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United States Patent	12389575
Kind Code	B2
Date of Patent	August 12, 2025
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Power conversion apparatus

Abstract

In a power conversion apparatus, at least one intra-casing cooling passage is a passage through which a coolant for cooling at least a power converter flows, and is arranged in a casing. At least one extra-casing cooling passage communicates with the at least one intra-casing cooling passage and is drawn out from an inside of the casing. The at least one extra-casing cooling passage is disposed not to be in contact to the outer periphery of the casing. The power converter is arranged to be cooled by the coolant flowing through the at least one intra-casing cooling passage, and a heat exchanger and the casing are arranged to be subjected to cooling air, resulting in the heat exchanger and the casing being cooled by the cooling air.

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Appl. No.: 18/217870

Filed: July 03, 2023

Prior Publication Data

Document Identifier	Publication Date
US 20230354563 A1	Nov. 02, 2023

Foreign Application Priority Data

JP	2021-025043	Feb. 19, 2021
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Related U.S. Application Data

Publication Classification

Int. Cl.: H05K7/20 (20060101)

U.S. Cl.:

CPC H05K7/20909 (20130101); H05K7/20145 (20130101); H05K7/20272 (20130101); H05K7/2039 (20130101); H05K7/20927 (20130101);

Field of Classification Search

CPC: H05K (7/1432); H05K (7/20145); H05K (7/20218); H05K (7/20254); H05K (7/20272); H05K (7/2039); H05K (7/20409); H05K (7/20509); H05K (7/20854); H05K (7/20872); H05K (7/209); H05K (7/20909); H05K (7/20927); H05K (7/20936); H05K (7/20945); H01L (23/36-3677); H02K (5/22); H02K (9/19)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
7579805	12/2008	Saito	318/800	H05K 7/20927
2014/0198449	12/2013	Osada	361/689	H01L 24/34
2015/0152987	12/2014	Ishikawa	285/350	H05K 7/20927
2016/0105083	12/2015	Ishimaru et al.	N/A	N/A
2018/0219488	12/2017	Nakamura	N/A	H05K 7/20936
2018/0269682	12/2017	Specht	N/A	H02B 1/565
2018/0286781	12/2017	Yoshihara	N/A	H01L 23/49548

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
2007-294655	12/2006	JP	N/A

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Background/Summary

REFERENCE TO RELATED APPLICATIONS (1) This application is a bypass continuation application of currently pending international application No. PCT/JP2022/004999 filed on Feb. 9, 2022 designating the United States of America, the entire disclosure of which is incorporated herein by reference, the internal application being based on and claiming the benefit of priority from Japanese Patent Application No. 2021-25043 filed on Feb. 19, 2021.

TECHNICAL FIELD

(1) The present disclosure relates to power conversion apparatuses.

BACKGROUND OF THE INVENTION

(2) For example, Japanese Patent Application Publication No. 2016-77118 discloses a motor apparatus. The motor apparatus includes a motor unit and a power conversion apparatus, such as an inverter, that are integrally installed in a single casing. The power conversion apparatus generates alternating-current (AC) power that drives the motor unit. The power conversion apparatus includes a power converter, a capacitor, and a controller that includes a control circuit. The power converter includes power devices, such as switches, which are controlled to be turned on or off. A larger amount of heat given off by the power converter, which is one of these power converter, capacitor, and controller, results in the power converter being more likely to increase its temperature.

(3) From this viewpoint, the motor apparatus disclosed in the patent publication is configured such that (i) the power converter, which is a main heat-generating component, and (ii) the capacitor and controller, each of which is a lesser heat-generating component, are located in respective different spaces that are physically isolated from one another. This suppresses an increase in temperature of one of the spaces in which the control circuit is located; the control circuit has a relatively lower heat resistance.

(4) Additionally, cooling passages provided between the motor unit and the power converter reduce heat dissipation from the motor unit to the power converter.

SUMMARY OF THE INVENTION

(5) An increase in temperature of a coolant, which circulates through the cooling passages, due to, for example, an increase in the amount of heat given off by the motor unit and/or an increase in the environment temperature around the motor apparatus may result in the casing of the motor apparatus being heated. This may increase the temperature inside one of the spaces in which the control circuit is located. This may result in devices included in the control circuit becoming susceptible to damage.

(6) From this viewpoint, it has been considered to further increase the cooling capability in the casing. This increase in the cooling capability in the casing may require that heat dissipators, such as heat dissipating fins, be additionally installed in the casing and/or the size of the casing increase to accordingly increase the cooling capacity in the casing. This however may result in the motor apparatus, i.e., the power conversion apparatus, becoming oversized. This therefore may deteriorate the installability of the power conversion apparatus.

(7) In view of the circumstances set forth above, one aspect of the present disclosure seeks to provide power conversion apparatuses, each of which has a smaller size and a higher cooling capability with superior installability.

(8) An exemplary measure of the present disclosure provides a power conversion apparatus. The power conversion apparatus includes a power converter that includes a plurality of switches, a control-circuit unit configured to control the power converter, and a casing that has an outer periphery and houses the power converter and the control-circuit unit therein. The power conversion apparatus includes a cooling passage assembly that includes at least one intra-casing cooling passage (30) through which a coolant for cooling at least the power converter flows. The at least one intra-casing cooling passage is arranged in the casing. The cooling passage also includes at least one extra-casing cooling passage communicating with the at least one intra-casing cooling passage and drawn out from an inside of the casing. The at least one extra-casing cooling passage is disposed not to be in contact to the outer periphery of the casing. The power conversion apparatus includes at least one pump mounted communicably at an arbitrary location of the cooling passage assembly and configured to cause the coolant to flow through the cooling passage assembly. The power conversion apparatus includes a heat exchanger mounted integrally to the outer periphery of the casing and configured to dissipate heat of the coolant flowing through the at least one extra-casing cooling passage to an outside of the power conversion apparatus. The power converter is arranged to be cooled by the coolant flowing through the at least one intra-casing cooling passage,

and the heat exchanger and the casing are arranged to be subjected to cooling air, resulting in the heat exchanger and the casing being cooled by the cooling air.

(9) The power conversion apparatus of the exemplary aspect is configured such that the coolant flowing through the at least one intra-casing cooling passage absorbs heat from the power converter, which produces a relatively large amount of heat, resulting in the absorbed heat being dissipated to the outside of the power conversion apparatus in the at least one extra-casing cooling passage.

(10) This reduces an increase in temperature of the whole of the casing due to heat of the coolant flowing through the at least one intra-casing cooling passage.

(11) Additionally, the at least one extra-casing cooling passage is disposed not to be in contact to, i.e., separate from, the outer periphery of the casing. This enables heat transfer from the coolant, which has a high temperature, flowing through the cooling passage assembly to the inside of the casing through the outer periphery of the casing, making it possible to curb an increase in temperature of the inner space **19** of the casing, thus curbing an increase in temperature of the whole of the casing.

(12) Additionally, the power conversion apparatus of the exemplary aspect is configured such that the cooling air cools the casing to accordingly dissipate heat of the control-circuit unit, which produces a relatively low amount of heat.

(13) The heat exchanger, which is mounted integrally to the casing, eliminates the need of providing a housing and connection cables, which are required to hold the heat exchanger away from the casing. This therefore offers the power conversion apparatus, which has a smaller size, a higher cooling capability, and superior installability.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The above object, other objects, characteristics, and advantageous benefits of the present disclosure will become apparent from the following description with reference to the accompanying drawings in which:

(2) FIG. 1 is a block diagram illustrating a functional configuration of a power conversion apparatus according to the first embodiment of the present disclosure;

(3) FIG. 2 is a plan view schematically illustrating a diagrammatic configuration of the power conversion apparatus of the first embodiment;

(4) FIG. 3 is a cross-sectional view taken along line III-III in FIG. 2, which schematically illustrates a diagrammatic configuration of the power conversion apparatus of the first embodiment;

(5) FIG. 4 is a side view schematically illustrating a diagrammatic configuration of a power conversion apparatus according to the second embodiment of the present disclosure;

(6) FIG. 5 is a side view schematically illustrating a diagrammatic configuration of a power conversion apparatus according to one modification of the second embodiment of the present disclosure; and

(7) FIG. 6 is a plan view schematically illustrating a part of a power conversion apparatus according to an additional modification of each embodiment of the present disclosure.

DETAILED DESCRIPTION

(8) The following describes exemplary embodiments with reference to accompanying drawings.

First Embodiment

(9) A1 Configuration of Power Conversion Apparatus

(10) The following describes the configuration of a power conversion apparatus **101** according to the first embodiment with reference to FIGS. 1 to 3.

(11) The power conversion apparatus **101** of the first embodiment is connected to a vehicular motor

device, and is configured to generate alternating-current (AC) power for driving the motor device. The power conversion apparatus **101** and the motor device are installable in a vehicle equipped with an electric motor, such as an electric vehicle or a hybrid vehicle. The power conversion apparatus **101** operates based on direct-current (DC) power of a battery as a power source, converts the DC power into AC power for driving the motor device, and supplies the AC power to the motor device.

(12) The power conversion apparatus **101** includes, as illustrated in FIG. **1**, a power converter **11**, a control-circuit unit **12**, a single casing **13**, a pump **14**, a cooling passage assembly **15**, and a heat exchanger **16**.

(13) The power converter **11** is comprised of a plurality of switches **17** (see FIG. **2**), such as Insulated Gate Bipolar Transistors (IGBTs) or Sic-MOSFETs. The control-circuit unit **12** is configured as a control board for controlling on-off switching operations of the switches **17** of the power converter **11** to accordingly convert DC power of the battery into AC power. Because the switches **17** of the power converter **11** generate heat when controlled by the control-circuit unit **12**, the power converter **11** can be regarded as a heat generator.

(14) The following describes a specific configuration of the power conversion apparatus **101** with reference to FIGS. **2** and **3**. In FIG. **2**, a top member of the casing **13** has been omitted in order to clearly illustrate the internal configuration of the power conversion apparatus **101**. Each component of the power conversion apparatus **101** disposed in an inner space **19** of the casing **13** is illustrated by solid line in FIG. **2**. The casing **13** has an actually sealed structure described later. In the present specification, a direction perpendicular to the plane of FIG. **2** is defined as a vertical direction. One side of the vertical direction, which goes into the plane of FIG. **2**, is defined as a lower side, and the other side of the vertical direction, which goes away from the plane of FIG. **2** is defined as an upper side.

(15) The casing **13** is, as illustrated in FIGS. **2** and **3**, a tubular cylindrical member that has a tubular cylindrical configuration. The casing **13** has a center axis C extending in the vertical direction in FIG. **2**, and extending in a right-and-left direction in FIG. **3**. Any views of the power conversion apparatus **101** as seen from the upper side of the center axis C will be defined as top plan views.

(16) The casing **13** has a sealed structure, and has the enclosed inner space **19**. Specifically, the casing **13** houses, in the enclosed inner space **19**, the power converter **11**, the control-circuit unit **12**, and the pump **14**. That is, the power converter **11** and the control-circuit unit **12** are installed in the same sealed inner space **19**. An unillustrated capacitor unit is installed in the casing **13**. The capacitor unit is provided in an electric circuit connecting between the battery and the power converter **11**, and configured to smooth the DC power supplied from the battery.

(17) The casing **13** has an outer periphery **18**. The power conversion apparatus **101** includes main-power input terminals **21**, motor connection terminals **22**, and a connection connector **23**. The main-power input terminal **21**, motor connection terminals **22**, and connection connector **23** are formed through the casing **13** to protrude, from the outer periphery **18** of the casing **13**, radially outward. The first location of the set of the main-power input terminals **21** on the casing **13**, the second location of the set of the motor connection terminals **22** on the casing **13**, and the third location of the connection connector **23** on the casing **13** substantially partition the casing **13** into three equal casing segments. The set of the main-power input terminals **21**, the set of the motor connection terminals **22**, and the connection connector **23** are arranged in this order in the clockwise direction in planar view. The motor connection terminals **22** are connected to a three-phase motor. The connection connector **23** serves as a connector unit that enables the control-circuit unit **12** to operate, and is connected to one or more communication cables extending from an unillustrated control apparatus.

(18) The power converter **11** is arranged in the casing **13** adjacent to a predetermined portion of the casing **13**; the motor connection terminals **22** are formed through the predetermined portion of the

casing **13**. The pump **14** is arranged in the casing **13** adjacent to a predetermined portion of the casing **13**; the connection connector **23** is formed through the predetermined portion of the casing **13**. This arrangement of the pump **14** enables the pump **14** to be separate from the power converter **11** that is regarded as a high heat-generating component.

(19) The pump **14** is configured to pump from a part of the cooling passage assembly **15** into another part of the cooling passage assembly in the direction of arrow **A2** to accordingly cause the coolant to flow through first to third external passages **41** to **43** described later.

(20) The cooling passage assembly **15** is a closed circulating flow passage through which the coolant for cooling the power converter **11** flows. For example, water or antifreeze can be used for the coolant.

(21) The cooling passage assembly **15** includes intra-casing cooling passages **30**, extra-casing cooling passages **40**, and connecting flow passages **50** that are circularly joined to constitute the cooling passage assembly **15**.

(22) The intra-casing cooling passages **30** include a first internal passage **31**, a second internal passage **32**, and a third internal passage **33**. The extra-casing cooling passages **40** include the first external passage **41**, the second external passage **42**, and the third external passage **43**.

(23) The connecting flow passages **50** include a first joint passage **51**, a second joint passage **52**, a third joint passage **53**, a fourth joint passage **54**, a fifth joint passage **55**, and a sixth joint passage **56**.

(24) Hereinafter, if there is no need of individually describing the first, second, and third external passages **41**, **42**, and **43**, the first, second, and third external passages **41**, **42**, and **43** will be collectively described as the extra-casing passages **40**. Similarly, if there is no need of individually describing the first, second, and third internal passages **31**, **32**, and **33**, the first, second, and third internal passages **31**, **32**, and **33** will be collectively described as the intra-casing passages **30**. Additionally, if there is no need of individually describing the first to sixth joint passages **51** to **56**, the first to sixth joint passages **51** to **56** will be collectively described as the connecting flow passages **50**.

(25) The first internal passage **31**, the first joint passage **51**, the first external passage **41**, the second joint passage **52**, the second internal passage **32**, the third joint passage **53**, the second external passage **42**, the fourth joint passage **54**, the third internal passage **33**, the fifth joint passage **55**, the third external passage **43**, and the sixth joint passage **56** are connected in this order in the clockwise direction in planar view. The assembly of the connected passages **31**, **51**, **41**, **52**, **32**, **53**, **42**, **54**, **33**, **55**, **43**, and **56** has a substantially ring configuration.

(26) The intra-casing cooling passages **30** are arranged in the casing **13** to be adjacent to the top member of the casing **13**.

(27) The first internal passage **31** is disposed in the casing **13** to bypass the motor connection terminals **22**. A portion of the first internal passage **31** is in contact with the power converter **11** through an unillustrated insulating plate. The coolant flowing through the first internal passage **31** absorbs heat generated from the power converter **11** to accordingly cool the power converter **11**.

(28) The second internal passage **32** is disposed in the casing **13** to bypass the connection connector **23**. The pump **14** is communicably mounted at any location of the second internal passage **32**.

(29) The third internal passage **33** is disposed in the casing **13** to bypass the power input terminals **21**.

(30) The intra-casing cooling passages **30**, which are disposed in the casing **13**, can be mounted on an inner surface of the casing **13** or disposed away from the inner surface of the casing **13**.

(31) The connecting flow passages **50** are located at the outside of the casing **13**. Each joint flow passage **50** joins a corresponding one of the intra-casing cooling passages **30** and a corresponding one of the extra-casing cooling passages **40**. The connecting flow passages **50** are disposed to protrude, through an outer circumference of the top member of the casing **13**, radially outward.

(32) Each of the extra-casing cooling passages **40** communicates with a corresponding pair of intra-

casing passages **30** through a corresponding pair of connecting flow passages **50**, and is drawn out from the inside of the casing **13** to the outside thereof.

(33) Specifically, each of the first to third external passages **41** to **43** has opposing upstream and downstream ends. The upstream end of the first external passage **41** is joined to the first internal passage **31** through the first joint passage **51**, and the downstream end of the first external passage **41** is joined to the second internal passage **32** through the second joint passage **52**. Similarly, the upstream end of the second external passage **42** is joined to the second internal passage **32** through the third joint passage **53**, and the downstream end of the second external passage **42** is joined to the third internal passage **33** through the fourth joint passage **54**. Additionally, the upstream end of the third external passage **43** is joined to the third internal passage **33** through the fifth joint passage **55**, and the downstream end of the third external passage **43** is joined to the first internal passage **31** through the sixth joint passage **56**. The extra-casing cooling passages **40** are disposed not to be in contact to the outer periphery **18** of the casing **13**, i.e., disposed away from the outer periphery **18** of the casing **13**.

(34) Each of the extra-casing cooling passages **40** has a cross-section along a virtual plane including the center axis C of the casing **13**; the cross-section of each of the extra-casing cooling passages **40** has a flat shape (see FIG. 3). The cross-section of each of the extra-casing cooling passages **40** has a predetermined first length in the axial direction of the casing **13**, and a predetermined second length in a radial direction of the casing **13**; the first length is set to be three times or more the second length. Each of the extra-casing cooling passages **40** has a predetermined width in the vertical direction, which corresponds to a length thereof in the right-and-left direction in FIG. 3, and the width of each of the extra-casing cooling passages **40** is set to be substantially identical to the axial length of the casing **13**. Each of the extra-casing cooling passages **40** is comprised of a metallic flat tubular plate, and includes one or more unillustrated inner fins formed thereinside.

(35) Each of the first to third external passages **41** to **43** has a substantially circular-arc shape in planar view. Each of the circular-arc shaped external passages **41** to **43** has a center angle that substantially lies within the range from 80° to 100° inclusive. Each of the first to third external passages **41** to **43** is arranged to face a corresponding portion of the outer periphery **18** of the casing **13** with a predetermined distance to the outer periphery **18** thereof while extending along the corresponding portion of the outer periphery **18**. The extra-casing cooling passages **40** are disposed to bypass the respective terminals **21**, **22**, and **23**, and the assembly of the extra-casing cooling passages **40** has a substantially annular ring shape.

(36) Each adjacent joint pair of these passages **31**, **32**, **33**, **41**, **42**, **43**, **51**, **52**, **53**, **54**, **55**, and **56** of the cooling passage assembly **15** have a joint boundary therebetween, and the joint boundary of each adjacent joint pair of these passages **31**, **32**, **33**, **41**, **42**, **43**, **51**, **52**, **53**, **54**, **55**, and **56** of the cooling passage assembly **15** has smoothly curved corners. The smoothly curved corners of the joint boundary of each adjacent joint pair of these passages **31**, **32**, **33**, **41**, **42**, **43**, **51**, **52**, **53**, **54**, **55**, and **56** of the cooling passage assembly **15** enables pressure drop across the corresponding adjacent joint pair of these passages **32**, **33**, **41**, **42**, **43**, **51**, **52**, **53**, **54**, **55**, and **56** to be reduced.

(37) The heat exchanger **16** is arranged to surround the outer periphery **18** of the casing **13** while being mounted integrally to the casing **13**.

(38) The heat exchanger **16** includes a first heat dissipator **61**, a second heat dissipator **62**, and a third heat dissipator **63**. The first heat dissipator **61** is provided for the first external passage **41**, the second heat dissipator **62** is provided for the second external passage **42**, and the third heat dissipator **63** is provided for the third external passage **43**. That is, the first to third heat dissipators **61** to **63** of the heat exchanger **16** are arranged in a substantially annular ring shape.

(39) Each of the first to third heat dissipators **61**, **62**, and **63** includes, for example, corrugated fins **64**; each of the corrugated fins **64** serves as a heat dissipation fin.

(40) Each of the corrugated fins **64** extends in a wavelike fashion in the circumferential direction of

the casing **13**. The corrugated fins **64** provided for the first external passage **41** are arranged on both radial sides of the first external passage **41** along a cross-section perpendicular to the axial direction of the casing **13** (see FIG. 3). Similarly, the corrugated fins **64** provided for the second external passage **42** are arranged on both radial sides of the second external passage **42** along the cross-section perpendicular to the axial direction of the casing **13** (see FIG. 3), and the corrugated fins **64** provided for the third external passage **43** are arranged on both radial sides of the third external passage **43** along the cross-section perpendicular to the axial direction of the casing **13** (see FIG. 3).

(41) Specifically, one of the first corrugated fins **64** provided for the first external passage **41** is arranged radially inside the first external passage **41**, and the other of the first corrugated fins **64** provided for the first external passage **41** is arranged radially outside the first external passage **41**. Similarly, one of the second corrugated fins **64** provided for the second external passage **42** is arranged radially inside the second external passage **42**, and the other of the second corrugated fins **64** provided for the second external passage **42** is arranged radially outside the second external passage **42**. Additionally, one of the third corrugated fins **64** provided for the third external passage **43** is arranged radially inside the third external passage **43**, and the other of the third corrugated fins **64** provided for the third external passage **43** is arranged radially outside the third external passage **43**.

(42) The power conversion apparatus **101** is located in a predetermined space of the vehicle; cooling air is supplied to the space in the vehicle by an unillustrated air blower installed in the vehicle. This results in the power conversion apparatus **101** being subjected to the cooling air flowing in the axial direction of the casing **13** (see the arrows A1 illustrated in FIGS. 1 and 3). That is, the cooling air partly flows along the outer periphery **18** of the casing **13** in the axial direction of the casing **13**. This results in the cooling air partly passing through each of the corrugated fins **64** in the axial direction of the casing **13**. The corrugated fin **64** provided for each external passage **41**, **42**, **43** can be arranged for one side of the corresponding external passage **41**, **42**, **43**.

(43) The cooling air partly hits the casing **13** itself in addition to the heat exchanger **16**. That is, the cooling air partly passes through the annularly arranged heat dissipators **61** to **63** around the casing **13** while passing through the casing **13** itself and passing through portions of the power conversion apparatus **101** around the casing **13**; no heat dissipators are provided in the respective portions of the power conversion apparatus **101**. In other words, the power conversion apparatus **101** is arranged such that the cooling air partly passes through the annularly arranged heat dissipators **61** to **63** around the casing **13** while passing through the casing **13** itself and passing through portions of the power conversion apparatus **101** around the casing **13**; no heat dissipators are provided in the respective portions of the power conversion apparatus **101**.

(44) This therefore results in both the heat exchanger **16** and the casing **13**, which are integrated with one another, being simultaneously subjected to the cooling air. The heat exchanger **16** receives heat from the coolant flowing through the extra-casing cooling passages **40**, and dissipates, as illustrated by an arrow A3 in FIG. 3, the received heat to the outside of the power conversion apparatus **101**. The corrugated fins **64** enable contact areas of the corrugated fins **64** with respect to the cooling air to be sufficiently ensured, resulting in heat exchange between the coolant and the cooling air being efficiently carried out.

(45) A2 Cooling Operation in Power Conversion Apparatus **101**

(46) The following describes how cooling operations are carried out in the power conversion apparatus **101**.

(47) Heat generated in the power converter **11** is received by the coolant flowing through the first internal passage **31** located adjacently below the power converter **11**. This enables the power converter **11**, whose temperature for example has risen up to 150° C., to be cooled, resulting in the temperature of the power converter **11** decreasing down to a desired specific low temperature of, for example, 50° C. The coolant, whose temperature has risen up to 100° C. or thereabout, flows

through the first to third external passages **41** to **43** back to the first internal passage **31** while heat of the coolant is dissipated by the heat exchanger **16**. This results in the temperature of the coolant decreasing down to 50° C. or thereabout.

(48) The whole of the casing **13** is subjected to the cooling air, so that the whole of the casing **13** is cooled. Specifically, heat of the control-circuit unit **12** is dissipated from the outer surfaces of the casing **13**, resulting in the temperature of the control-circuit unit **12** decreasing down to a desired specific low temperature. Separately arranging the extra-casing cooling passages **40** from the outer periphery **18** of the casing **13** enables heat transfer from the coolant, which has a high temperature, to the casing **13** through the extra-casing cooling passages to be restricted. Cooling the outer surfaces of the casing **13** by the cooling air enables the temperature in the casing **13** to be lower than the temperature of the coolant.

(49) The situation where the power converter **11** is cooled represents a situation where the temperature of the power converter **11**, which is subjected to heat exchange between the power converter **11** and the coolant flowing through the extra-casing cooling passages **40**, becomes lower than the temperature of the power converter **11**, which is not subjected to heat exchange between the power converter **11** and the coolant flowing through the extra-casing cooling passages **40**. For this reason, the situation where the power converter **11** is cooled can include (I) A first situation where heat exchange between the power converter **11** and the coolant flowing through the extra-casing cooling passages **40** results in the temperature of the power converter **11** reducing (II) A second situation where heat exchange between the power converter **11** and the coolant flowing through the extra-casing cooling passages **40** results in the temperature of the power converter **11** being maintained, i.e., unchanged (III) A third situation where heat exchange between the power converter **11** and the coolant flowing through the extra-casing cooling passages **40** results in the temperature of the power converter **11** increasing

(50) The following describes advantageous benefits achieved by the first embodiment.

(51) A larger amount of heat given off by the power converter **101** due to the supply of a high current thereto from the battery causes the temperature of the power converter **11** included in all the components of the power conversion apparatus **101** to be likely to increase up to a high temperature of, for example, 150° C. or more.

(52) From this viewpoint, the power conversion apparatus **101** of the first embodiment is configured such that (I) The coolant flowing through the cooling passage assembly **15** dissipates heat of the power converter **11**, which produces a relatively large amount of heat (II) The cooling air supplied from the air blower cools the casing **13** to accordingly dissipate heat of the control-circuit unit **12**, which produces a relatively low amount of heat

(53) The power conversion apparatus **101** is additionally configured such that the cooling air supplied from the air blower cools the whole of the heat exchanger **16** and the casing **13**.

(54) Separately arranging the extra-casing cooling passages **40** from the outer surfaces of the casing **13** enables heat transfer from the coolant, which has a high temperature, to the casing **13** through the extra-casing cooling passages **40** to be restricted to be as low as possible, making it possible to curb an increase in temperature of the inner space **19** of the casing **13**.

(55) The heat exchanger **16**, which is integrated with the casing **13**, eliminates the need of providing a housing and connection cables, which are required to hold the heat exchanger **16** away from the casing **13**. This therefore offers the power conversion apparatus **101**, which has a smaller size, a higher cooling capability, and superior installability.

(56) The pump **14** is communicably mounted at any location of one of the intra-casing cooling passage **30**, i.e., the second internal passage **32**, and installed in the casing **13**. This configuration enables the length of a passage required for joint of the pump **14** to be as short as possible, making it possible to minimize the volume and weight of the coolant. This configuration additionally eliminates the need of external joint members, making it possible to simplify the overall configuration of the power conversion apparatus **101**, facilitate replacement of the power

conversion apparatus **101**, and improve the maintainability of the power conversion apparatus **101**.
(57) The casing **13** has a sealed structure, and the heat exchanger **16** is mounted integrally to the outer periphery **18** of the casing **13**.

(58) For example, let us consider a comparative example of an electronic device, which includes a cooling apparatus, disclosed in Japanese Patent Application Publication No. 2007-294655. The electronic device of the comparative example is configured to introduce outside air thereinto, and dissipate heat from a heat-generating component in the electronic device. This may result in water drops and/or foreign particles entering inside of the electronic device. In particular, if such an electronic device is a high-voltage electronic device, the entry of water drops and/or foreign particles into the high-voltage electronic device may deteriorate the electric-isolation performance of the high-voltage electronic device, and the deterioration in electric-isolation performance of the high-voltage electronic device may cause a risk of damage to the high-voltage electronic device.

(59) From this viewpoint, the configuration of the power conversion apparatus **1** according to the first embodiment is configured to perform heat dissipation in the casing **13** without introducing outside air into the casing **13**. This configuration therefore prevents damage to the high-voltage power conversion apparatus **101**, which includes the casing **13** having a sealed structure and a waterproof structure, due to entry of water and/or foreign particles into the casing **13**.

Second Embodiment

(60) The following describes a power conversion apparatus **102** according to the second embodiment with reference to FIG. **4**. In the first and second embodiments, descriptions of like parts between the first and second embodiments, to which like reference characters are assigned, are omitted or simplified to avoid redundant description.

(61) Because the configuration of a casing **70** of the power conversion apparatus **102** is mainly different from that of the casing **13** of the power conversion apparatus **101**, FIG. **4** illustrates mainly the casing **70** and the heat exchanger **16** while eliminating illustration of the detailed structure of the other components.

(62) The power conversion apparatus **102** of the second embodiment is, as illustrated in FIG. **4**, installed in a duct **72** to be subjected to cooling air created in the duct **72** by a centrifugal fan **71** serving as an air blower. The casing **70** of the second embodiment has an outer periphery that is in conformity with an inner periphery of the duct **72**. In other words, the casing **70** has the outer periphery that is shaped to be along the flow of the cooling air illustrated by arrows **A4** in FIG. **4**.

(63) Specifically, the casing **70** is comprised of a cylindrical bottom **73**, a cylindrical tubular wall **74**, a first tubular truncated cone wall **75**, and a second tubular truncated cone wall **76** that are coaxially aligned in a predetermined axial direction. The heat exchanger **16** is arranged to surround the outer periphery of the cylindrical tubular wall **74**. That is, the cylindrical tubular wall **74** of the casing **70** corresponds to the casing **13** of the first embodiment, and therefore, the configuration of the cylindrical tubular wall **74** is substantially identical to the configuration of the casing **13** of the first embodiment.

(64) The first tubular truncated cone wall **75** is tapered along the flow of the cooling air from the right to the left in FIG. **4**. In contrast, the second tubular truncated cone wall **76** is configured such that the diameter thereof becomes larger along the flow of the cooling air from the right to the left in FIG. **4**. An outer periphery of the first tubular truncated cone wall **75**, which extends adjacently along the inner periphery of the duct **72** in the axial direction, serves as a pressure-loss reducing portion **77**.

(65) Specifically, the radial dimension of the pressure-loss reducing portion **77** of the casing **70** becomes smaller as the pressure-loss reducing portion **77** recedes away from the extra-casing cooling passages located inside the heat exchanger **16**. In other words, the radial dimension of the pressure-loss reducing portion **77** of the casing **70** becomes smaller toward the downstream of the cooling-air flow. The duct **72** has an inlet from which the cooling air is introduced thereinto, and an unillustrated filter or an unillustrated centrifugal separator is installed in the inlet of the duct **72**.

The unillustrated filter or centrifugal separator removes, from the cooling air, dirt and/or dust contained in the cooling air to accordingly prevent clogging of passages defined by the fins of the heat exchanger **16**.

(66) The power conversion apparatus **102** of the second embodiment achieves advantages benefits that are substantially identical to those achieved by the power conversion apparatus **101** of the first embodiment.

(67) Additionally, the casing **70** of the power conversion apparatus **102** includes the pressure-loss reducing portion **77** that is shaped to reduce pressure loss of the cooling air. This efficiently uses the cooling air to cool the heat exchanger **16**, making it possible to improve the cooling capability of the power conversion apparatus **102**.

Modifications

(68) A wind tunnel formed between the inner periphery of a duct in which the power converter **101** of the first embodiment is installed and the outer periphery of the casing **13** can be configured to increase the flow rate of the cooling air that hits a portion of the heat exchanger **16** adjacent to the power converter **11**, i.e., a portion of the first heat dissipator **61** adjacent to the upstream of the first external passage **41**.

(69) Similarly, a wind tunnel formed between the inner periphery of the duct **72** in which the power converter **102** of the second embodiment is installed and the outer periphery of the casing **70** can be configured to increase the flow rate of the cooling air that hits a portion of the heat exchanger **16** adjacent to the power converter **11**, i.e., a portion of the first heat dissipator **61** adjacent to the upstream of the first external passage **41**.

(70) The above modification of each of the first and second embodiments enables the cooling air to efficiently hit the portion of the heat exchanger **16**, which is adjacent to the power converter **11**, making it possible to increase the cooling capability of the portion of the heat exchanger **16**, the temperature of the coolant that is flowing through the portion of the heat exchanger **16** may be particularly high.

(71) Like the second embodiment, the longitudinal cross-section of the casing **13** can be configured such that the outer periphery **18** of the casing **13** is shaped to be along the inner periphery of the duct in which the power conversion apparatus **101** is installed. This modification enables the casing **13** of the power conversion apparatus **101** to include the pressure-loss reducing portion **77**, making it possible to efficiently use the high-speed flow of the cooling air generated adjacent to the power converter **11**.

(72) Each of the extra-casing cooling passages **40** according to each of the first and second embodiments can be comprised of, for example, a circular pipe that has a circular cross-section.

(73) The casing **70** of the second embodiment, which has the first tubular truncated cone wall **75** and second tubular truncated cone wall **76**, can be modified to have another configuration, such as a circular cone wall or a streamlined wall, as long as the modified configuration of the casing **70** reduces the pressure loss of the cooling air. For example, as illustrated in FIG. 5, a modified casing **81** can include a circular cone wall **82** in place of the first and second tubular truncated cone walls **75** and **76**.

(74) Each of the power conversion apparatuses **101** and **102** of the first and second embodiments can include, as illustrated in FIG. 6, fins **83** mounted on the outer periphery of the casing **13**, **70**. This facilitates heat dissipation of the casing **13**, **70**, making it possible to further improve the cooling capability of each of the power conversion apparatuses **101** and **102** of the first and second embodiments. As illustrated in FIG. 6, each of the first to third heat dissipators **61**, **62**, and **63** can include straight fins **65** in place of the corrugated fins **64**.

(75) Each of the power conversion apparatuses **101** and **102** of the first and second embodiments is configured such that both the heat exchanger **16** and the casing **13**, **70** are subjected to the cooling air, but can be configured such that only the heat exchanger **16** disposed to surround the outer periphery of the casing **13**, **70** is subjected to the cooling air.

- (76) If the vehicle or another mobility device in which the power conversion apparatus **101** or **102** is to be installed moves at high velocity, the power conversion apparatus **101** or **102** can be configured to be subjected to self-produced air. Such a natural-cooling power conversion apparatus **101** or **102** can eliminate air blowers, such as fans.
- (77) Each of the power conversion apparatuses **101** and **102** can include plural pumps **14** and fans. The location of one or more pumps **14** can be changed.
- (78) Each of the power conversion apparatuses **101** and **102** of the first and second embodiments is connected to a vehicular motor device, and is installable in a vehicle. Each of the power conversion apparatuses **101** and **102** of the first and second embodiments can be installable in an electric train, an aircraft, or a ship. Each of the power conversion apparatuses **101** and **102** of the first and second embodiments can be applied as an electronic device with a cooling function, such as personal computer or a gaming device, as long as the power converter **11** serves as a heat-generating processor.
- (79) The casing **13** of the first embodiment, which has a tubular cylindrical shape, but can have any shape. The heat exchanger **16** is configured to include the first to third heat dissipators **61** to **63**, but the present disclosure is not limited to this configuration. Specifically, the heat exchanger **16** according to the present disclosure can include one or more heat dissipators whose shapes are freely changed as long as the one or more heat dissipators are mounted integrally to the outer periphery of the casing **13**.
- (80) The density of the fins provided in one portion of the heat exchanger **16** can be changed as compared with the density of the fins provided in another portion of the heat exchanger **16**. For example, the density of the fins provided in the first heat dissipator **61** can be changed as compared with the density of the fins provided in each of the other second and third heat dissipators **62** and **63** such that the interval of each adjacent pair of fins provided in the first heat dissipator **61** is wider, resulting in the volume of the cooling air therethrough being greater.
- (81) While the illustrative embodiments of the present disclosure have been described herein, the present disclosure is not limited to the embodiments and their modifications described herein, can be implemented by one of various configurations within the scope of the present disclosure.
- (82) The present disclosure can include replacement of one or more technical features included in one of the embodiments, which correspond to one or more technical features described in the summary of the invention, with one or more new technical features in order to address a part or all of the above issues or achieve a part or all of the above advantageous benefits. The present disclosure can include combination of one or more technical features included in one of the embodiments, which correspond to one or more technical features described in the summary of the invention, in order to address a part or all of the above issues or achieve a part or all of the above advantageous benefits. One or more technical features, which have not been described as essential features, can be deleted as necessity arises.
- (83) The following describes an electronic device (**101**) that includes a heat-generating portion (**11**), a sealed casing (**13**), a cooling passage (**15**), at least one pump (**14**), and a heat exchanger (**16**). The heat-generating portion is installed in the sealed casing. The at least one pump is configured to cause a coolant for cooling the heat-generating portion to flow through the cooling passage.
- (84) In particular, the sealed casing has an outer periphery, and the cooling passage includes an extra-casing passage. The heat exchanger is mounted integrally to the outer periphery of the casing, and is configured to dissipate heat received by the coolant flowing through the extra-casing passage to an outside of the electronic device.
- (85) The electronic device is configured such that the heat-generating portion is cooled by the coolant flowing through the cooling passage, and the heat exchanger and the casing are cooled by cooling air.

Claims

1. A power conversion apparatus comprising: a power converter that includes a plurality of switches; a control-circuit unit configured to control the power converter; a casing that has an outer periphery and houses the power converter and the control-circuit unit therein; a cooling passage assembly including: at least one intra-casing cooling passage through which a coolant for cooling at least the power converter flows, the at least one intra-casing cooling passage being arranged in the casing; and at least one extra-casing cooling passage communicating with the at least one intra-casing cooling passage and drawn out from an inside of the casing, the at least one extra-casing cooling passage being disposed not to be in contact to the outer periphery of the casing; at least one pump mounted communicably at an arbitrary location of the cooling passage assembly and configured to cause the coolant to flow through the cooling passage assembly; and a heat exchanger mounted integrally to the outer periphery of the casing and configured to dissipate heat of the coolant flowing through the at least one extra-casing cooling passage to an outside of the power conversion apparatus, the power converter being arranged to be cooled by the coolant flowing through the at least one intra-casing cooling passage, the heat exchanger and the casing being arranged to be subjected to cooling air, resulting in the heat exchanger and the casing being cooled by the cooling air.
 2. The power conversion apparatus according to claim 1, wherein: the at least one pump is communicably mounted at the arbitrary location of the at least one intra-casing cooling passage, and is installed in the casing.
 3. The power conversion apparatus according to claim 1, wherein: the at least one extra-casing cooling passage and the heat exchanger are arranged to surround the casing.
 4. The power conversion apparatus according to claim 3, wherein: the casing is a tubular cylindrical member, and has a center axis; and the at least one extra-casing cooling passage has a cross-section along a virtual plane including the center axis of the casing, the cross-section of the at least one extra-casing cooling passage having a flat shape and extending in the direction of the center axis of the casing.
 5. The power conversion apparatus according to claim 4, wherein: the heat exchanger includes one or more heat dissipation fins arranged on at least one side of the at least one extra-casing cooling passage along the virtual plane including the center axis of the casing.
 6. The power conversion apparatus according to claim 1, wherein: the heat exchanger is arranged to be subjected to the cooling air created by an air blower.
 7. The power conversion apparatus according to claim 6, wherein: the casing is a tubular cylindrical member, and has a center axis; and the casing includes a pressure-loss reduction portion configured such that a radial dimension of the pressure-loss reduction portion of the casing becomes smaller as the pressure-loss reduction portion recedes away from the at least one extra-casing cooling passage in a downstream direction of flow of the cooling air.
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