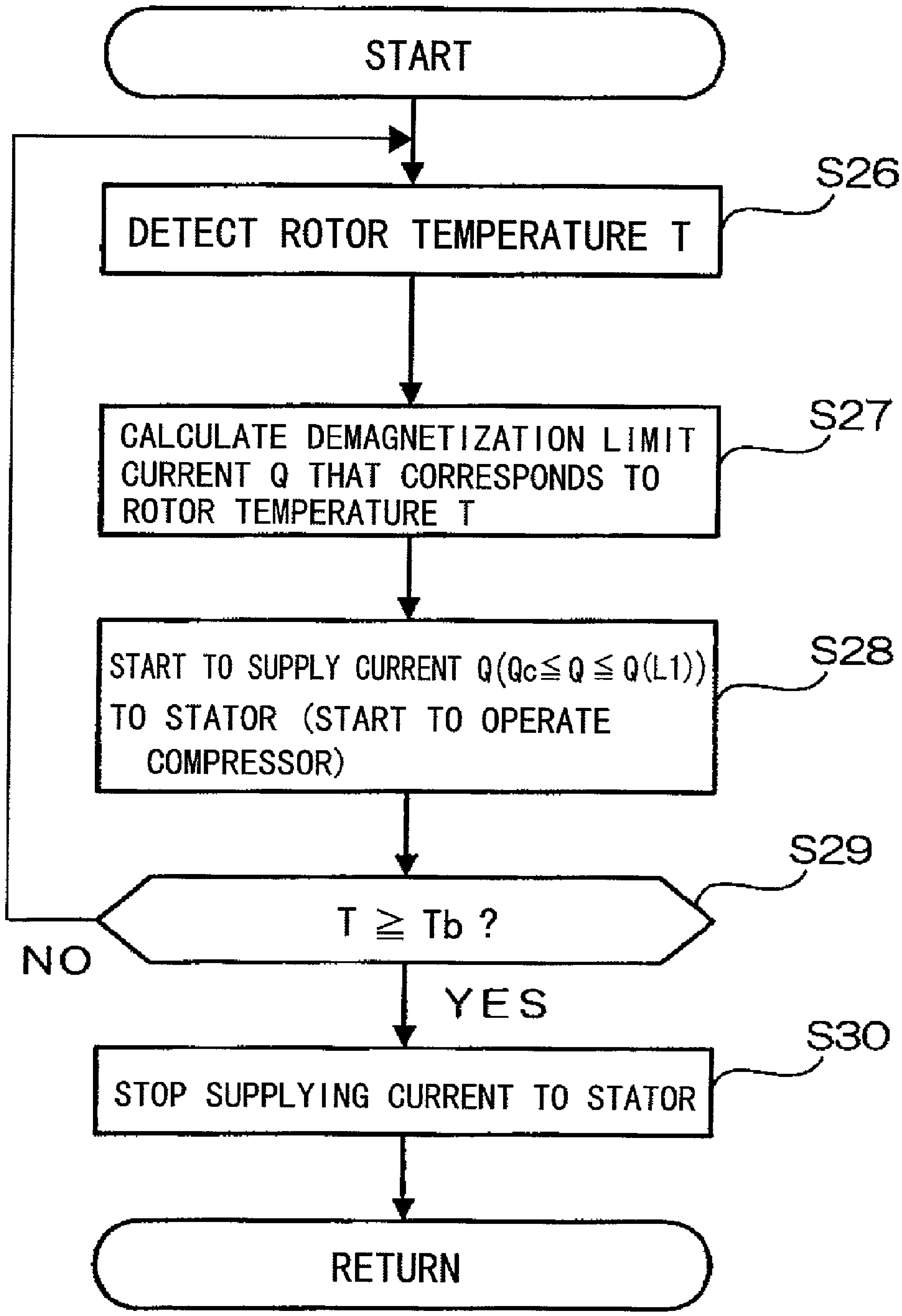

START
DETECT ROTOR TEMPERATURE T
S26
CALCULATE DEMAGNETIZATION LIMIT CURRENT Q THAT CORRESPONDS TO ROTOR TEMPERATURE T
S27
START TO SUPPLY CURRENT Q(Qc≦Q≦Q(L1)) TO STATOR (START TO OPERATE COMPRESSOR)
S28
T ≧ Tb ?
S29
NO
YES
STOP SUPPLYING CURRENT TO STATOR
S30
RETURN

FIG. 7

AIR CONDITIONING SYSTEMS AND METHODS FOR OPERATING THE SAME

[0001] This application claims priority to Japanese patent application number 2001-060607 filed Mar. 5, 2001, the contents of which are hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention generally relates to air conditioning systems, and in particular, to air conditioning systems having an air conditioning circuit and an electrically powered compressor for circulating cooling medium within the air conditioning circuit.

[0004] 2. Description of the Related Art

[0005] A vehicle air conditioning system may include an electrically powered compressor that serves to circulate cooling medium within the air conditioning circuit. Known electrically powered compressors are driven by an electric motor that includes a rotor and a stator. When electric current is supplied to the stator, a magnetic force is generated, thereby causing the rotor to rotate. The rotation of the rotor is then acts to compress the cooling medium within the compressor.

[0006] However, if an excessive current is supplied to the stator, the rotor may be demagnetized. In other words, when the current supplied to the stator exceeds a demagnetization limit current, the rotor may not hold a proper magnetic field, thereby resulting in a reduction of the magnetic force that can be generated.

[0007] The demagnetization limit current generally increases as temperature (e.g., rotor temperature or ambient temperature) rises and generally decreases as the temperature falls. Therefore, if the rotor temperature is relatively low when the compressor is started (e.g., because the ambient temperature is relatively low and the compressor has not been operated for some time), the peak stator current will likely exceed the rotor demagnetization limit current during the initial operation of the compressor. In order to solve this problem, Japanese Laid-Open Patent Publication No. 2000-270587 teaches an air conditioning system, in which a current is supplied to the stator so as to heat the rotor to an appropriate temperature before the rotor is rotated. That is, while the rotor is being heated, the current supplied to the stator is not sufficient to cause the rotor to rotate. Therefore, the likelihood that the peak stator current will reach or exceed the demagnetization current value may be reduced, thereby preventing the rotor from being demagnetized.

[0008] However, according to the teachings of Japanese Laid-Open Patent Publication No. 2000-270587, when the ambient temperature is low, power must be supplied to the stator to positively increase the rotor temperature before the compressor can be operated. Therefore, the operation of the compressor must be delayed while the rotor is being heated, because the rotor does not rotate during the heating operation. This delay may present a problem for using the air conditioning system, especially if the air conditioning system is used for a vehicle. Thus, when the ambient temperature is low (and thus the vehicle interior is also relatively cold), the known air conditioning system can not begin generating heat for the vehicle interior until the rotor temperature has been sufficiently raised in order to avoid demagnetization.

SUMMARY OF THE INVENTION

[0009] It is, accordingly, one object of the present invention to teach improved air conditioning systems having electrically powered compressors. For example, in one aspect of the present teachings, the compressors may be reliably driven even when the rotor (or ambient) temperature is relatively low.

[0010] Thus, in one aspect of the present teachings, apparatus are taught that may include a compressor arranged and constructed to compress a cooling medium. An electric motor may be coupled to the compressor in order to drive the compressor. The motor will generally include a stator and a rotor and the stator produces a magnetic force to rotate the rotor when sufficient current is supplied to the stator. A temperature sensor may be coupled to the rotor so as to either (1) directly detect the rotor temperature or (2) detect a temperature that is representative of the rotor temperature, e.g., the ambient temperature. A controller or processor, e.g., an electrical control unit (ECU), may control the supply of current to the stator in response to the detected temperature of the rotor. For example, the rotor is preferably rotated using current(s) that is (are) sufficient to rotate the rotor but will not cause the rotor to demagnetize.

[0011] In another aspect, the controller may supply an initial current to the stator as long as the initial stator current does not exceed a demagnetization limit current (i.e., a current that may cause rotor demagnetization). The controller or processor may determine the demagnetization limit current based upon the detected rotor temperature. In addition or in the alternative, the controller or processor also may determine the initial stator current based upon the detected rotor temperature and supply the initial stator current until the rotor temperature substantially reaches a predetermined temperature. For example, the initial stator current may be nearly the demagnetization limit current at the time when current is initially supplied to the stator.

[0012] In one optional embodiment, the initial stator current may be supplied for a predetermined time period as determined by the controller. In addition, the controller may vary the initial stator current as the rotor temperature changes. For example, the initial stator current is preferably less than, but nearly equal to, the demagnetization limit current. In another optional embodiment, the controller may supply the initial stator current to the stator until the detected rotor temperature reaches a demagnetization limit temperature that is determined for a normal stator current.

[0013] In another aspect, a compressor may be arranged and constructed to compress a cooling medium. A motor may be coupled to the compressor for driving the compressor. The motor may include a stator and a rotor and the stator may produce a magnetic force to rotate the rotor when current is supplied to the stator. A temperature sensor may detect a temperature that represents the temperature of the rotor. For example, the temperature sensor may detect ambient temperature, which is likely to be the same or nearly the same as the rotor temperature when the compressor has not been operated for a period of time, or may directly detect the temperature of the rotor.

[0014] A controller or processor may control the supply of current to the stator based upon output signals from the temperature sensor, so that the rotor rotates without being demagnetized. In another optional embodiment, the controller may store a chart (e.g., look up table) or a function that correlates the detected rotor temperature to the demagnetization limit current for the detected rotor temperature. Thus, such a correlation chart or function may be utilized to determine the upper limit for the current that will be supplied to the stator. Thus, the controller preferably controls the supply of the initial stator current so that the initial stator current is less than and/or nearly equal to the demagnetization limit current, but the initial stator current is sufficient to cause the rotor to begin rotating. Thus, the compressor can be reliably driven without demagnetizing the rotor, even when ambient (and thus the rotor temperature) is relatively low. Further, in this embodiment, it is not necessary to heat the rotor before rotating the rotor, thereby providing heat to the vehicle interior much earlier than known electrically driven compressors.

[0015] In another aspect, the controller may set the initial stator current to nearly, but slightly less than, the demagnetization limit current at the time when the current is supplied to the motor. Further, the controller may supply the initial stator current for a predetermined time period, which is calculated by the controller.

[0016] In addition or in the alternative, the controller may vary the initial stator current as the rotor temperature changes, such that the initial stator current is selected to be less than, but nearly equal to, the demagnetization limit current at that time. For example, the initial stator current may be increased as the rotor temperature increases, thereby increasing the output of the compressor. The controller also may supply the initial stator current to the stator until the detected rotor temperature reaches a demagnetization limit temperature for a predetermined stator temperature, which demagnetization limit temperature may be found by the correlation chart or function.

[0017] In another embodiment, a controller or processor (e.g., an ECU or another microprocessor) may control the supply of current to the stator based upon output signals from the temperature sensor. The current is preferably selected to be sufficient to cause the rotor to rotate without causing the rotor to demagnetize. The processor may, e.g., comprise instructions or programs to:

[0018] (i) calculate a demagnetization limit current based upon the detected rotor temperature when the motor is started (e.g., when current is first supplied to the stator in order to rotate the rotor),

[0019] (ii) calculate a demagnetization limit temperature for a normal stator current, and

[0020] (iii) calculate a time period that is necessary to supply a current to the rotor in order to raise the rotor temperature, e.g., to a normal operating rotor temperature. The current is preferably less than, but nearly equal to, the calculated demagnetization limit current and is sufficient to cause the rotor to rotate.

[0021] In another embodiment, the processor may comprise instructions or programs to:

[0022] (i) calculate a demagnetization limit current based upon the rotor temperature detected by the temperature sensor,

[0023] (ii) calculate a demagnetization limit temperature for a normal stator current, and

[0024] (iii) supply current to the stator during an initial period until the detected rotor temperature reaches the calculated demagnetization limit temperature.

[0025] In this embodiment, the supplied current may be increased as the rotor temperature increases, thereby increasing the compressor output during the initial operation.

[0026] In another aspect, air conditioning systems may include a compressor having a motor that includes a rotor and a stator. Preferably, the rotor rotates due to a magnetic force generated by supplying current to the stator, thereby circulating a cooling medium within an air conditioning circuit. The air conditioning systems also may include means for detecting the temperature of the rotor or an ambient temperature when the rotor starts to rotate and means for calculating a demagnetization limit current of the rotor based upon the detected temperature. The supplied current is preferably less than or equal to the demagnetization limit current and greater than or equal to a minimum current that is required to rotate the rotor.

[0027] Such air conditioning systems optionally may further include means for calculating a demagnetization limit temperature of the rotor for normal operation and means for calculating a period of time that is necessary for the rotor to reach the demagnetization limit temperature while the current is supplied to the stator. Furthermore, means optionally may be provided for supplying the current to the stator for at least the calculated period of time. The calculating and supplying means may be disposed, e.g., within a controller, a processor or an ECU.

[0028] In a further aspect, air conditioning systems may include means for supplying current to the stator at least until the temperature of the rotor reaches the demagnetization limit temperature. The current supplying means may increase the supply of current to the stator as the detected rotor temperature increases, but the supplied current is preferably less than the demagnetization limit current for the detected rotor temperature. A processor, controller, etc. may be utilized to control the supply of current to the stator in this aspect as well.

[0029] Additional objects, features and advantages of the present invention will be readily understood after reading the following detailed description together with the accompanying drawings and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] **FIG. 1** is a schematic diagram of a first representative air conditioning system;

[0031] **FIG. 2** is a graph showing the correlation between rotor temperature and the demagnetization limit current;

[0032] **FIG. 3** is a graph showing the correlation between rotor temperature and a period of time for supplying current to a stator;

[0033] **FIG. 4** is a flowchart showing a first representative method for controlling the compressor motor;

[0034] **FIG. 5** is a flowchart showing a first representative method for controlling stator current;

[0035] **FIG. 6** is a graph showing the correlation between rotor temperature and the demagnetization limit current in a manner similar to **FIG. 2** and showing an initial operation area according a second representative method; and

[0036] **FIG. 7** is a flowchart showing a second representative method for controlling the stator current.

DETAILED DESCRIPTION OF THE INVENTION

[0037] Air conditioning systems are taught that may include an air conditioning circuit and an electrically powered compressor. The compressor may be driven by an electric motor that includes a rotor and a stator. The compressor may preferably include a scroll compressor if it is used within a vehicle air conditioning system, although other electrically driven compressors are contemplated by the present teachings. Generally speaking, the rotor of the electric motor rotates due to magnetic forces produced when current is supplied to the stator. The rotating rotor drives the compressor in order to compress the cooling medium (or refrigerant or coolant) and the pressurized cooling medium is circulated within the air conditioning circuit in order to perform an air conditioning operation.

[0038] In one representative embodiment, a temperature sensor may detect the rotor temperature or the ambient temperature either before the rotor starts to rotate or when the rotor starts to rotate. A current calculator (e.g., a processor or controller) may calculate a demagnetization limit current for the rotor at the detected temperature. For example, such a demagnetization limit current may be calculated from a chart or look up table (LUT) that provides a correlation between various rotor temperatures and demagnetization limit currents. In the alternative, the current calculator may execute a function that calculates the demagnetization limit current based upon the detected temperature. The calculated demagnetization limit current is preferably utilized to determine the maximum current that may be supplied to the stator during a predetermined period (e.g., a period of initial operation when the rotor temperature is less than a normal operating rotor temperature). Thus, the current that is supplied to the stator is preferably less than the demagnetization limit current. In addition, the current that is supplied to the stator is preferably greater than a minimum current that is required to rotate the rotor. Therefore, the rotor can be rotated in order to begin the compressor operation without demagnetizing the rotor. The predetermined period may be suitably determined in response to the nature of the rotor, so that control of the motor can be easily performed.

[0039] Generally speaking, as the stator current increases, the likelihood that the rotor will begin rotating also increases. That is, the rotor generally will not rotate if the stator current is less than a minimum current. When the current supplied to the stator is greater than the minimum current, the rotation of the rotor may be ensured to rapidly begin driving the compressor. Moreover, the demagnetization limit current generally increases as the rotor temperature rises. If the current supplied to the stator is less than the demagnetization limit current for the ambient (or rotor) temperature when the current is initially supplied to the stator, the supplied current will not exceed the demagnetization limit current during normal operation when the rotor temperature is higher than the rotor temperature at the time that the stator current was initially supplied. As a result, the rotor may be prevented from being demagnetized. The operation for calculating the appropriate current to be supplied to the stator optionally may be performed by a processor, such as a vehicle electric control unit (ECU).

[0040] In another representative embodiment, air conditioning systems may further include a temperature calculator and a time calculator. The temperature calculator may calculate the demagnetization limit temperature of the rotor during normal operation. For example, the stator current may have a substantially uniform value during normal operation. In that case, the demagnetization limit temperature may be calculated from a chart or look up table (LUT) that provides a correlation between the rotor temperature and the demagnetization current value. In the alternative, an analog or digital circuit may directly compute the demagnetization limit current based upon the detected rotor temperature.

[0041] The time calculator may calculate a period of time that is necessary for the rotor to reach the demagnetization limit temperature. In this representative embodiment, the determination as to whether or not the rotor temperature has reached a particular demagnetization limit temperature may be performed by determining whether or not the current has been supplied to the stator for the calculated period of time. For example, a timer may be started at the same time that the current is initially supplied to the stator. The time when a particular demagnetization limit current will be reached may be determined based on the fact that the time period counted by the timer indicates the calculated period of time. In this representative embodiment, the current may be supplied to the stator at least during the period of time that is calculated by the time calculator. As a result, rotor demagnetization may be more easily and reliably avoided. The operation for calculating the demagnetization limit temperature and the time calculation optionally may be performed by a processor, such as a vehicle electric control unit (ECU).

[0042] In another representative embodiment, air conditioning systems are taught that may include a temperature sensor, a temperature calculator and a current calculator for preventing rotor demagnetization. The temperature sensor may detect the rotor temperature, preferably at predetermined time intervals after the current was initially supplied to the stator. The temperature calculator may calculate the demagnetization limit temperature for the rotor during normal operation. If the stator current has a substantially uniform value during normal operation, the demagnetization limit temperature may be calculated from a chart or look up table (LUT) that provides a correlation between rotor temperatures and demagnetization current values. The current calculator may calculate the demagnetization limit current from the temperature detected by the temperature sensor. For example, the demagnetization limit current may be calculated using the correlation between the detected rotor temperature and the demagnetization current value. The stator current may be supplied to the stator at least until the temperature of the rotor reaches the demagnetization limit temperature. The stator current may be less than the demagnetization limit current and may be greater than a minimum current that is required to rotate the rotor. Thus, the current preferably does not exceed the demagnetization limit current because the supplied current will be less than the demagnetization limit current for the detected rotor temperature. The determination as to whether or not the rotor temperature has reached the particular demagnetization limit current may be performed directly based upon the detected rotor temperature.

[0043] Therefore, according to the embodiments described above and below, electrically driven compressors may be rapidly and reliably driven after supplying current to the stator even at relatively low ambient temperatures and without demagnetizing the rotor. For example, the current supplied to the stator may be selected so as to be nearly equal to (e.g., slightly less than) the demagnetization limit current, because the stator current will vary in response to changes in the rotor temperature. Thus, compressor operation can promptly begin and compressor output can be gradually increased during an initial operating period (e.g., before the rotor reaches its normal operating temperature).

[0044] In another aspect of the present teachings, various methods for operating a vehicle air conditioning system are taught. Such methods may include detecting the rotor temperature or ambient temperature when the rotor starts to rotate. Such methods may also include calculating a demagnetization limit current of the rotor at the detected temperature. Thereafter, current may be supplied to the stator for a predetermined period. The current may be less than the calculated demagnetization limit current and may be greater than a minimum current that is required to rotate the rotor. In addition or in the alternative, the rotor temperature may be detected, the demagnetization limit temperature for normal operation may be calculated, the demagnetization limit current may be calculated from the detected temperature, and current may be supplied to the stator at least until the rotor reaches the demagnetization limit temperature.

[0045] Each of the additional features and teachings disclosed above and below may be utilized separately or in conjunction with other features and teachings to provide improved air conditioning systems and methods for designing and using such air conditioning systems. A representative example of the present invention, which examples utilize many of these additional features and teachings both separately and in conjunction, will now be described in detail with reference to the attached drawings. This detailed description is merely intended to teach a person of skill in the art further details for practicing preferred aspects of the present teachings and is not intended to limit the scope of the invention. Only the claims define the scope of the claimed invention. Therefore, combinations of features and steps disclosed in the following detail description may not be necessary to practice the invention in the broadest sense, and are instead taught merely to particularly describe representative examples of the invention. Moreover, various features of the representative examples and the dependent claims may be combined in ways that are not specifically enumerated in order to provide additional useful embodiments of the present teachings.

First Representative Air Conditioning System

[0046] A first representative air conditioning system will now be described with reference to the drawings. As shown in **FIG. 1, a** representative air conditioning system **1** may include an air conditioning circuit **2**, in which the circulation path of a cooling medium (also known as refrigerant or coolant) is indicated by arrows shown in solid lines. The air conditioning system **1** may be designed to perform a heat pump cycle and the air conditioning circuit **2** may generally include an electrically powered compressor C, an interior heat exchanger F and an exterior heat exchanger G.

[0047] The compressor C may optionally be a scroll compressor that is driven by an electric motor M. The compressor C**1** preferably serves to compress the cooling medium (not shown) and to output the cooling medium under pressure. The interior heat exchanger F may include an interior condenser F**1** and an evaporator F**2**. The exterior heat exchanger G may serve as a condenser or an evaporator.

[0048] An expansion valve H and a change-over valve I also may be disposed within the air conditioning circuit **2** between the interior condenser F**1** and the exterior heat exchanger G. Preferably, the changer-over valve I may be positioned so as to bypass the expansion valve H. A second expansion valve J may be disposed within the air conditioning circuit **2** between the exterior heat exchanger G and the evaporator F**2**. A second change-over valve K may be disposed on the upstream side of the expansion valve J and may serve to provide a short circuit for connecting the exterior heat exchanger G to a suction port of the compressor C.

[0049] During a heating operation, the pressurized cooling medium outputted or discharged from the compressor C may flow within the air conditioning circuit **2** through the interior condenser F**1**, the expansion valve H, the exterior heat exchanger G and the change-over valve K and then may return to the compressor C as indicated by the solid line arrows shown in **FIG. 1**. During this operation, the exterior heat exchanger G may serve as an evaporator. On the other hand, during a cooling operation, the cooling medium outputted or discharged from the compressor C may flow within the air conditioning circuit **2** through the interior condenser F**1**, the change-over valve I, the exterior heat exchanger G, the expansion valve J and the evaporator F**2** and then may return to the compressor C. During this operation, the exterior heat exchanger G may serve as a condenser.

[0050] The compressor motor M may include a stator **14** and a rotor **12**. The stator **14** may be secured to the inner wall of a motor housing (not shown) and the rotor **12** may be fixed to a drive shaft **10** that is rotatably supported by the motor housing. Preferably, the rotor **12** may be formed of permanent magnets, such as ferrite magnets. The stator **14** may have stator coils (not shown) that may serve to produce the magnetic forces that will rotate the rotor **12** when current is supplied to the stator coils. The drive shaft **10** may rotate together with the rotor **12** and may drive the compressor C, so that the compressor C will compress the cooling medium.

[0051] When the current supplied to the stator **14** exceeds a predetermined value (i.e., a demagnetization limit current), the rotor **12** may not appropriately hold a magnetic field. As a result, the magnetic force of the rotor **12** may be reduced. This predetermined value (i.e., the demagnetization limit current) generally correlates with temperature (e.g., rotor or ambient temperature) as indicated by line L1 shown in **FIG. 2**. In other words, the demagnetization limit current generally increases as the rotor temperature increases. Because the demagnetization limit current decreases as the rotor temperature decreases, the stator current can exceed the demagnetization limit current when the compressor motor M is operated at a relatively low ambient temperature (i.e., the rotor temperature will likely be relatively low when the ambient temperature is low and the compressor motor M has not been operated recently).

[**0052**] The correlation between the demagnetization limit current and the temperature may depend on the nature of the rotor **12** that is incorporated into the air conditioning system **1**. Therefore, the stator **14** may have different demagnetization limit current values in response to various magnetization properties of the rotor **12**. Thus, the demagnetization limit current generally must be determined on a case-by-case basis.

[**0053**] Preferably, a temperature sensor **22** and an ECU (electronic control unit) **20** may be associated with the motor M. The temperature sensor **22** may serve to detect the temperature of the rotor **12** or may detect ambient temperature, if the ambient temperature closely corresponds to the rotor temperature. The ECU **20** may serve to control the operation of the motor M (e.g., the ECU **20** may control the supply of current to the motor M). The ECU **20** may include a temperature calculation section **24**, a current calculation section **26** and a time calculation section **28**. That is, the ECU **20** may include programs for calculating (1) the rotor demagnetization temperature limit based upon the detected ambient temperature (or the detected rotor temperature), (2) the demagnetization current limit and (2) the time period in which the rotor temperature will likely be heated to the rotor demagnetization temperature during normal operation. Each of these programs may be executed within a single ECU or may be performed by two or more ECUs. Further, circuits other than a processor, such as a dedicated digital or analog calculator, can perform these calculations.

[**0054**] In one preferred embodiment, the temperature calculation section **24** may serve to calculate the demagnetization limit temperature. The current calculation section **26** may serve to calculate the demagnetization limit current. The time calculation section **28** may serve to calculate the time period that is required for the rotor **12** to be heated to the demagnetization limit temperature during normal operation. The ECU **20** may output control signals to the motor M based on the rotor temperature detected by the temperature sensor **22** and the results of the calculations by the temperature calculation section **24**, the current calculation section **26** and the time calculation section **28**.

First Representative Method

[**0055**] A first representative method for controlling the compressor C within the air conditioning system **1** will now be described with reference to FIGS. **2** to **5**. As described above, the demagnetization limit current may increase as the temperature of the rotor **12** increases, which is indicated by line Li in **FIG. 2**. Therefore, if the supplied current is within the area above line L1 (hereinafter called the "rotor demagnetization area"), the rotor **12** may not hold an appropriate magnetic field and the magnetic force of the rotor may be degraded. According to line L1 of **FIG. 2**, point A indicates the point when the operation is started in the representative method. The demagnetization limit current Qa may be found at point A based upon the detected rotor temperature Ta. Point B indicates the point when the compressor C is permitted to operate normally. The demagnetization limit current Qb for rotor temperature Tb is found at point B.

[**0056**] According to this representative method, in view of the fact that the demagnetization limit current decreases as the ambient temperature decreases, a current, which is less than a normal operating current, may be supplied to the stator **14** at least during the period from point A to point B, or at least during a period of time t**1** that is necessary for the rotor **12** to be heated from temperature Ta to temperature Tb. Such current is preferably less than the demagnetization limit current Qa (found at temperature Ta when starting the operation), but may still be sufficient to cause the rotor **12** to rotate. As shown by line L**2** in **FIG. 3**, the period of time t**1** generally decreases as the difference between temperature Ta (e.g., the temperature when starting to rotate the rotor **12**) and temperature Tb (e.g., rotor temperature during normal operation) decreases. Thus, the ECU **20** may control the current supplied to the stator **14** such that the supplied current falls within the area below line L**1**, and in particular within the "initial operation area" as indicated in **FIG. 2**, which will be further described below.

[**0057**] The first representative method will now be described in more detail with reference to **FIGS. 4 and 5**, which respectively show flow charts for a motor control process and a stator current control process.

[**0058**] A start switch (not shown) for the air conditioning system **1** may be turned ON at Step **10** in order to start the motor M. The process may then proceed to Step **12**, in which the temperature sensor **22** directly detects the temperature Ta of the rotor **12** at that time. In the alternative, the temperature sensor **22** may detect the ambient temperature and define the detected ambient temperature as temperature Ta, because the rotor temperature is likely to be substantially equal to the ambient temperature when starting the compressor operation.

[**0059**] The process then proceeds to Step **14**, in which the ECU **20** calculates the demagnetization limit temperature Tb. The demagnetization limit temperature Tb may be found from the current Qb (e.g., the current supplied during normal operation) based upon line L**1**, which was described above with reference to **FIG. 2**.

[**0060**] The process then proceeds to Step **S16**, in which the ECU **20** determines whether or not the start temperature Ta (i.e., when starting the rotor) is higher than the demagnetization limit temperature Tb (i.e., when normal operation is permitted). If the determination in Step **S16** is YES, the process proceeds to Step **20**, in which the ECU **20** performs the stator current control process that will be hereinafter explained with reference to **FIG. 5**. On the other hand, if the determination in Step **S16** is NO, the process preferably will not proceed to Step **S20** for the stator current control process, but instead, will proceed to Step **S40**, in which normal control of the motor M is performed. Thus, if the start temperature Ta is higher than the demagnetization temperature Tb, the current supplied to the stator **14** will not exceed the demagnetization current limit, even if the current is supplied to the stator **14** for normal control of the motor M. Thus, step **S16** determines whether the compressor C will be operated in a relatively low ambient temperature environment and determines whether additional steps are necessary to ensure that the supplied current will be less than the demagnetization limit current for the particular rotor temperature that is detected.

[0061] A representative stator current control process for Step **20** will now be described in further detail with reference to **FIG. 5**. In Step S**21**, the ECU **20** may calculate the demagnetization limit current Qa (i.e., when starting the rotor **12**) based upon the start temperature Ta and line L**1** of **FIG. 2**. The process then proceeds to Step S**22**, in which ECU **20** calculates the period of time t**1** for supplying current to the stator **14** in order to heat the rotor **12** from the start temperature Ta to the demagnetization limit temperature Tb. Then, the process proceeds to Step **23**, in which ECU **20** starts to supply current to the stator **14**, which current may be less than the demagnetization limit current Qa, but is preferably greater than a minimum current Qc that is required to rotate the rotor **12** (see the "initial operation area" in **FIG. 2**). More preferably, the current to be supplied to the stator **14** may be nearly or slightly less than the demagnetization limit current Qa, although the current may be appropriately determined as long as the current is within the range between Qa and Qc. The process then proceeds to Step S**24**, in which a timer (not shown) of the ECU **20** may begin counting the time after initiating the supply of current to the stator **14**.

[0062] Next, the process proceeds to Step S**25**, in which the ECU **20** determines whether or not the time counted by the timer exceeds the time period t**1**. If the determination in Step S**25** is YES, the process proceeds to Step S**30** in order to terminate the counting operation and to terminate the supply of current to the stator **14** according to the operation shown in **FIG. 5**. Thus, in this representative method, the ECU **20** determines that the temperature of the rotor **12** has reached or exceeded the demagnetization limit temperature Tb based upon the fact that the current has been supplied to the stator **14** for the calculated time period t**1**. After the supply of current to the stator **14** has been terminated, the process returns to the Step S**40** of the motor control process of **FIG. 4**, so that motor control according to normal operation may be performed.

[0063] As described above, according to the representative air conditioning system **1** and the first representative method for controlling the air conditioning system **1**, current is supplied to the stator **14** for time period t**1**, which current is less than the demagnetization limit current Qa (for the temperature when starting the motor M) and is greater than the minimum current Qc. As a result, the rotor **12** is demagnetized even though the rotor **12** is rotated when the rotor temperature is less than the rotor temperature Tb. Therefore, the compressor C can be reliably driven without delay even in a low ambient temperature environment. More specifically, the compressor C can be reliably driven to compress the cooling medium immediately after supplying current to the stator **14**.

Second Representative Method for Controlling the Air Conditioning System

[0064] A second representative air conditioning system may be different from the first representative air conditioning system in that the ECU **20** does not include a time calculation section **28**. In other respects, the second representative air conditioning system may the same, or substantially the same, as the first representative air conditioning system. Therefore, further illustration of the second representative air conditioning system is not required. Instead, a second representative method, which is directed to the control of the second representative air conditioning system, will now be described with reference to **FIGS. 6 and 7**, which respectively show a graph illustrating the correlation between the rotor temperature and the demagnetization limit current, and a flowchart for a stator current control process. In **FIGS. 6 and 7**, the same reference numerals are affixed to the elements that are similar to those in **FIGS. 2 and 5** of the first representative embodiment. Therefore, further description of these elements is not required.

[0065] According to the second representative method, the ECU **20** determines whether or not the temperature of the rotor **12** has reached the particular demagnetization limit temperature based upon the temperature of the rotor **12** that is detected by the temperature sensor **22**. Thus, the ECU **20** does not use the time calculation section **28** for this determination as in the first representative method. Instead, the temperature sensor **22** may repeatedly detect the temperature of the rotor **12** during the initial operation of the compressor C.

[0066] In addition, according to the second representative method, current may be supplied to the stator **14** until the temperature T of the rotor **12** reaches at least the demagnetization limit temperature Tb for the normal operation, which current is preferably less than demagnetization limit current Q(L1) (i.e., for the current temperature T of the rotor **12**) but is greater than the minimum current Qc (i.e., current that is sufficient to rotate the rotor **12**). In this embodiment, the demagnetization limit current Q(L1) may be found from the current temperature T based upon line L1 of **FIG. 6**. Therefore, the ECU **20** may control the current supplied to the stator **14** such that the current is within an area (e.g., the "initial operation area" of **FIG. 6**) that is below (or less than) line L1. More preferably, the current to be supplied to the stator **14** may be nearly or slightly less than the demagnetization limit current Q(L1), although the current may be appropriately determined as long as the current is within the area described above.

[0067] For example, the ECU **20** may execute a motor control process that is similar to the process described in connection with **FIG. 4**. However, the ECU preferably executes a stator current control process that is shown by the flowchart of **FIG. 7**.

[0068] The process shown in **FIG. 7** will now be described in further detail. After the motor control process shown in **FIG. 4** has proceeded to Step S**20**, the process proceeds to Step S**26** of the stator current control process shown in **FIG. 7**, in which the temperature sensor **22** detects the current temperature T of the rotor **12**. The process then proceeds to Step S**27**, in which the ECU **20** calculates the demagnetization limit current Q(L1) at the detected temperature T based upon line L1 as shown in **FIG. 6**.

[0069] The process then proceeds to Step S**28**, in which the ECU **20** initiates the supply of current to the stator **14**, which current is preferably less than the demagnetization limit current Q(L1) but greater than the minimum current Qc for rotating the rotor **12**. Thereafter, the process proceeds to Step **29**, in which the ECU **20** determines whether or not the temperature T of the rotor **12** is higher than the demagnetization limit temperature Tb for normal operation. If the determination in Step S**29** is YES, the process proceeds to Step S**30**, in which the supply of current to the stator **14** is terminated. After the supply of current to the stator **14** has been terminated for the initial operation, the process returns to Step S**40** of the motor control process shown in **FIG. 4**. Thus, current is supplied to the stators **14** for normal operational control of the motor M. On the other hand, if the determination in Step S29 is NO, the process returns to Step S26 to repeatedly perform Steps S26 to S29 until the determination in Step 29 becomes YES.

[0070] According to the second representative air conditioning system and method for controlling the air conditioning system 1, a current may be supplied to the stator 14 until the temperature of the rotor 12 exceeds the calculated demagnetization limit temperature and that current is preferably less than the demagnetization limit current Q(L1) but is greater than the minimum current Qc. Therefore, the compressor C may be driven and rotated without delay while avoiding demagnetization of the rotor 12. As a result, the compressor C may reliably compress the cooling medium immediately after starting the supply of current to the stator 14 even if the ambient temperature is relatively low (which would ordinary result in demagnetization of the rotor 12 in a known air conditioning system). In addition, because the current to be supplied to the stator 14 may vary (e.g., increase) in response to changes (e.g., increases) in the temperature of the rotor 12 according to the second representative method, fine or precise control of the current supplied to the stator 14 may be performed such that the current may be extremely close to the demagnetization limit current at all times during the initial operation. In other words, the current supplied to the stator 14 may be increased as the detected temperature T of the rotor 12 increases, thereby increasing the output of the compressor C and raising the rotor temperature more quickly. Further, although the possible range of stator currents is selected in the second representative method to be below the correlation line Q(L1) and above the minimum current Qc, such range of currents may be selected to be below the correlation line Q(L1) and above the demagnetization limit current Qa found at start point A.

[0071] Although the present teachings may be advantageously applied to vehicle air conditioning systems, the present teachings also find application to air conditioning systems for other uses. For example, the present teachings may be applied to air conditioning systems for electrical household appliances and equipment.

[0072] In addition, the present teachings are not limited to the above representative embodiments but may be modified in various ways. For example, the first representative method determines the condition for supplying the current to the stator 14 based upon signals from the temperature sensor 22 and the calculations performed by the temperature calculation section 24, the current calculation section 26 and the time calculation section 28 (e.g., ECU 20). However, the condition for supplying current to the stator 14 may be determined based only upon the signal from the temperature sensor 22 and the calculation performed by the current calculation section 26. Thus, in such a method, a current may be supplied to the stator 14 during a predetermined period that may be determined in response to the nature of the rotor 12 and that current is preferably less than the demagnetization limit current Qa of the rotor 12 but is greater than the minimum current Qc. As a result, it is possible to prevent the rotor 12 from being demagnetized by means of a simple ECU or a simple method in comparison with the first representative air conditioning system and method.

[0073] Furthermore, although the above representative embodiments have been described in connection with air conditioning systems that perform heat pump cycles, the present teachings also may be applied to air conditioning systems that perform other cycles, such as a hot gas cycle as taught in Japanese Laid-Open Patent Publication No. 5-223357, which cycle will be briefly explained. According to Japanese Laid-Open Patent Publication No. 5-223357, a compressor in a refrigerant circuit may compress the cooling medium and output the cooling medium as a hot gas. The hot gas may then be supplied to a heat exchanger while bypassing a condenser, so that the heat taken out of the hot gas by the heat exchanger may be used for secondarily heating the vehicle interior. Thus, the heat provides a secondary heating means for a vehicle. In Japanese Laid-Open Patent Publication No. 5-223357, the heating is primarily performed by a hot water heater (main heating device) associated with an internal combustion engine, and the hot gas cycle provides secondary heating.

[0074] According to the present teachings, rational air conditioning techniques may be realized in air conditioning systems that include an air control circuit and an electrically driven compressor for circulating cooling medium in the air control circuit. Therefore, the compressor can be promptly and reliably driven even during relatively low temperature conditions.

1. An apparatus comprising:

a compressor arranged and constructed to compress a cooling medium,

an electrically driven motor driving the compressor, the motor having a stator and a rotor, the stator producing a magnetic force that causes the rotor to rotate when sufficient current is supplied to the stator,

a temperature sensor arranged and constructed to detect a temperature that is representative of the rotor temperature, and

a controller arranged and constructed to control the supply of current to the stator in response to the temperature detected by the temperature sensor, wherein the controller is further arranged and constructed to supply current to the stator during an initial operation, in which the rotor temperature is relatively low, the supplied current being greater than or equal to a minimum current required to rotate the rotor and less than or equal to a demagnetization limit current.

2. An apparatus as in claim 1, wherein the controller is further arranged and constructed to determine the demagnetization limit current based upon the detected rotor temperature.

3. An apparatus as in claim 2, wherein the controller is further arranged and constructed to determine an initial stator current based upon the detected rotor temperature at the initiation of compressor operation and to supply the initial stator current until the rotor temperature substantially reaches a predetermined temperature.

4. An apparatus as in claim 3, wherein the initial stator current is slightly less than the demagnetization limit current at the time when current is initially supplied to the stator.

5. An apparatus as in claim 3, wherein the controller is further arranged and constructed to increase the stator current as the rotor temperature increases, wherein the current supplied to the stator is less than, but nearly equal to, the demagnetization limit current.

6. An apparatus as in claim 5, wherein the controller is further arranged and constructed to supply current to the stator until the detected rotor temperature reaches a demagnetization limit temperature that is determined for a normal stator current.

7. A method for supplying current to a compressor motor that includes a rotor and a stator, the rotor being rotated by a magnetic force generated by supplying current the stator, the method comprising:

detecting a temperature representative of a rotor temperature when compressor operation is initiated,

calculating a demagnetization limit current of the rotor at the detected temperature, and

supplying current to the stator, the current being less than or equal to the demagnetization limit current and greater than or equal to a minimum current that is required to rotate the rotor.

8. A method as in claim 7, further comprising:

calculating a demagnetization limit temperature of the rotor for normal operation; and

calculating a period of time that is necessary for the rotor to reach the demagnetization limit temperature while the current is supplied to the stator;

supplying the current to the stator for at least the calculated period of time.

9. A method as in claim 7, further comprising:

calculating a demagnetization limit temperature of the rotor for normal operation,

periodically detecting the temperature representative of the rotor temperature and

supplying current to the stator at least until the temperature of the rotor reaches the demagnetization limit temperature, the amount of current supplied to the stator being increased as the detected temperature increases.

10. An apparatus for supplying current to a compressor motor that includes a rotor and a stator, the rotor being rotated by a magnetic force generated by supplying current the stator, the apparatus comprising:

means for detecting a temperature representative of a rotor temperature when compressor operation is initiated,

means for calculating a demagnetization limit current of the rotor at the detected temperature, and

means for supplying current to the stator, the current being less than or equal to the demagnetization limit current and greater than or equal to a minimum current that is required to rotate the rotor.

11. An apparatus as in claim 10, further comprising:

means for calculating a demagnetization limit temperature of the rotor for normal operation; and

means for calculating a period of time that is necessary for the rotor to reach the demagnetization limit temperature while the current is supplied to the stator;

means for supplying the current to the stator for at least the calculated period of time.

12. An apparatus as in claim 10, further comprising:

means for calculating a demagnetization limit temperature for normal operation,

means for periodically detecting the temperature representative of the rotor temperature and

means for supplying current to the stator at least until the temperature of the rotor reaches the demagnetization limit temperature, the amount of current supplied to the stator being increased as the detected temperature increases.

13. An apparatus comprising:

a compressor arranged and constructed to compress a cooling medium,

a motor coupled to the compressor for driving the compressor, the motor having a stator and a rotor, the stator producing a magnetic force to rotate the rotor when current is supplied to the stator,

a temperature sensor arranged and constructed to detect a temperature that represents the temperature of the rotor, and

a controller arranged and constructed to control the supply of current to the stator based upon output signals from the temperature sensor, wherein the rotor rotates without being demagnetized, the controller storing a chart or function for correlating the detected rotor temperature to a demagnetization limit current, which correlation chart or function determines an upper limit for the current supplied to the stator and the controller being further arranged and constructed to supply an initial stator current that is less than or equal to the demagnetization limit current, but greater than or equal to a minimum current required to rotate the rotor.

14. An apparatus as in claim 13, wherein the controller is further arranged and constructed to set the initial stator current to nearly the demagnetization limit current at the time when the current is supplied to the motor.

15. An apparatus as in claim 13, wherein the controller is arranged and constructed to vary the initial stator current as the rotor temperature changes, wherein the initial stator current is selected to be less than, but nearly equal to, the demagnetization limit current at that time.

16. An apparatus as in claim 15, wherein the controller is arranged and constructed to supply the initial stator current to the stator until the detected rotor temperature reaches a demagnetization limit temperature for a predetermined demagnetization limit current, which demagnetization limit temperature is found by the correlation chart or function.

17. An apparatus comprising:

a compressor arranged and constructed to compress a cooling medium,

a motor coupled to the compressor for driving the compressor, the motor having a stator and a rotor, the stator producing a magnetic force to rotate the rotor when current is supplied to the stator,

a temperature sensor arranged and constructed to detect a temperature that represents the temperature of the rotor, and

a processor arranged and constructed to control the supply of current to the stator based upon output signals from the temperature sensor, wherein the rotor rotates without being demagnetized,

the processor comprising instructions to:

calculate a demagnetization limit current based upon the detected rotor temperature when the motor is started;

calculate a demagnetization limit temperature for a normal stator current; and calculate a time period of time that is necessary to supply a current to the stator, wherein the current supplied to the stator is less than or equal to the calculated demagnetization limit current.

18. An apparatus comprising:

a compressor arranged and constructed to compress a cooling medium,

a motor coupled to the compressor for driving the compressor, the motor having a stator and a rotor, the stator producing a magnetic force to rotate the rotor when current is supplied to the stator,

a temperature sensor arranged and constructed to detect a temperature that represents the temperature of the rotor, and

a processor arranged and constructed to control the supply of current to the stator based upon output signals from the temperature sensor, wherein the rotor rotates without being demagnetized,

the processor comprising instructions to:

calculate a demagnetization limit current based upon the rotor temperature detected by the temperature sensor,

calculate a demagnetization limit temperature for a normal stator current, and

supply current to the stator during an initial period until the detected rotor temperature reaches the calculated demagnetization limit temperature.

19. An apparatus comprising:

a compressor having a motor that includes a rotor and a stator, the rotor being rotated by a magnetic force generated by supplying current the stator, whereby a cooling medium is circulated within an air conditioning circuit,

means for detecting the temperature of the rotor or an ambient temperature when the rotor starts to rotate,

means for calculating a demagnetization limit current of the rotor at the detected temperature, and

means for supplying current to the stator for a predetermined time period, the current being less than or equal to the demagnetization limit current and greater than or equal to a minimum current that is required to rotate the rotor.

20. An apparatus as in claim 19, further comprising:

means for calculating a demagnetization limit temperature of the rotor for normal operation,

means for calculating a period of time that is necessary for the rotor to reach the demagnetization limit temperature while the current is supplied to the stator, and

means for supplying the current to the stator for at least the calculated period of time.

21. An apparatus comprising:

a compressor having a motor that comprises a rotor and a stator, the rotor being rotated by magnetic force generated by supplying current to the stator, whereby a cooling medium is circulated within an air conditioning circuit,

means for detecting the temperature of the rotor,

means for calculating a demagnetization limit temperature for normal operation,

means for calculating a demagnetization limit current from the detected temperature, and

means for supplying current to the stator at least until the temperature of the rotor reaches the demagnetization limit temperature, the current being less than or equal to the demagnetization limit current and being greater than or equal to a minimum current that is required to rotate the rotor.

22. An air conditioning system comprising:

a compressor having a motor, the motor including a rotor and a stator, the rotor being rotated by a magnetic force generated by supplying current to the stator, whereby a cooling medium is circulated within an air conditioning circuit,

a temperature sensor arranged and constructed to detect either the rotor temperature or an ambient temperature,

a current calculator arranged and constructed to calculate a demagnetization limit current for the rotor at a temperature detected when current is initially supplied to the stator, and

means for supplying current to the stator for a predetermined period, which current is less than or equal to the calculated demagnetization limit current and is greater than or equal to a minimum current that is required to rotate the rotor.

23. An air conditioning system as in claim 22, further including:

a temperature calculator arranged and constructed to calculate a demagnetization limit temperature for the rotor during normal operation, and

a time calculator arranged and constructed to calculate a period of time that is necessary for the rotor to reach the calculated demagnetization limit temperature while the current is being supplied to the stator, wherein the current supplying means supplies the current to the stator at least during the period of time that is calculated by the time calculator.

24. An air conditioning system comprising:

a compressor having a motor, the motor including a rotor and a stator, the rotor being rotated by a magnetic force generated by supplying current the stator, whereby a cooling medium is circulated within a air conditioning circuit,

a temperature sensor arranged and constructed to detect the temperature of the rotor; and

a temperature calculator arranged and constructed to calculate a demagnetization limit temperature of the rotor during normal operation;

a current calculator arranged and constructed to calculate a demagnetization limit current from the temperature detected by the temperature sensor; and

means for supplying current to the stator at least until the detected temperature of the rotor reaches the demagnetization limit temperature, wherein the supplied current is less than or equal to the demagnetization limit current and is greater than or equal to a minimum current that is required to rotate the rotor.

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