



(19) **United States**

(12) **Patent Application Publication**
Nubbe

(10) **Pub. No.: US 2016/0072161 A1**

(43) **Pub. Date: Mar. 10, 2016**

(54) **BATTERY PACK WITH EMBEDDED HEATERS**

(52) **U.S. Cl.**

CPC *H01M 10/5055* (2013.01); *H01M 10/502* (2013.01); *H01M 10/0525* (2013.01); *H01M 10/503* (2013.01); *H01M 10/5083* (2013.01)

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(57)

ABSTRACT

(21) Appl. No.: **14/481,638**

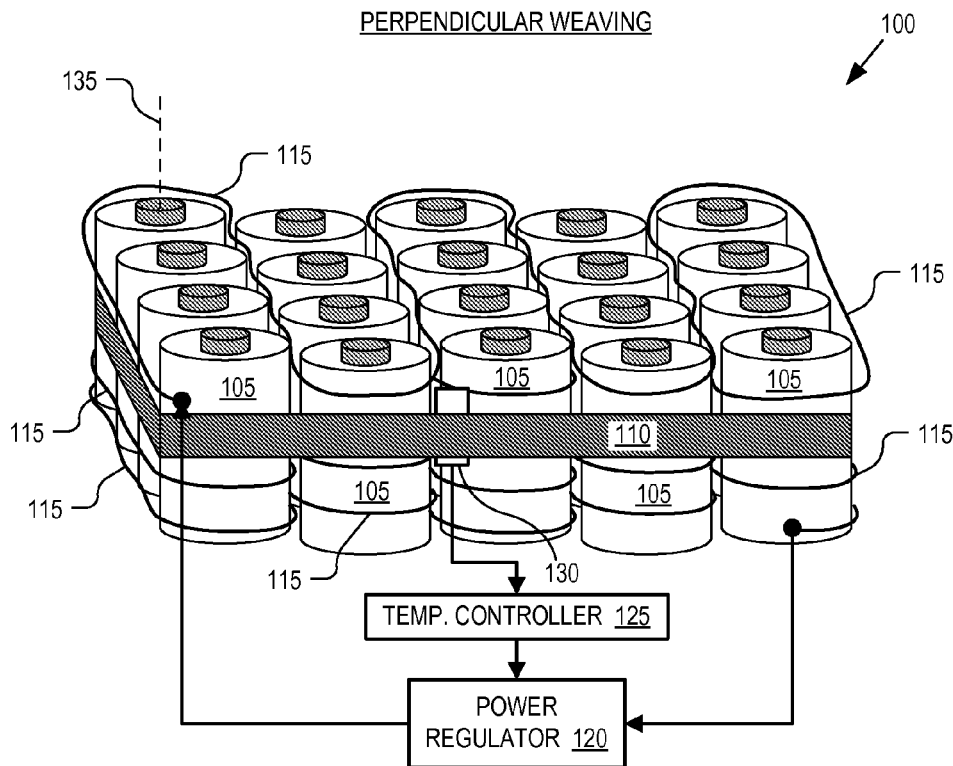
(22) Filed: **Sep. 9, 2014**

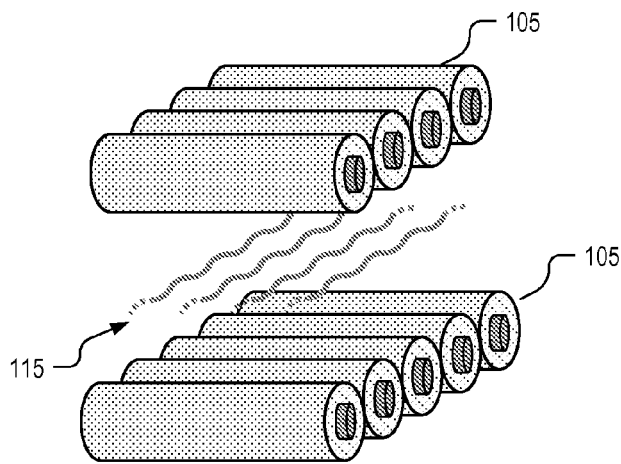
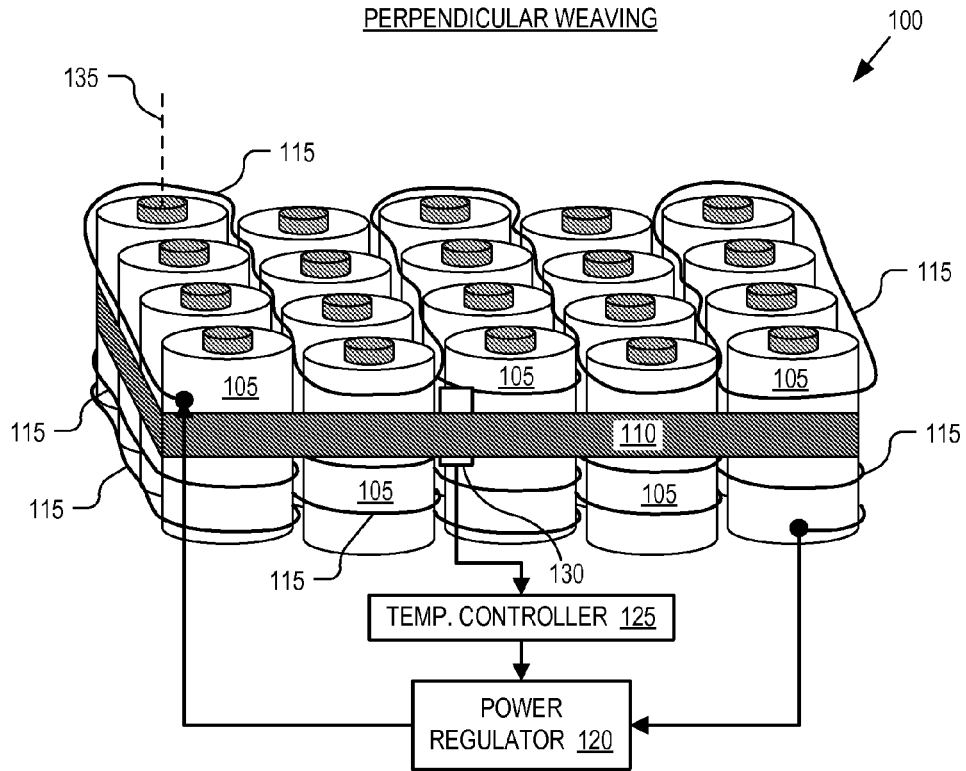
A heat battery pack system includes a battery pack including a plurality of battery cells electrically interconnected to each other, a binding coupled to mechanically hold the battery cells physically together, and a heater system coupled to the battery pack to heat the battery cells. The heater system includes a heating element interweaved between the battery cells of the battery pack and a heating controller electrically coupled to the heating element to drive current through the heating element and provide heat to the battery cells of the battery pack. The weaving of the heating element between the battery cells provides fixed mechanical support to the heating element.

Publication Classification

(51) **Int. Cl.**

- H01M 10/6555* (2006.01)
- H01M 10/6571* (2006.01)
- H01M 10/643* (2006.01)
- H01M 10/63* (2006.01)
- H01M 10/0525* (2006.01)





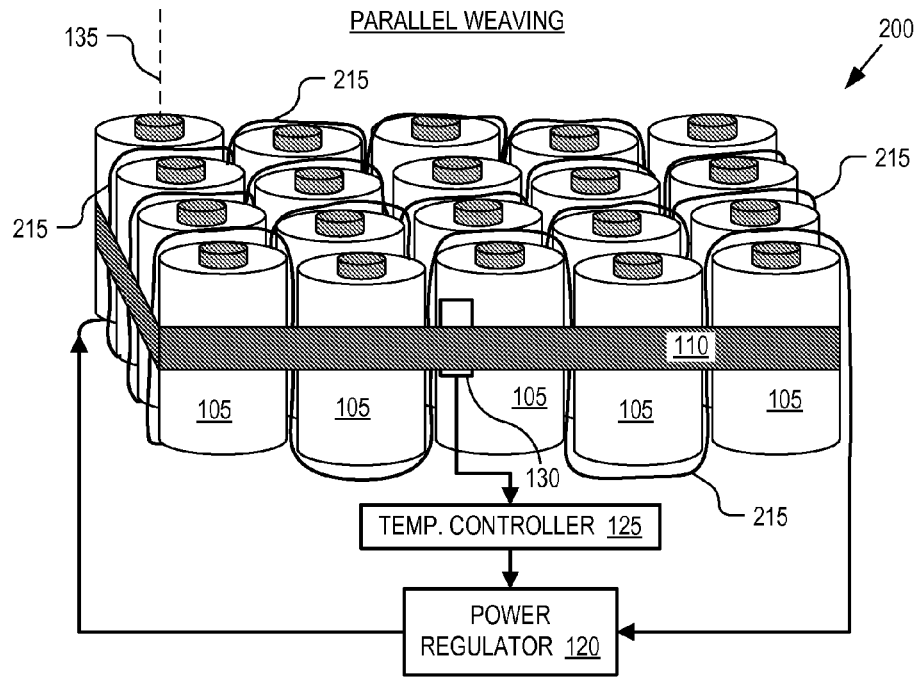
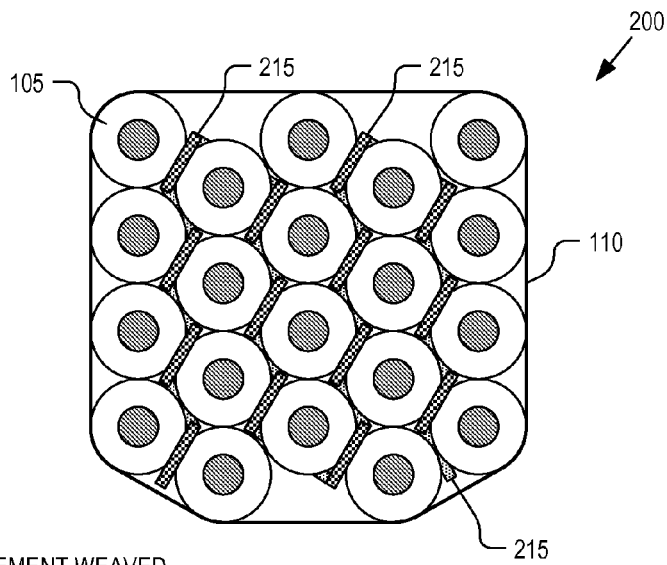


FIG. 2A



HEATING ELEMENT WEAVED ABOVE BATTERY CELL

HEATING ELEMENT WEAVED BELOW BATTERY CELL

FIG. 2B

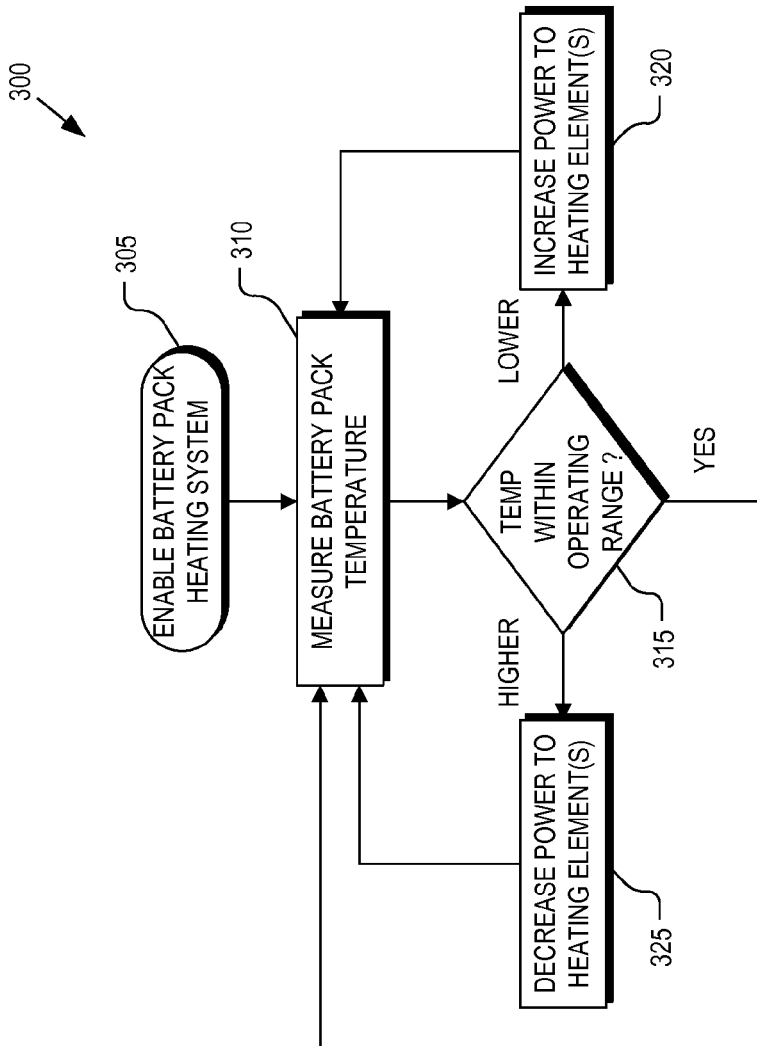


FIG. 3

BATTERY PACK WITH EMBEDDED HEATERS

TECHNICAL FIELD

[0001] This disclosure relates generally to heating battery packs.

BACKGROUND INFORMATION

[0002] Cold temperatures have negative effects on battery packs. For example, lithium ion battery packs generally lose substantial discharge capacity at sub-freezing temperatures and are even susceptible to irreversible damage if charged in sub-freezing temperatures. In order to maintain optimal performance in sub-freezing environments, heating modules may be provided with a battery pack to maintain minimum operating temperatures. However, these heating modules can add significant mass to the assembled battery pack and often have high watt densities that form localized hot spots.

[0003] Heaters meant for batteries are fairly uncommon and tend to be supplied as an afterthought to be installed as an independent solution. One conventional heater solution includes metallized foil heaters formed from a thin metal film sandwiched in kapton film or silicone. Metallized foil heaters are useful at higher watt densities, but have excess weight, mostly in the insulation. Another conventional solution includes bare Nichrome wires integrated into a bulky enclosure to protect the ultra-high temperature wires and maintain safe operating distances. Another conventional solution includes cartridge heaters or point source heaters integrated into a thermally conductive block. These heaters have high mass and high watt densities. Finally, resistors including through hole resistors and surface mount chip resistors can serve as heaters. However, these solutions tend to have irregular shapes and/or mounting issues making uniform heating difficult.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Non-limiting and non-exhaustive embodiments of the invention are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles being described.

[0005] FIGS. 1A & 1B are perspective illustrations of a battery pack with a heating element weaved using a perpendicular weave pattern between the battery cells, in accordance with an embodiment of the disclosure.

[0006] FIGS. 2A & 2B are perspective illustrations of a battery pack with a heating element weaved using a parallel weave pattern between the battery cells, in accordance with an embodiment of the disclosure.

[0007] FIG. 3 is a flow chart illustrating a process for maintaining a temperature of a battery pack within an operating range, in accordance with an embodiment of the disclosure.

[0008] FIG. 4 illustrates an aerial vehicle that includes sub-systems powered by a battery pack that is heated, in accordance with an embodiment of the disclosure.

DETAILED DESCRIPTION

[0009] Embodiments of a system, apparatus, and method for operation of a battery pack heater are described herein. In the following description numerous specific details are set forth to provide a thorough understanding of the embodi-

ments. One skilled in the relevant art will recognize, however, that the techniques described herein can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring certain aspects.

[0010] Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

[0011] FIGS. 1A & 1B are perspective illustrations of a battery pack with a heating element interweaved between battery cells using a perpendicular weave pattern, in accordance with an embodiment of the disclosure. The illustrated embodiment includes a battery pack 100 including individual battery cells 105 bound together via a binder 110 and a battery heating system. The illustrated battery heating system includes one or more heating elements 115, a power regulator 120, a temperature controller 125, and a temperature sensor 130.

[0012] Battery cells 105 may represent a variety of different battery technologies including lithium ion batteries, nickel metal hydrate batteries, nickel cadmium batteries, or other battery technologies that lose efficiency or are damaged when operated at cold temperatures. The illustrated embodiment of battery pack 100 includes twenty interconnected cylindrically shaped battery cells 105; however, it should be appreciated that battery pack 100 may include more or less interconnected battery cells 105 having different physical shapes and bound into different shaped packages than the single layer rectangular package illustrated in FIG. 1A.

[0013] In one embodiment, heating element 115 is implemented as a resistive element that is embedded between and/or around battery cells 105 to provide distributed heat throughout battery pack 110. Heating element 115 may be implemented as a single long strand that is weaved throughout battery pack 100 and coupled at either end to power regulator 120. Alternatively, heating element 115 may be implemented as a number of parallel or series coupled resistive elements.

[0014] FIGS. 1A and 1B illustrate a perpendicular weave pattern embodiment where heating element 115 is weaved along a path that runs substantially perpendicular to a primary axis 135 (e.g., axis of symmetry running through a radial center) of the cylindrically shaped battery cells 105. In the illustrated embodiment, heating element 115 weaves back and forth between the battery cells 105, following a corrugated or undulating path through interior portions of battery pack 100, and around the outer perimeter edges of battery pack 100. In one embodiment, the heating element 115 traverses several repeating loops or courses through battery pack 100 with each loop offset vertically to evenly heat the volume occupied by battery cells 105.

[0015] The interweaving of heating element 115 between and around battery cells 105 also serves to provide the mechanical support to hold heating element 115 in place. In other words, in some embodiments, heating element 115 does not have an independent support structure other than the

battery cells themselves. Battery cells **105** are physically secured together by binder **110**. Binder **110** may be implemented using shrink wrap, a strap, a band, or other binding material. Thus, binder **110** provides mechanical support to rigidly hold battery cells **105** while the weave of heating element **115** around battery cells **105** provides the mechanical support to hold heating element **115** in place.

[0016] Although FIGS. 1A and 1B illustrate a perpendicular weave pattern, heating element **115** may be interwoven throughout battery pack **100** amongst battery cells **105** using a variety of weave patterns to achieve distributed heat. In some embodiments, the weave pattern achieves a substantially uniform coverage to provide uniform heating. However, in other embodiments, it may be desirable to use a non-uniform weave pattern to concentrate heating to certain localities, such as additional winding around the outer perimeters (e.g., sides, top, bottom), if a given side is exposed to lower temperatures. FIGS. 2A & 2B illustrate of a battery pack **200** with a heating element **215** weaved according to a parallel weave pattern. As illustrated, heating element **215** is weaved around each battery cell **105** such that it runs substantially parallel to primary axis **135** along the sides of each battery cell **105** and loops over the top or under the bottom between adjacent battery cells **105**. Of course, other weave patterns and distributions may be implemented using one long continuous heating element **215** or several heating elements **215** connected in series or parallel with power regulator **120**.

[0017] In one embodiment, heating element **115** (or **215**) is a resistive wire coated with an electrical insulator to reduce the possibility of electrical shorts with battery cells **105**. The gauge of the resistive wire may be selected according to allowable wattage per length, desired wattage, operating voltage/current need to achieve the desired amount of heating, and/or wire length. The wire may have a circular cross-section, elongated cross-section, flat/rectangular cross-section (e.g., foil strip), or otherwise. Heating element **115** is operated using low operational temperatures relative to typical heating filaments. This low watt density operation is sufficient to heat battery pack **100**, since the heating element **115** is weaved around and throughout battery pack **100** to provide a distributed even heating solution. This is in contrast to localized or point source heaters that use high watt density heating elements that operate at high temperatures. This low watt density solution permits heating element **115** to be coated with an electrical insulator, such as plastic, that does not melt at operational temperatures of the heating element. For example, the coating may be a heat resistant insulation such as ethylene tetrafluoroethylene (ETFE), polytetrafluoroethylene (PTFE), perfluoroalkoxy alkanes (PFA), polyimide, or otherwise.

[0018] The heating system of battery pack **100** includes cooperative operation between temperature sensor **130**, temperature controller **125**, power regulator **120**, and heating element **115**. In one embodiment, power regulator **120** along with temperature controller **125** and temperature sensor **130** provide feedback control to maintain a temperature of battery pack **100** within a defined operating temperature when battery pack **100** is operated in a cold ambient environment. The absence of an independent mechanical housing or enclosure for heating element **115** provides a lightweight, low power heating solution that is well-suited for weight sensitive applications such as aerial vehicles, though this heating solution is also suitable for other applications including terrestrial

vehicles, water vehicles, or otherwise. Furthermore, the omission of an independent enclosure of heating element **115** reduces costs. The distributed low power operational regime of heating element **115** improves the heating uniformity while also improving reliability since delicate, high temperature heating filaments are avoided.

[0019] FIG. 3 is a flow chart illustrating a process **300** for maintaining a temperature of battery pack **100** within an operating range, in accordance with an embodiment of the disclosure. Process **300** is described with reference to battery pack **100**, but is equally applicable to battery pack **200**. The order in which some or all of the process blocks appear in process **300** should not be deemed limiting. Rather, one of ordinary skill in the art having the benefit of the present disclosure will understand that some of the process blocks may be executed in a variety of orders not illustrated, or even in parallel.

[0020] In a process block **305**, the heating system for battery pack **100** is enabled. The heating system may be enabled in response to a control signal input into temperature controller **125** or based upon a low temperature reading output from temperature sensor **130**. In one embodiment, temperature controller **125** is implemented with a microcontroller that includes operational logic implemented in software/firmware, hardware, or a combination of both. In one embodiment, temperature controller **125** is an analog control circuit. In one embodiment, temperature sensor **130** is implemented using one or more thermistors embedded within battery pack **100**. Other temperature sensor technologies (e.g., thermocouple, quartz thermometer, resistance temperature detector (RTD), silicon bandgap temperature sensor, infrared thermometer, etc.) may be used as well.

[0021] In a process block **310**, temperature controller **125** acquires a temperature reading based upon a sensor signal output from temperature sensor **130**. If the reading falls below a specified operating range (decision block **315**), then temperature controller **125** outputs a control signal to power regulator **120** to increase the power delivered to heating element **115** (process block **320**). If the reading is above the specified operating range (decision block **315**), then temperature controller **125** outputs a control signal to power regulator **120** to decrease the power delivered to heating element **115** (process block **325**). If the reading is within the specified operating range (decision block **315**), then temperature controller **125** instructs power regulator **120** to maintain a constant power output. While FIG. 3 illustrates power control logic with a hysteresis loop, other simpler control algorithms (e.g., single ON/OFF threshold) or more complex control algorithms (e.g., PID algorithms) may be implemented by temperature controller **125**.

[0022] In one embodiment, power regulator **120** is a voltage controlled current source that controls the current through heating element **115** in response to a voltage control signal output from temperature controller **125**. In other embodiments, power regulator **120** may be implemented as an adjustable voltage source or otherwise. Power regulator **120** may control the power delivery into heating element **115** via increasing/decreasing the magnitude of an applied current or voltage, modulating a duty cycle of a fixed current/voltage source (e.g., pulse width modulation), or otherwise.

[0023] FIG. 4 illustrates an example vehicle that includes sub-systems powered by a battery pack, such as battery pack **100** or **200**, which is heated using embodiments of the techniques described above. The low power density, light weight

solution of the heating systems described above is well suited for aerial vehicles, such as an unmanned air vehicle (UAV).

[0024] In the illustrated embodiment, an aerial vehicle **400** includes a narrow, elongated fuselage **421** coupled to one or more wings **422** or other lifting surfaces. The aerial vehicle **400** can further include a stabilizer boom or empennage **424** carrying one or more stabilizers **423** that provide stability and control functions. The aerial vehicle **400** can still further include a propulsion system **426**, which can in turn include one or more nacelles **429**, each of which houses an electric motor **428** that powers a corresponding propeller **427**.

[0025] UAVs have proliferated recently because they can perform a variety of valuable tasks without incurring the costs and risks associated with a piloted aircraft. Typical UAV tasks include public safety and communication tasks. However, one drawback with many existing UAVs is that they have limited endurance and can accordingly remain on-station for only a limited period of time. As a result, it can be difficult to provide the foregoing tasks consistently for an extended period of time.

[0026] One approach to addressing the foregoing endurance issues is to provide solar power to a UAV, potentially enabling the UAV to remain on-station for extended periods of time because it generates the power it requires while in flight. Aerial vehicle **400** includes one or more battery packs to power on-board electrical sub-systems (e.g., propulsion systems **426**, actuators for adjusting flight surfaces, communication systems, navigation system, control systems, etc.). Solar cells **410** are coupled to the battery packs to provide continuous charging when solar energy is incident upon their surfaces.

[0027] Aerial vehicle **400** can be particularly configured to fly at very high altitudes (e.g., 65,000 ft) under the power produced by its solar cells **410**. At very high altitudes, extreme cold conditions exist, which can detrimentally impact the performance of the battery packs. As such, the heating systems described above serve to efficiently maintain desired operational temperatures in a durable and lightweight form factor.

[0028] The processes explained above are described in terms of computer software and hardware. The techniques described may constitute machine-executable instructions embodied within a tangible or non-transitory machine (e.g., computer) readable storage medium, that when executed by a machine will cause the machine to perform the operations described. Additionally, the processes may be embodied within hardware, such as an application specific integrated circuit ("ASIC") or otherwise.

[0029] A tangible machine-readable storage medium includes any mechanism that provides (i.e., stores) information in a non-transitory form accessible by a machine (e.g., a computer, network device, personal digital assistant, manufacturing tool, any device with a set of one or more processors, etc.). For example, a machine-readable storage medium includes recordable/non-recordable media (e.g., read only memory (ROM), random access memory (RAM), magnetic disk storage media, optical storage media, flash memory devices, etc.).

[0030] The above description of illustrated embodiments of the invention, including what is described in the Abstract, is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustra-

tive purposes, various modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize.

[0031] These modifications can be made to the invention in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification. Rather, the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

What is claimed is:

1. An apparatus, comprising:
 - a battery pack including a plurality of battery cells electrically interconnected to each other;
 - a binding coupled to mechanically hold the battery cells physically together; and
 - a heater system coupled to the battery pack to heat the battery cells, the heater system including:
 - a heating element interweaved between the battery cells of the battery pack, wherein the weaving of the heating element between the battery cells provides mechanical support to the heating element; and
 - a heating controller electrically coupled to the heating element to drive current through the heating element and provide heat to the battery cells of the battery pack.
2. The apparatus of claim 1, wherein the heating element comprises a resistive wire coated with an electrical insulator.
3. The apparatus of claim 2, wherein the electrical insulator comprises a plastic that does not melt at operational temperatures of the heating element.
4. The apparatus of claim 1, further comprising a plurality of heating elements interweaved between the battery cells of the battery pack, the plurality of heating elements each coupled to the heating controller to provide distributed heat throughout the battery pack.
5. The apparatus of claim 1, wherein the heating element is weaved adjacent to each of the battery cells to provide heat to each of the battery cells of the battery pack.
6. The apparatus of claim 5, wherein the heating element is weaved multiple times at least partially around or between each of the battery cells to provide distributed heat to each of the battery cells of the battery pack.
7. The apparatus of claim 6, wherein the battery cells comprise cylindrically shaped battery cells and the heating element is weaved along a path that runs substantially perpendicular to primary axes of each of the battery cells.
8. The apparatus of claim 6, wherein the battery cells comprise cylindrically shaped battery cells and the heating element is weaved along a path that periodically runs substantially parallel to primary axes of each of the battery cells.
9. The apparatus of claim 1, wherein the battery cells comprise cylindrically shaped lithium ion battery cells.
10. The apparatus of claim 1, wherein the heating controller comprises:
 - a temperature sensor embedded within the battery pack;
 - a power regulator coupled to the heating element to drive power into the heating element; and
 - a temperature controller coupled to receive a sensor signal from the temperature sensor and to generate a control signal responsive to the sensor signal, the control signal coupled to the power regular to control an amount of power delivered into the heating element based at least in part on the sensor signal.

11. The apparatus of claim 1, wherein the heating element does not have an independent mechanical support from the battery cells or the binding to hold the heating element in an interweaved pattern between the battery cells.

12. The apparatus of claim 11, wherein the binding comprises shrink wrap.

13. A heated battery pack system, comprising:

a battery pack including a plurality of battery cells electrically interconnected to each other;

a binding coupled to mechanically hold the battery cells physically together; and

a heater system coupled to the battery pack to heat the battery cells, the heater system including:

a heating element interweaved between the battery cells of the battery pack, wherein the weaving of the heating element between the battery cells provides fixed mechanical support to the heating element; and

a heating controller electrically coupled to the heating element to drive current through the heating element and provide heat to the battery cells of the battery pack,

wherein the heating element does not have an independent mechanical support from the battery cells or the binding to hold the heating element interwoven between the battery cells.

14. The heated battery pack system of claim 13, wherein the binding comprises shrink wrap.

15. The heated battery pack system of claim 13, wherein the heating element comprises a resistive wire coated with an electrical insulator.

16. The heated battery pack system of claim 13, further comprising a plurality of heating elements interweaved between the battery cells of the battery pack, the plurality of heating elements each coupled to the heating controller to provide distributed heat throughout the battery pack.

17. The heated battery pack system of claim 13, wherein the heating element is weaved multiple times at least partially around or between each of the battery cells to provide distributed heat to each of the battery cells of the battery pack.

18. The heated battery pack system of claim 13, wherein the battery cells comprise cylindrically shaped battery cells and the heating element is weaved along a path that runs substantially perpendicular to primary axes of each of the battery cells.

19. The heated battery pack system of claim 13, wherein the battery cells comprise cylindrically shaped battery cells and the heating element is weaved along a path that periodically runs substantially parallel to primary axes of each of the battery cells.

20. The heated battery pack system of claim 13, wherein the heating controller comprises:

a temperature sensor embedded within the battery pack;

a power regulator coupled to the heating element to drive power into the heating element; and

a temperature controller coupled to receive a sensor signal from the temperature sensor and to generate a control signal responsive to the sensor signal, the control signal coupled to the power regular to control an amount of power delivered into the heating element based at least in part on the sensor signal.

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