DEVICE FOR AIR-COOLING OF MOTORS

RELATED APPLICATION

[0001] This application claims the benefit of priority to the Singapore application no. 10202400492U filed February 23, 2024, the contents of which are hereby incorporated herein by reference in their entirety for all purposes.

TECHNICAL FIELD

[0002] The present disclosure relates to thermal management and, more particularly, a device for air-cooling of motors.

BACKGROUND

[0003] In operation, motors can generate a substantial amount of heat. Conventional motor cooling faces challenges as uneven flow of cooling medium can create hot spots and exacerbate temperature gradients that negatively impact the efficiency of the motor.

SUMMARY

[0004] In one aspect, a device includes a finned cooling structure and a shroud. The shroud defines a primary inlet, an outlet, and a channel extending along a longitudinal axis from the primary inlet to the outlet. The finned cooling structure is disposed in the channel between the primary inlet and the outlet. The shroud defines a plurality of secondary openings proximal to the finned cooling structure.

[0005] The device may further include a suction fan disposed in the channel between the finned cooling structure and the outlet.

[0006] The finned cooling structure may be disposed in a second section. The finned cooling structure may include a plurality of fins. Each of the plurality of fins may be annularly shaped.

[0007] The plurality of secondary openings may be defined as one or more arrays of secondary openings. In some embodiments, each array of secondary openings includes a honeycomb distribution of hexagonal openings.

[0008] In another aspect, the device, in assembly with a motor, may have the finned cooling structure disposed around the motor in thermal contact with the motor. In operation, the device is configured to enable an air flow entering the channel via the primary inlet and via the secondary openings. The air flow in the channel may be characterized by laminar flow paths. The air flow in a downstream region may be free of any one of a stagnation zone and a recirculation zone, the downstream region being downstream of the finned cooling structure and upstream of the suction fan.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Various embodiments of the present disclosure will be described with reference to the following figures:

[0010] **FIG. 1** is a perspective view of a schematic drawing of a device according to one embodiment of the present disclosure;

[0011] **FIG. 2** is a cross-section view of the device of **FIG. 1**;

[0012] **FIG. 3** is a schematic diagram of **FIG. 2** to illustrate flow paths of the cooling medium;

[0013] **FIG. 4** is a front view of the device of **FIG. 1**;

[0014] **FIG. 5** is a top view of the device of **FIG. 1**;

[0015] **FIG. 6** is a perspective view showing a panel with grid-shaped secondary openings;

[0016] **FIG. 7** is a perspective view showing a panel with honeycomb-shaped secondary openings;

[0017] **FIG. 8** is a top view showing a panel with slot-like secondary openings;

[0018] **FIG. 9** is a Computational Fluid Dynamics (CFD) simulation of a motor case with rectangular fins undergoing convectional cooling;

[0019] **FIG. 10** is a CFD simulation of a motor case with annular fins undergoing convectional cooling;

[0020] **FIG. 11** is a plot of bicycle time illustrating evolutions of an average contact surface temperature for 25 mm rectangular and annular fins, respectively;

[0021] **FIG. 12** is a plot of bicycle time illustrating evolutions of average contact surface temperature for 50 mm rectangular and annular fins, respectively;

[0022] **FIG. 13** is a CFD simulation of a motor undergoing convectional cooling with a velocity colour bar for streamlines and a temperature colour bar for the motor's surface;

[0023] **FIG. 14** is a CFD simulation of a motor installed in the shroud without a suction fan, with a velocity colour bar for streamlines and a temperature colour bar for the motor's surface; and

[0024] **FIG. 15** is a CFD simulation of a motor installed in the shroud with an operating suction fan, with a velocity colour bar for streamlines and a temperature colour bar for the motor's surface.

DETAILED DESCRIPTION

[0025] The following detailed description is made with reference to the accompanying drawings, showing details and embodiments of the present disclosure for the purposes of illustration and to aid understanding, and not to be limiting. Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments, even if not explicitly described in these other embodiments. Additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0026] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0027] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

[0028] As used herein, the singular 'a' and 'an' may be construed as including the plural "one or more" unless apparent from the context to be otherwise.

[0029] The terms "about" and "approximately" as applied to a stated numeric value encompasses the exact value and a reasonable variance as will be understood by one of ordinary skill in the art, and the terms "generally" and "substantially" are to be understood in a comparable manner, unless otherwise specified.

[0030] Some processes may be described in terms of steps merely to aid understanding and/or for convenient reference. The delineation between one step and another step may be described as such merely for convenient reference in the present disclosure. It will be understood that in actual implementation there may not be a clear division or transition from one step to another subsequent step. There may be a certain amount of overlap among the steps and/or more than one step may occur or be performed concurrently in time, etc.

[0031] As used herein, the term "concurrent", or "concurrently", is used loosely to refer to two or more occurrences (or events) that at least partially overlap in time. The occurrences may or may not start at the same time instant and/or end at the same time instant.

[0032] Terms such as "first" and "second" are used in the description and claims only for the sake of brevity and clarity, and do not necessarily imply a priority or order, unless required by the context.

[0033] All examples described herein, whether of apparatus, methods, materials, or products, are presented for the purpose of illustration and to aid understanding and are not intended to be limiting or exhaustive. Modifications not involving inventive effort may be made by one of ordinary skill in the art without departing from the scope of the claimed invention.

[0034] **FIG. 1** is a schematic illustration of a device 100 according to embodiments of the present disclosure. The device 100 includes a shroud 200. For the sake of brevity, in the present disclosure, the term "shroud" may refer to an interior surface of the shroud, a wall part of the shroud, or more generally, to the whole shroud, as would be clear from the context.

[0035] The shroud 200 defines a first opening leading into a channel 202. In the present disclosure, for the sake of brevity, the first opening is also referred to as a primary inlet 212. The shroud 200 includes a plurality of secondary openings 302. In the present disclosure, for the sake of brevity. The plurality of secondary openings 302 may be disposed in one or more arrays 300. The channel 202 extends generally from the primary inlet 212 to a third opening. In the present disclosure, for the sake of brevity, the third opening is also referred to as an outlet 232.

[0036] The device 100 includes a finned cooling structure 500. The finned cooling structure 500 includes a plurality of fins 510. The plurality of fins 510 are distributed, with adjacent ones of the plurality of fins 510 being spaced apart from one another, to define a corresponding array of secondary channels 520 between adjacent ones of the plurality of fins 510. The finned cooling structure 500 may be disposed outside or surrounding a heat generating apparatus such as but not limited to a motor 600. In the present disclosure, for the sake of brevity, the device 100 will be described as used with a motor (such as but not limited to an electric motor in an electric vehicle) solely to aid understanding and not to be limiting. The finned cooling structure 500 is disposed in the channel 202, between the primary inlet 212 and the outlet 232. The plurality of secondary openings 302 are defined in a sidewall of the shroud proximal to the finned cooling structure 500.

[0037] In some examples, the device 100 may include a suction fan 400 disposed in the channel 202, between the finned cooling structure 500 and an outlet 242. In the present disclosure, terms such as "suction fan", "ventilator fan", "exhaust fan", etc., may be used interchangeably, and refer to apparatus configured to move a volume of air through the shroud 200.

[0038] **FIG. 2** schematically illustrates a longitudinal cross-section of the device 100. An interior surface of the shroud 200 may be formed to define the channel 202 as a contiguous tunnel. The shroud 200 may be described in terms of a first section 210, a second section 220, and a third section 230, merely to aid understanding and for convenient reference. The first section 210, the second section 220, and the third section 230 may be aligned along a longitudinal axis 101, with one end of the first section 210 defining the primary inlet 212 and an opposing end of the third section 230 defining the outlet 232.

[0039] Example 1.

[0040] In some embodiments, the first section 210 of the shroud 200 may have a generally frustoconical profile when cut along a plane in which the longitudinal axis is wholly disposed (as schematically illustrated in FIG. 2). In some examples, the longitudinal cross-sectional profile (as illustrated in FIG. 2) may be symmetrical about the longitudinal axis 101.

[0041] In some examples, the shroud 200 has substantially circular transverse cross-sections (e.g., cut in a plane normal to the longitudinal axis 101) or partially circular transverse cross-sections.

[0042] The frustoconical profile defines a first transverse dimension (e.g., diameter d1) that is larger than a second transverse dimension (e.g., diameter d2), and in which the second transverse dimension (e.g., diameter d2) is larger than a third transverse dimension (e.g., diameter d3). For example, the first transverse dimension may be a diameter of the primary inlet 212, the second transverse dimension (d2) may be a diameter at the transition between the first section 210 and the second section 220, and the third transverse dimension (d3) may be a diameter of the outlet 232.

[0043] In some examples, the shroud 200 defines a first transverse cross-sectional area A1 (e.g., $A1 \propto d1^2$) that is greater than a second transverse cross-sectional area A2 (e.g., $A2 \propto d2^2$), and a third traverse cross-sectional area A3 (e.g., $A3 \propto d3^2$) that is smaller than the second transverse cross-sectional area A2 (e.g., $A2 \propto d2^2$).

[0044] In some examples, as illustrated in **FIG. 2**, the first section 210 includes a curved surface 214. The curved surface 214 provides a gradual change in the transverse dimension between the primary inlet 212 and the second section 220. The curved surface 214 may be configured to facilitate a smooth delivery or a substantially laminar flow of a fluid from the primary inlet 212 towards the finned cooling structure 500. In some examples, the first section 210 may have a flared shaped such that the primary inlet 212 defines a flared opening. In some examples, the first section 210 and the second section 220 are configured to avoid, reduce, or minimize sudden velocity changes in a flow velocity of the fluid flowing through the channel 202. In some examples, the channel 202 is configured to reduce turbulence in the fluid flowing through the channel 202.

[0045] Example 2.

[0046] In some other embodiments, the first section 210 of the shroud 200 may define a polygonal transverse cross section when cut in a plane that is normal to the longitudinal axis 101. As illustrated schematically in **FIG. 4**, in some examples, the shroud 200 has substantially rectangular transverse cross-sections or partially

rectangular transverse cross-sections. In some examples, the longitudinal cross-sectional profile when cut along a plane in which the longitudinal axis 101 is wholly disposed (as illustrated in **FIG. 2**) may be symmetrical about the longitudinal axis 101.

[0047] The longitudinal profile (e.g., as illustrated in **FIG. 2**) may define a first transverse dimension (d1) that is larger than a second transverse dimension (d2), and in which the second transverse dimension (d2) is larger than a third transverse dimension (d3). Referring also to **FIG. 4** and **FIG. 5**, for example, the first transverse dimension may be a height (h1) or a width (w1) of the primary inlet 212, the second transverse dimension may be a height (h2) or a width (w2) at the transition between the first section 210 and the second section 220, and the third transverse dimension may be a height (h3) or a width (w3) of the outlet 232.

[0048] In some examples, as illustrated in **FIG. 2**, the first section 210 includes a curved surface 214. The curved surface 214 provides a gradual change in the transverse dimension between the first transverse dimension (d1) and the second transverse dimension (d2). The curved surface 214 may be configured to facilitate a smooth delivery or a substantially laminar flow of a fluid from the primary inlet 212 towards the finned cooling structure 500. In some examples, the first section 212 may have a flared shaped. The primary inlet 212 may define a flared opening. In some examples, the first section 210 and the second section 220 are configured to avoid, reduce, or minimize sudden velocity changes in a flow velocity of the fluid flowing through the channel 202. In some examples, the channel 202 is configured to reduce turbulence in the fluid flowing through the channel 202.

[0049] Example 3.

[0050] In some examples, as illustrated in **FIG. 4** and **FIG. 5**, the shroud 200 defines a constant or substantially constant transverse dimension along the longitudinal axis 101 (e.g., $w1 \cong w2 \cong w3$) as well as at least a first transverse dimension (e.g., d1 at the first section 210) that is greater than a second transverse dimension (e.g., d2 at the second section 220). In some examples, the shroud 200 further defines a third transverse dimension (e.g., d3 at the third section 230) that is smaller than a second transverse dimension (e.g., d2 at the second section 220).

[0051] In some examples, the shroud 200 defines a first transverse cross-sectional area (e.g., d1 x w1) that is greater than a second transverse cross-sectional area (e.g., d2 x w2), and a third traverse cross-sectional area (e.g., d3 x w3) that is smaller than the second transverse cross-sectional area (e.g., d2 x w2).

[0052] Secondary openings

[0053] For the sake of brevity, in the present disclosure, a cooling medium flowing in the shroud 200 may be referred to generally as "air" but this does not limit the use of the shroud 200 with other gaseous mixtures or other fluid cooling media. **FIG. 3** schematically illustrates fluid flow paths or air flow paths 800 in the shroud 200 in a state where there is a temperature gradient between the motor 600 and the air in or around the shroud 200, for example, when the motor 600 is operating and generating heat.

[0054] In use, air enters the channel 202 of the shroud 200 along a first flow path 810. The suction fan 400 may be operated to draw air around the motor 600 towards the outlet 232. Air expelled from the shroud 200 along the second flow path 820 may include contribution from the first flow path 810 and from a plurality of third flow paths 830. Air may be drawn into the shroud 200 through a plurality of the secondary openings 302, along corresponding third flow paths 830, towards a downstream region 840. The downstream region 840 refers to a region downstream of the finned cooling structure 500 and upstream of the suction fan 400.

[0055] The channel 202 is in fluid communication with an environment exterior of the shroud 200 via the primary inlet 212, the plurality of secondary openings 302, and the outlet 232.

[0056] In some embodiments, in the absence of the suction fan 400 or when the suction fan 400 is not in operation, air heated by the motor 600 may exit the shroud 200 (or exit the channel 202) via the plurality of secondary openings 302.

[0057] The suction fan 400 effects a draft of air from an external region (relative to the shroud 200) to an internal region (e.g., the channel 202). A low-pressure zone is created, e.g., by operation of the suction fan 400, which encourages air to move across surfaces of the finned cooling structure 500, toward the outlet 232. The fluid flow velocity is increased by the configuration of the device 100. Stagnation zones can be substantially eliminated from the downstream region 840.

[0058] In some embodiments, the finned cooling structure 500 and the motor 600 are separate articles, with the motor 600 received within the finned cooling structure 500. In some other embodiments, the finned cooling structure 500 is formed as part of a housing of the motor 600. In either embodiments, the finned cooling structure 500 is disposed around the motor 600 in thermal contact with the motor 600, i.e., with the plurality of fins 510 disposed to conduct heat away from the motor 600.

[0059] Still referring to **FIG. 2** to **FIG. 5**, in some embodiments, the finned cooling structure 500 may include a plurality of fins 510 disposed around the motor 600, in which each annular fin 510 is a separate annular or ring-like article. In some applications, the fins 510 of the finned cooling structure 500 may be made from thermally conductive materials, such as but not limited to copper or aluminium. The relatively delicate fins 510 may be protected by the shroud 200.

[0060] In some other embodiments, the fins 510 may be one continuous spiral article disposed with spiral rings spaced apart from one another. In general, each fin 510 may be described as a thin and flat ring with two opposing major surfaces. The opposing major surfaces define a fin normal axis 105. In the shroud 200, the finned cooling structure 500 is oriented with the fin normal axis 105 parallel to a transverse axis of the shroud 200. Alternatively, the transverse axis may be referred to as a motor axis 106 that is defined by the motor 600. The finned cooling structure 500 is oriented relative to the primary inlet 212 and the outlet 232 apart to define air flow paths across curved sectors of the major surfaces of the fins 510. In other words, the plurality of fins 510 may be transversely oriented relative to the longitudinal axis 101 of the shroud 200, with adjacent fins being spaced at a predetermined distance from one another.

[0061] In some examples, the plurality of fins 510 are annularly shaped and form a stack transversely oriented relative to the longitudinal axis 101.

[0062] In some embodiments, each array 300 of the secondary openings 302 may be formed as a panel. Each panel 300 may define a panel axis 104 normal to the panel (**FIG. 4**). Each panel (or cover) may be disposed relative to the rest of the shroud 200 with the secondary openings 302 oriented to enable secondary air intake proximal to the finned cooling structure 500, and at least slightly upstream of the downstream region 840 (**FIG. 3** and **FIG. 5**).

[0063] In some examples, the shroud 200 may include two arrays 300 of the secondary openings 302 disposed on one or both of two opposing walls of the shroud 200 (**FIG. 2** and **FIG. 3**). Each array 300 may be fabricated in the form of a panel that can be decoupled from the rest of the shroud 200 and replaced, e.g., to facilitate cleaning and/or maintenance. Each panel may define thousands of secondary openings 302. The secondary openings 302 in one panel may collectively define an area that is about two thirds the size of primary inlet area. **FIG. 6** is a perspective view illustrating an example of the array 300 of secondary openings 302 in the form of a grid array of rectangular openings or square openings. **FIG. 7** is a perspective view illustrating another example of the array 300 of secondary openings 302 in the form of a honeycomb distribution of hexagonal openings. In the example illustrated, the size of the primary inlet (the primary inlet area) may be approximately 3000 to approximately 4000 times the size of each secondary opening (e.g., the secondary opening size or the size of each "cell") of the panel. In other words, in one device 100, there are thousands of secondary openings and only one primary inlet. In some embodiments, the size (the primary inlet area) of the primary inlet may be approximately 1.5 times the size of a panel (or the collective area of the secondary openings 302 in one array 300). The panels are preferably made of a damage resistant material, e.g., including a heat-resistant material. Examples of materials that may be used for forming at least a part of the panel include but are not limited to plastics such as a polytetrafluoroethylene (Teflon). Other robust plastics can be selected, e.g., plastics with easy cleaning or self-cleaning properties, heat resistant, etc. **FIG. 8** is a top view illustrating an array 300 of secondary openings 302 in which the secondary openings 302 are configured to include slot-shaped openings. In some examples, the shroud 200 may include one or more panels, in which each panel is made of a porous material. In some other examples, the shroud 200 may be an air duct with a pre-defined streamwise wall profile, with sections of a top wall and a bottom wall (or sections of opposing walls) of the duct made of a matter of a porous nature. The pre-defined streamwise wall profile refers to a profile that guides cooling air over the plurality of fins 510.

[0064] The one or more arrays 300 of the secondary openings 302 enable cooling by natural convection in the examples where the suction fan 400 fails to operate, or when the suction fan 400 is switched off. The plurality of fins 510 may be in contact with the motor 600 to establish a heat transfer path via conduction between the motor 600 and the plurality of fins 510. The plurality of fins 510 may also enable a heat transfer path via convection between the finned cooling structure 500, the interior of the shroud 200, and the environment external of the shroud 200.

[0065] In some examples, the finned cooling structure 500 is provided around a heat generating device including other components, including for example other engine components, pipes, etc.

[0066] Experimental Results or Simulation Results

[0067] Computational Fluid Dynamics (CFD) simulations, as shown in **FIG. 9** to **FIG. 12**, were conducted to visualize the effects of shapes and sizes of fins on the cooling effect of motors. Two types of fin shapes on motor casings (namely, rectangular and annular as shown in **FIG. 9** and **FIG. 10** respectively) were compared. In the experiments, the motor casing may be made of aluminium, e.g., AL383. For the motor casing with rectangular fins, the incoming air flow is parallel to the motor axis 106, while for the motor casing with annular fins, the incoming air flow is perpendicular to the motor axis 106. **FIG. 11** and **FIG. 12** show the results of the simulations. The average contact surface temperature (in degrees Celsius or °C) for the annular fins is lower than that of the rectangular fins for a range of bicycle (relative air) speeds from 0 m/s (meter per second) to 20 m/s. Compared to rectangular fins, it was found that the annular fins can be configured to provide a greater surface area for contact with the air flow, and enable a higher rate of heat transfer and a higher rate of cooling. Fin sizes of 25 mm (millimeters) and 50 mm were compared, and the average contact surface temperatures were found to follow the same trend as described above.

[0068] For fin sizes (e.g., fin heights) of 25 mm and 50 mm, the largest decrease in the average contact surface temperature occurred when the bicycle speed was increased from 0 m/s to 5 m/s. As the bicycle speed was increased beyond 5 m/s, the average contact surface temperature experienced a gradual decrease. Advantageously, it is indicative that a fan power in the range of 3 W (watts) to 5 W

suffices to achieve the target cooling rate. In other words, the power expenditure to drive the required level of cooling is relatively low. In other examples, parametric CFD studies conducted indicated that less than 10 W is required to operate the suction fan. In some examples, the suction fan is optional. In some examples, the suction fan may be installed in the shroud but operated at selected times, e.g., the suction fan may be used only when necessary upon starting the motor or upon shutting down of the motor.

[0069] CFD simulations were performed to visualize different configurations. **FIG. 13** shows the air flow patterns in a case of air cooling of a motor disposed in a finned cooling structure without a shroud. **FIG. 13** was used as a baseline reference for comparison. **FIG. 14** shows the air flow patterns in a case of air cooling of a motor disposed in a finned cooling structure that is in turn disposed in a shroud. **FIG. 15** shows the air flow patterns in a case of air cooling of a motor disposed in a finned cooling structure that is in turn disposed in a shroud, with a suction fan (also referred to as a wind-catcher fan) operating downstream of the finned cooling structure.

[0070] In **FIG. 13**, substantial stagnation zones can be observed at the downstream region (zone 700). The velocity streamlines indicate that the presence and velocity of air flow within the stagnation zones is minimal. This is indicative of air recirculating, with little or no cooling of the motor occurring in the stagnation zones.

[0071] In **FIG. 14**, the stagnation zones at zone 710 are significant smaller than the case of **FIG. 13**. The shroud may be described as providing a conical nozzle and longitudinal profile that can guide the air flow, shaping the air flow path to the extent of reducing the stagnation zones. In **FIG. 15**, the suction fan is operated to draw air through the panels into the shroud. The panels in this example were configured with secondary openings in an array similar to honeycomb cells. The secondary openings provide additional air flow paths that facilitate further reduction of the stagnation zone 720. It may be observed that, in the case illustrated by **FIG. 15**, the stagnation zone may be eliminated.

[0072] **FIG. 15** shows that, with the present device 100, it is possible to achieve uniform or substantially uniform temperature distribution, as indicated by the

temperature streamlines. It can be observed that there are no hotspots (or zones of extremely high temperatures) in the case of **FIG. 15**.

[0073] In conventional systems, stagnation or recirculation zones can be a serious problem. Such stagnation or recirculation zones are characterized by areas where the cooling fluid slows down or comes to a near halt due to adverse pressure gradients. The fluid in a stagnation zone experiences a lack of forward momentum, causing it to recirculate within the localized area. Heat is prevented from being dissipated. On the contrary, localized areas of extreme temperatures or hotspots may form. Recirculation creates turbulence and disrupts the otherwise laminar or controlled flow pattern. In the case of motor cooling, this uneven flow distribution can have significant consequences. The presence of stagnation zones results in uneven cooling across the motor's surface, leading to hot spots where heat is not effectively carried away. These regions can exacerbate temperature gradients, which can negatively impact the motor's efficiency, potentially reducing its performance or lifespan due to localized overheating. Stagnation and recirculation zones are particularly problematic in areas with poor airflow dynamics, such as corners or confined spaces within the motor housing. Moreover, the development of such zones can increase thermal stress on the motor components, especially in critical regions like windings and bearings, where high temperatures can cause insulation degradation or mechanical failures.

[0074] The experimental or simulation results show that the present device 100 is capable of forming cooling air flow patterns that address issues faced by conventional systems. With the present device 100, stagnation or recirculation zones no longer form in the downstream regions of the motor. The present device 100 enables formation of flow regions where the fluid moves steadily and facilitates heat transfer. In fact, the experimental and simulation results show that the present device 100 is capable of effectively mitigating the formation of stagnation zones by improving airflow patterns. The present device 100 is therefore a viable solution for effectively removing heat from heat generating apparatus such as motors.

[0075] According to various embodiments, the present application discloses a device that includes a finned cooling structure and a shroud. The shroud defines a primary inlet, an outlet, and a channel extending along a longitudinal axis from the

primary inlet to the outlet. The finned cooling structure is disposed in the channel between the primary inlet and the outlet. The shroud defines a plurality of secondary openings proximal to the finned cooling structure.

[0076] The device may further include a suction fan disposed in the channel between the finned cooling structure and the outlet.

[0077] The shroud may include a first section and a second section. One end of the first section forms the primary inlet. The finned cooling structure may be disposed in the second section. The first section may have a larger transverse cross-sectional area than the second section.

[0078] The first section may define the primary inlet as a flared opening.

[0079] The finned cooling structure may include a plurality of fins. Adjacent ones of the plurality of fins may be spaced apart from one another to define a corresponding plurality of secondary channels.

[0080] Each of the plurality of secondary channels may be characterized by a constant spacing.

[0081] Each of the plurality of fins is preferably annularly shaped. The plurality of fins may be transversely oriented relative to the longitudinal axis. The plurality of fins may be distributed in a stack.

[0082] The plurality of secondary openings may be defined as one or more arrays of secondary openings.

[0083] Two of the arrays of secondary openings may be disposed in opposing sidewalls of the shroud.

[0084] In some embodiments, each array of secondary openings includes a honeycomb distribution of hexagonal openings. In some embodiments, each array of secondary openings includes a grid distribution of square openings. In some embodiments, each array of secondary openings includes slot-shaped openings.

[0085] The device, in assembly with a motor, may have the finned cooling structure disposed around the motor in thermal contact with the motor.

[0086] In operation, the device is configured to enable an air flow entering the channel via the primary inlet and via the secondary openings. The air flow in the channel may be characterized by laminar flow paths. The air flow in a downstream region may be free of any one of a stagnation zone and a recirculation zone, the

downstream region being downstream of the finned cooling structure and upstream of the suction fan.

[0087] The primary inlet may define a primarily inlet area that is 1.5 times a collective area of the secondary openings in each one of the one or more array of secondary openings.

[0088] The primary inlet may define a primary inlet area that is 3000 to 4000 times a secondary opening area, the secondary opening area being defined by any one of the plurality of secondary openings.

[0089] All examples and embodiments described herein, whether of apparatus, methods, materials, or products, are presented for the purpose of illustration and to aid understanding and are not intended to be limiting or exhaustive. Modifications may be made by one of ordinary skilled in the art without departing from the scope of the application as claimed.

CLAIMS

1. A device comprising:
   a finned cooling structure; and
   a shroud, the shroud defining a primary inlet, an outlet, and a channel extending along a longitudinal axis from the primary inlet to the outlet,
   wherein the finned cooling structure is disposed in the channel between the primary inlet and the outlet,
   and wherein the shroud defines a plurality of secondary openings proximal to the finned cooling structure.

2. The device as recited in claim 1, further comprising a suction fan disposed in the channel between the finned cooling structure and the outlet.

3. The device as recited in claim 2, wherein the shroud comprises:
   a first section, one end of the first section forming the primary inlet; and
   a second section, the finned cooling structure being disposed in the second section, wherein the first section has a larger transverse cross-sectional area than the second section.

4. The device as recited in claim 3, wherein the first section defines the primary inlet as a flared opening.

5. The device as recited in claim 3, wherein the finned cooling structure comprises a plurality of fins, and wherein adjacent ones of the plurality of fins are spaced apart from one another to define a corresponding plurality of secondary channels.

6. The device as recited in claim 5, wherein each of the plurality of secondary channels is characterized by a constant spacing.

7. The device as recited in claim 5, wherein each of the plurality of fins is annularly shaped.

8. The device as recited in claim 5, wherein the plurality of fins are transversely oriented relative to the longitudinal axis.

9. The device as recited in claim 5, wherein the plurality of fins are distributed in a stack.

10. The device as recited in claim 5, wherein the plurality of secondary openings are defined as one or more arrays of secondary openings.

11. The device as recited in claim 10, wherein two of the arrays of secondary openings are disposed in opposing sidewalls of the shroud.

12. The device as recited in claim 10, wherein each array of secondary openings comprises a honeycomb distribution of hexagonal openings.

13. The device as recited in claim 10, wherein each array of secondary openings comprises a grid distribution of square openings.

14. The device as recited in claim 10, wherein each array of secondary openings comprises slot-shaped openings.

15. The device as recited in claim 10 in assembly with a motor, wherein the finned cooling structure is disposed around the motor in thermal contact with the motor.

16. The device as recited in claim 15, wherein the device in operation enables an air flow entering the channel via the primary inlet and via the secondary openings.

17. The device as recited in claim 16, wherein the air flow in the channel is characterized by laminar flow paths.

18. The device as recited in claim 16, wherein the air flow in a downstream region is free of any one of a stagnation zone and a recirculation zone, the downstream region being downstream of the finned cooling structure and upstream of the suction fan.

19. The device as recited in claim 10, wherein the primary inlet defines a primarily inlet area that is 1.5 times a collective area of the secondary openings in each one of the one or more array of secondary openings.

20. The device as recited in claim 10, wherein the primary inlet defines a primary inlet area that is 3000 to 4000 times a secondary opening area, the secondary opening area being defined by any one of the plurality of secondary openings.