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Inventor(s)

Bouras; Scott R. et al.

COLD PLATE WITH TEMPERATURE UNIFORMITY AND INTEGRATED COOLING BOSSES

Abstract

A cold plate is provided and includes an additively manufactured integral components layered together to form a unitary body. The additively manufactured integral components include a cold plate body having a region on which a power module is disposable and defining a first interior channel extending across the region in a first plane, a frame to support the cold plate body and a cooling boss. The frame defines a second interior channel communicative with the first interior channel and extends along a periphery of the cold plate body in the first plane. The cooling boss is attached to the frame. The cooling boss defines a third interior channel communicative with the second channel and extends in a second plane transverse to the first plane.

Inventors: Bouras; Scott R. (Rockford, IL), Ofoegbu; Chukwunyere (Elgin, IL), Shepard; Charles (DeKalb, IL), Pal; Debabrata (Hoffman Estates, IL)

Applicant: Hamilton Sundstrand Corporation (Charlotte, NC)

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Background/Summary

BACKGROUND

[0002] Exemplary embodiments of the present disclosure relate generally to aircrafts and, in some embodiments, to a cold plate with temperature uniformity and integrated cooling bosses for an electrical power conversion and distribution system of an aircraft.

[0003] Aircraft electrical power conversion and distribution systems include many high-heat flux components. These include, but are not limited to, power modules and circuit breakers which form a critical part of aircraft electrical systems and associated components. As the aerospace industry evolves, power demands continue to increase. As such, power level capabilities of aircraft electrical power generation, conversion and distribution systems are also continuing to increase. This leads to increased heat dissipations of the power modules, bus bars and circuit breakers but the increased heat dissipations of these components tend to result in reduced reliability and premature wear out. Furthermore, power modules that are capable of the increased power levels tend to be relatively large and therefore more susceptible to temperature non-uniformity.

[0004] It has been found that current cooling solutions for the issues noted above may not be feasible, especially at increased power levels that are required for electrified propulsion and future high-power applications.

[0005] Accordingly, a continuing need exists for improvements in cooling solutions for power modules, bus bars and circuit breakers.

BRIEF DESCRIPTION

[0006] According to an aspect of the disclosure, a cold plate is provided and includes an additively manufactured integral components layered together to form a unitary body. The additively manufactured integral components include a cold plate body having a region on which a power module is disposable and defining a first interior channel extending across the region in a first plane, a frame to support the cold plate body and a cooling boss. The frame defines a second interior channel communicative with the first interior channel and extends along a periphery of the cold plate body in the first plane. The cooling boss is attached to the frame. The cooling boss defines a third interior channel communicative with the second channel and extends in a second plane transverse to the first plane.

[0007] In accordance with additional or alternative embodiments, the cold plate body has two or more regions on which power modules are disposable and the cooling boss is provided as two or more cooling bosses attached to the frame and respectively defining third interior channels.

[0008] In accordance with additional or alternative embodiments, the additively manufactured integral components forming the unitary body further include an inlet defining an interior channel inlet communicative with at least an upstream region of the first interior channel and an outlet defining an interior channel outlet communicative with at least a downstream region of the first interior channel. The inlet and the outlet further define a flow direction through the first, second and third interior channel.

[0009] In accordance with additional or alternative embodiments, the cold plate body includes fins extending through the first interior channel.

[0010] In accordance with additional or alternative embodiments, the fins include pin fins that are angled along the flow direction to lean away from incoming flow.

[0011] In accordance with additional or alternative embodiments, fin spacings of the fins differ at different locations along the flow direction.

[0012] In accordance with additional or alternative embodiments, a fin spacing of the fins decreases along the flow direction.

[0013] In accordance with additional or alternative embodiments, the second plane is perpendicular

to the first plane and the cooling boss includes a lower part below the first plane and an upper part above the first plane.

[0014] In accordance with additional or alternative embodiments, the lower part and the upper part are laterally offset from one another.

[0015] In accordance with additional or alternative embodiments, the lower part and the upper part each define U-shaped sections of the third interior channel.

[0016] In accordance with additional or alternative embodiments, the cooling boss defines the third interior channel as a serpentine channel.

[0017] According to an aspect of the disclosure, a cold plate assembly is provided and includes the cold plate, wherein the cold plate body has two or more regions on which power modules are disposable and the cooling boss is provided as two or more cooling bosses attached to the frame and respectively defining third interior channels, and at least one of a power module disposed on a corresponding one of the two or more regions, bus bar units disposed on a corresponding one of the two or more regions and a corresponding one of the two or more cooling bosses and a terminal block unit attached to a corresponding one of the two or more cooling bosses.

[0018] According to an aspect of the disclosure, a cold plate assembly is provided and includes additively manufactured integral components layered together to form a unitary body. The additively manufactured integral components include a cold plate body having a power module region and defining a first interior channel extending across the power module region in a first plane, a frame to support the cold plate body and a cooling boss. The frame defines a second interior channel communicative with the first interior channel and extends along a periphery of the cold plate body in the first plane. The cooling boss is attached to the frame. The cooling boss defines a third interior channel communicative with the second channel and extends in a second plane transverse to the first plane. The cold plate assembly further includes a power module disposed on the power module region, bus bar units disposed on the power module region and the cooling boss and a terminal block unit attached to the cooling boss.

[0019] In accordance with additional or alternative embodiments, the power module includes a metal-oxide-semiconductor field effect transistor (MOSFET) element.

[0020] In accordance with additional or alternative embodiments, the cold plate body has two or more power module regions and the cooling boss is provided as two or more cooling bosses attached to the frame and respectively defining third interior channels. The cold plate assembly further includes two or more power modules respectively disposed on the two or more power module regions, a divider disposed on the cold plate body between the two or more power module regions, first and second bus bar units disposed on the divider and the two or more cooling bosses, respectively, and two or more terminal blocks respectively attached to the two or more cooling bosses.

[0021] In accordance with additional or alternative embodiments, the additively manufactured integral components forming the unitary body further include an inlet defining an interior channel inlet communicative with at least an upstream region of the first interior channel and an outlet defining an interior channel outlet communicative with at least a downstream region of the first interior channel. The inlet and the outlet further define a flow direction through the first, second and third interior channels.

[0022] According to an aspect of the disclosure, a cold plate assembly fabrication method is provided and includes determining power modules, bus bars and terminal blocks to be disposed on or attached to the cold plate body, modeling temperatures of the cold plate body with the power modules, the bus bars and the terminal blocks disposed on or attached thereto and operating, iteratively redesigning the cold plate body and iteratively remodeling the temperatures to achieve a desired degree of temperature uniformity and additively manufacturing integral components to form the cold plate body as a unitary body once the desired degree of temperature uniformity is achieved.

[0023] In accordance with additional or alternative embodiments, the additively manufacturing of the integral components to form the cold plate body as the unitary body includes additively manufacturing a cold plate body having two or more regions on which two or more of the power modules are disposable and defining a first interior channel extending across the two or more regions in a first plane, additively manufacturing a frame to support the cold plate body, the frame defining a second interior channel communicative with the first interior channel and extending along a periphery of the cold plate body in the first plane, and additively manufacturing two or more cooling bosses attached to the frame and respectively defining two or more third interior channels communicative with the second channel and extending in a second plane transverse to the first plane.

[0024] In accordance with additional or alternative embodiments, the additively manufacturing of the integral components to form the cold plate body as the unitary body further includes additively manufacturing an inlet defining an interior channel inlet communicative with at least an upstream region of the first interior channel and additively manufacturing an outlet defining an interior channel outlet communicative with at least a downstream region of the first interior channel. The inlet and the outlet further define a flow direction through the first, second and third interior channels.

[0025] In accordance with additional or alternative embodiments, the additively manufacturing of the cold plate body includes building up fins extending through the first interior channel and at least one or more of the fins include pin fins that are angled along the flow direction to lean away from incoming flow, fin spacings of the fins differ at different locations along the flow direction and a fin spacing of the fins decreases along the flow direction.

[0026] In accordance with additional or alternative embodiments, the cold plate assembly fabrication method further includes respectively disposing the two or more power modules on the two or more power module regions, disposing a divider on the cold plate body between the two or more power module regions, disposing first and second bus bar units on the divider and the two or more cooling bosses, respectively, and respectively attaching two or more terminal blocks to the two or more cooling bosses.

[0027] These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0029] FIG. 1 is a perspective view of a cold plate assembly in accordance with embodiments;

[0030] FIG. 2 is a top-down view of a cold plate of the cold plate assembly of FIG. 1 in accordance with embodiments;

[0031] FIG. 3 is an elevational view of a cold plate of the cold plate assembly of FIG. 1 in accordance with embodiments;

[0032] FIG. 4 is a skeletal view of the cold plate of FIGS. 2 and 3 and internal channels in accordance with embodiments; and

[0033] FIG. 5 is a flow diagram illustrating a cold plate assembly fabrication method in accordance with embodiments.

[0034] These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

DETAILED DESCRIPTION

[0035] A detailed description of one or more embodiments of the disclosed apparatus and method

are presented herein by way of exemplification and not limitation with reference to the Figures. [0036] As will be described below, an additively manufactured cold plate is provided that is characterized in that temperature uniformity can be achieved over a large surface area in combination with heat transfer enhancement via integrated locally cooled mounting bosses. Improved thermal management is achieved with fins oriented for optimum print quality, variable fin density, flow balancing and z-axis cooling features. Fin density can be varied in flow directions to enable temperature uniformity in the flow directions and flow restriction features can be implemented for flow balancing to achieve temperature uniformity in directions normal to the flow directions. Cooling passages can be implemented within bosses in the z-axis to improve heat transfer at critical mounting locations.

[0037] With reference to FIGS. 1-3, a cold plate assembly **101** is provided and may include additively manufactured integral components that are layered together or provided in a matrix to form a unitary body **102** (i.e., by one or more of material jetting, binder jetting, material extrusion, powder bed fusion, sheet lamination, directed energy deposition, etc.). The cold plate assembly **101** may further include two or more power modules **121**, **122**, a divider **125**, first and second bus bar units **131**, **132** and two or more terminal blocks **141**, **142** (while this description relates to the case of the cold plate assembly **101** including the two or more power modules **121**, **122**, the first and second bus bar units **131**, **132** and the two or more terminal blocks **141**, **142**, it is to be understood that this is done for purposes of clarity and brevity and that there could be fewer or greater numbers of each; unless otherwise noted, the following description will relate to these embodiments). At least one of the two or more power modules **121**, **122** can include or be provided as a metal-oxide-semiconductor field effect transistor (MOSFET) element **123**.

[0038] The additively manufactured integral components that are layered together or provided in a matrix to form the unitary body **102** may include a cold plate body **150**, a frame **160** and two or more cooling bosses **171**, **172**. The cold plate body **150** can have two or more power module regions **151**, **152** and a periphery **153** surrounding the two or more power module regions **151**, **152**. The cold plate body **150** can be formed to define a first interior channel **154** (see FIGS. 2 and 3), with second and third interior channels discussed below. The first interior channel **154** is extendible across the two or more power module regions **151**, **152** in a first plane P1. The frame **160** is configured to support the cold plate body **150**. The frame **160** can be formed to define a second interior channel **161** (see FIG. 2). The second interior channel **161** is fluidly communicative with the first interior channel **154**. The second interior channel **161** is extendible along the periphery **153** of the cold plate body **150** in the first plane P1. The two or more cooling bosses **171**, **172** can each be integrally attached to the frame **150**. The two or more cooling bosses **171**, **172** can both be formed to define third interior channels **173**, **174**, respectively. Each of the third interior channels **173**, **174** is fluidly communicative with the second channel **161** and is extendible in a second plane P2, which can be transversely oriented or perpendicular relative to the first plane P1.

[0039] In an exemplary non-limiting embodiment, the two or more power modules **121**, **122** can be respectively disposed on the two or more power module regions **151**, **152**, the divider **125** can be disposed on the cold plate body **150** between the two or more power module regions **121**, **122**, the first bus bar unit **131** can be disposed on the divider **125** and the second bus bar unit **132** can be disposed on the two or more cooling bosses **171**, **172** and the two or more terminal blocks **141**, **142** can be respectively attached to the two or more cooling bosses **171**, **172**.

[0040] With continued reference to FIGS. 1-3 and with additional reference to FIG. 4, the additively manufactured integral components that are layered together or provided in a matrix to form the unitary body **102** can further include an inlet **180** and an outlet **190**. The inlet **180** can be formed to define an interior channel inlet **181** that is fluidly communicative with at least an upstream region **154A** of the first interior channel **154**, which is associated with and corresponds to power module region **151**. The outlet **190** can be formed to define an interior channel outlet **191** that is fluidly communicative with at least a downstream region **154B** of the first interior channel

154, which is associated with and corresponds to power module region **152**. The inlet **180** and the outlet **190** can further define a flow direction **D1** of cooling fluid through the first interior channel **154**, the second interior channel **161** and the third interior channels **173**, **174**.

[0041] In an exemplary non-limiting embodiment, the cold plate body **150** includes fins **201** that extend through the first interior channel **154**. The fins **201** can include or be provided as pin fins **202** that are angled along the flow direction **D1** to lean away from incoming flow, concentrations or fin spacings of the fins **201** can differ at different locations along the flow direction **D1** and/or a concentration or fin spacing of the fins **201** can decrease or increase along the flow direction **D1**. Thus, during an operation of the unitary body **102**, as fluid flows through the first interior channel **154**, the second interior channel **161** and the third interior channels **173**, **174**, a temperature of the unitary body **102** can remain substantially uniform or constant. This can be achieved, at least partially, by a concentration or fin spacing of the fins **201** in the upstream region **154A** of the first interior channel **154** being decreased relative to a concentration or fin spacing of the fins **201** in the downstream region **154B** of the first interior channel **154**. This can also be achieved, at least partially, by a concentration or fin spacing of the fins **201** increasing from the upstream region **154A** of the first interior channel **154** to the downstream region **154B** of the first interior channel **154**.

[0042] As shown in FIG. 3, the two or more cooling bosses **171**, **172** can each include a lower part **171A**, **172A** below the first plane **P1** and an upper part **171B**, **172B** above the first plane **P1**. For each of the two or more cooling bosses **171**, **172**, the lower part **171A**, **172A** and the upper part **171B**, **172B** can be laterally offset from one another (i.e., left-to-right in the image of FIG. 3). In any case, the lower part **171A**, **172A** and the upper part **171B**, **172B** can each define U-shaped sections **173A**, **173B** and **174A**, **174B** of the third interior channels **173**, **174**. Considered together, the two or more cooling bosses **171**, **172** can define the third interior channels **173**, **174** as a serpentine channel **175** (see FIG. 4).

[0043] With reference to FIG. 5, a cold plate assembly fabrication method **500** is provided for manufacturing the cold plate assembly **101** described above for example. In an exemplary non-limiting embodiment, the cold plate assembly fabrication method **500** can include designing a cold plate body or receiving a design of the cold plate body (block **501**), determining power modules, bus bars and terminal blocks to be disposed on or attached to the cold plate body (block **502**) and modeling temperatures of the cold plate body with the power modules, the bus bars and the terminal blocks disposed on or attached thereto and operating (block **503**). The cold plate assembly fabrication method **500** can also include determining whether a desired degree of temperature uniformity of the cold plate assembly is achieved (block **504**) and, if not, iteratively redesigning the cold plate body (see block **501**) and iteratively remodeling the temperatures (see block **503**) to achieve the desired degree of the temperature uniformity. In an event the desired degree of the temperature uniformity is determined to be achieved in block **504**, the cold plate assembly fabrication method **500** can further include additively manufacturing integral components to form the cold plate body as a unitary body (block **505**).

[0044] The additively manufacturing of the integral components to form the cold plate body as the unitary body of block **505** can include additively manufacturing a cold plate body and building up fins as described above (block **5051**), additively manufacturing a frame as described above (block **5052**) and additively manufacturing two or more cooling bosses as described above (block **5053**). In addition, the additively manufacturing of the integral components to form the cold plate body as the unitary body of block **505** can include additively manufacturing an inlet and an outlet as described above (block **5054**) such that the inlet and the outlet define the flow direction **D1**. In each case, the additive manufacturing processes can include, but are not limited to, any type of three-dimensional (3D) printing, powder bed laser fusion (PBLF), etc.

[0045] With the cold plate body formed as the unitary body of block **505**, the cold plate assembly fabrication method **500** can also include respectively disposing the two or more power modules on

the two or more power module regions (block 506) disposing a divider on the cold plate body between the two or more power module regions (block 507) disposing first and second bus bar units on the divider and the two or more cooling bosses, respectively (block 508) and respectively attaching two or more terminal blocks to the two or more cooling bosses (block 509).

[0046] Technical effects and benefits of the features described herein are the provision of a cold plate that has improved temperature uniformity for improved power module reliability and integrated liquid cooled bosses for improved thermal management of cold plate mounted bus bars.

[0047] The term “about” is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application.

[0048] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

[0049] While the present disclosure has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this present disclosure, but that the present disclosure will include all embodiments falling within the scope of the claims.

Claims

1. A cold plate, comprising: additively manufactured integral components layered together to form a unitary body, comprising: a cold plate body having a region on which a power module is disposable and defining a first interior channel extending across the region in a first plane; a frame to support the cold plate body, the frame defining a second interior channel communicative with the first interior channel and extending along a periphery of the cold plate body in the first plane; and a cooling boss attached to the frame and defining a third interior channel communicative with the second channel and extending in a second plane transverse to the first plane.
2. The cold plate according to claim 1, wherein the additively manufactured integral components forming the unitary body further comprise: an inlet defining an interior channel inlet communicative with at least an upstream region of the first interior channel; and an outlet defining an interior channel outlet communicative with at least a downstream region of the first interior channel, wherein the inlet and the outlet further define a flow direction through the first, second and third interior channel.
3. The cold plate according to claim 2, wherein the cold plate body comprises fins extending through the first interior channel.
4. The cold plate according to claim 3, wherein the fins comprise pin fins that are angled along the flow direction to lean away from incoming flow.
5. The cold plate according to claim 3, wherein fin spacings of the fins differ at different locations along the flow direction.
6. The cold plate according to claim 3, wherein a fin spacing of the fins decreases along the flow direction.
7. The cold plate according to claim 1, wherein: the second plane is perpendicular to the first plane, and the cooling boss comprises a lower part below the first plane and an upper part above the first

plane.

8. The cold plate according to claim 7, wherein the lower part and the upper part are laterally offset from one another.

9. The cold plate according to claim 7, wherein the lower part and the upper part each define U-shaped sections of the third interior channel.

10. The cold plate according to claim 7, wherein the cooling boss defines the third interior channel as a serpentine channel.

11. A cold plate assembly, comprising: the cold plate according to claim 1, wherein the cold plate body has two or more regions on which power modules are disposable and the cooling boss is provided as two or more cooling bosses attached to the frame and respectively defining third interior channels; and at least one of a power module disposed on a corresponding one of the two or more regions, bus bar units disposed on a corresponding one of the two or more regions and a corresponding one of the two or more cooling bosses and a terminal block unit attached to a corresponding one of the two or more cooling bosses.

12. A cold plate assembly, comprising: additively manufactured integral components layered together to form a unitary body, comprising: a cold plate body having a power module region and defining a first interior channel extending across the power module region in a first plane; a frame to support the cold plate body, the frame defining a second interior channel communicative with the first interior channel and extending along a periphery of the cold plate body in the first plane; and a cooling boss attached to the frame and defining a third interior channel communicative with the second channel and extending in a second plane transverse to the first plane, the cold plate assembly further comprising a power module disposed on the power module region, bus bar units disposed on the power module region and the cooling boss and a terminal block unit attached to the cooling boss.

13. The cold plate assembly according to claim 12, wherein the power module comprises a metal-oxide-semiconductor field effect transistor (MOSFET) element.

14. The cold plate assembly according to claim 12, wherein: the cold plate body has two or more power module regions and the cooling boss is provided as two or more cooling bosses attached to the frame and respectively defining third interior channels, and the cold plate assembly further comprises: two or more power modules respectively disposed on the two or more power module regions; a divider disposed on the cold plate body between the two or more power module regions; first and second bus bar units disposed on the divider and the two or more cooling bosses, respectively; and two or more terminal blocks respectively attached to the two or more cooling bosses.

15. The cold plate assembly according to claim 12, wherein the additively manufactured integral components forming the unitary body further comprise: an inlet defining an interior channel inlet communicative with at least an upstream region of the first interior channel; and an outlet defining an interior channel outlet communicative with at least a downstream region of the first interior channel, wherein the inlet and the outlet further define a flow direction through the first, second and third interior channels.

16. A cold plate assembly fabrication method, comprising: determining power modules, bus bars and terminal blocks to be disposed on or attached to the cold plate body; modeling temperatures of the cold plate body with the power modules, the bus bars and the terminal blocks disposed on or attached thereto and operating; iteratively redesigning the cold plate body and iteratively remodeling the temperatures to achieve a desired degree of temperature uniformity; and additively manufacturing integral components to form the cold plate body as a unitary body once the desired degree of temperature uniformity is achieved.

17. The cold plate assembly fabrication method according to claim 16, wherein the additively manufacturing of the integral components to form the cold plate body as the unitary body comprises: additively manufacturing a cold plate body having two or more regions on which two or

more of the power modules are disposable and defining a first interior channel extending across the two or more regions in a first plane; additively manufacturing a frame to support the cold plate body, the frame defining a second interior channel communicative with the first interior channel and extending along a periphery of the cold plate body in the first plane; and additively manufacturing two or more cooling bosses attached to the frame and respectively defining two or more third interior channels communicative with the second channel and extending in a second plane transverse to the first plane.

18. The cold plate assembly fabrication method according to claim 17, wherein the additively manufacturing of the integral components to form the cold plate body as the unitary body further comprises: additively manufacturing an inlet defining an interior channel inlet communicative with at least an upstream region of the first interior channel; and additively manufacturing an outlet defining an interior channel outlet communicative with at least a downstream region of the first interior channel, wherein the inlet and the outlet further define a flow direction through the first, second and third interior channels.

19. The cold plate assembly fabrication method according to claim 18, wherein: the additively manufacturing of the cold plate body comprises building up fins extending through the first interior channel, and at least one or more of the fins comprise pin fins that are angled along the flow direction to lean away from incoming flow, fin spacings of the fins differ at different locations along the flow direction and a fin spacing of the fins decreases along the flow direction.

20. The cold plate assembly fabrication method according to claim 17, further comprising: respectively disposing the two or more power modules on the two or more power module regions; disposing a divider on the cold plate body between the two or more power module regions; disposing first and second bus bar units on the divider and the two or more cooling bosses, respectively; and respectively attaching two or more terminal blocks to the two or more cooling bosses.
