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Dodman

(10) **Patent No.: US 12,384,490 B2**
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(54) **BATTERY WHEEL ASSEMBLY**

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(22) Filed: **Aug. 24, 2022**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**

B62M 6/90 (2010.01)
B62J 43/13 (2020.01)

(Continued)

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

CPC ***B62M 6/90*** (2013.01); ***B62J 43/13*** (2020.02); ***B62J 43/20*** (2020.02); ***B62M 6/45*** (2013.01); ***B62M 6/65*** (2013.01); ***H01M 10/425*** (2013.01); ***H01M 50/213*** (2021.01); ***H01M 50/249*** (2021.01); ***H01M 50/264*** (2021.01); ***H01M 50/271*** (2021.01); *H01M 2010/4271* (2013.01); *H01M 2220/20* (2013.01)

(58) **Field of Classification Search**

CPC ... B62M 6/90; B62M 6/45; B62M 6/65; B62J 43/20; B62J 43/13; H01M 50/249; H01M 50/264; H01M 50/213; H01M 10/425; H01M 2010/4271; H01M 2220/20; H02M 5/271

USPC 180/65.51

See application file for complete search history.

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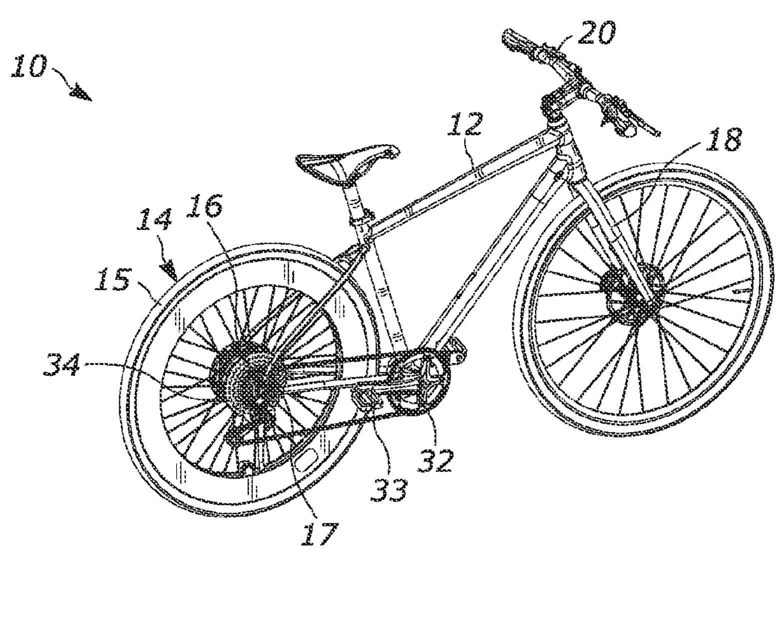
(57) **ABSTRACT**

A battery wheel assembly is disclosed that includes a wheel having an axle for securement to a vehicle, the axle having a central axle axis extending therethrough, a wheel rim and interconnected wheel hub rotatable about the central axle axis. The battery wheel assembly further includes a battery pack that includes a carrier wreath secured to the wheel rim, and a plurality of battery cells electrically interconnected and secured to the carrier wreath.

24 Claims, 18 Drawing Sheets



(51) **Int. Cl.**

B62J 43/20	(2020.01)
B62M 6/45	(2010.01)
B62M 6/65	(2010.01)
H01M 10/42	(2006.01)
H01M 50/213	(2021.01)
H01M 50/249	(2021.01)
H01M 50/264	(2021.01)
H01M 50/271	(2021.01)

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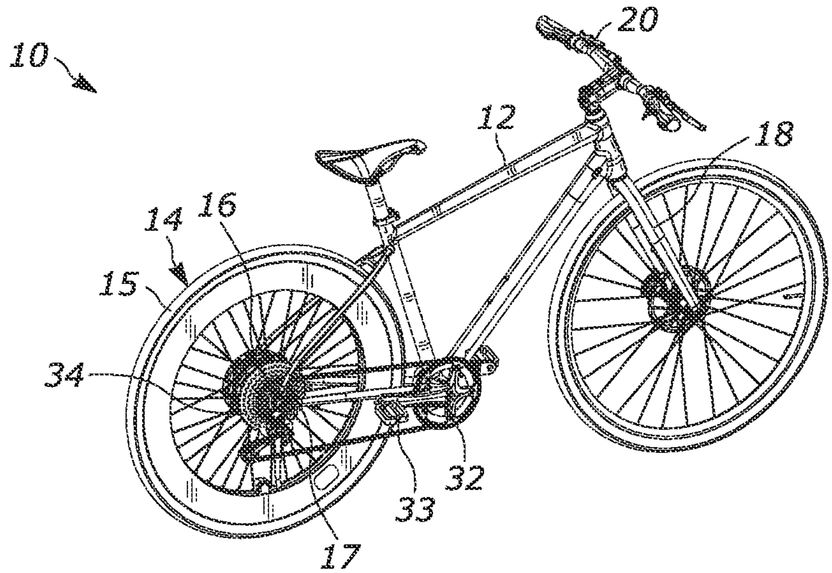
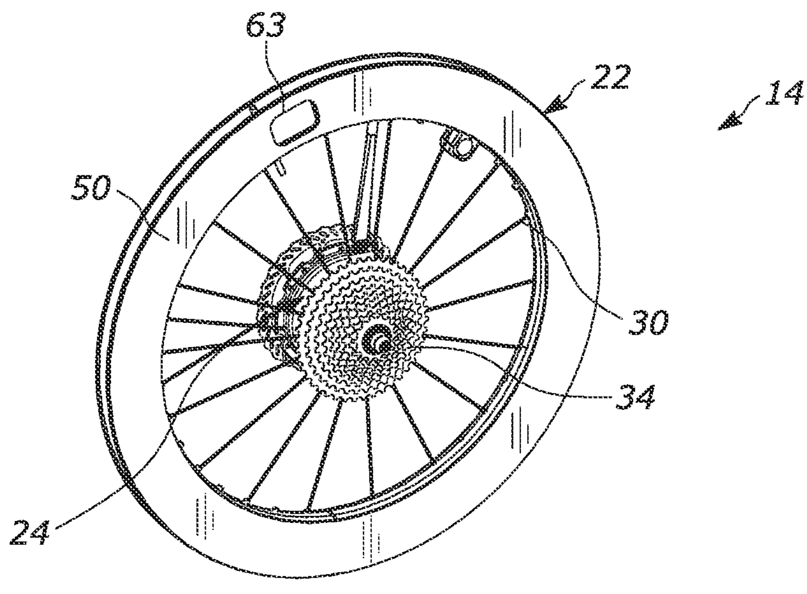


FIG. 1



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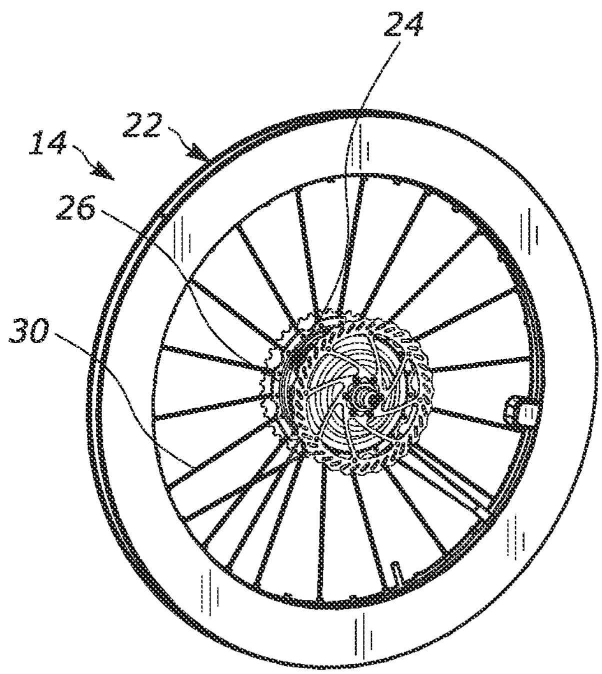

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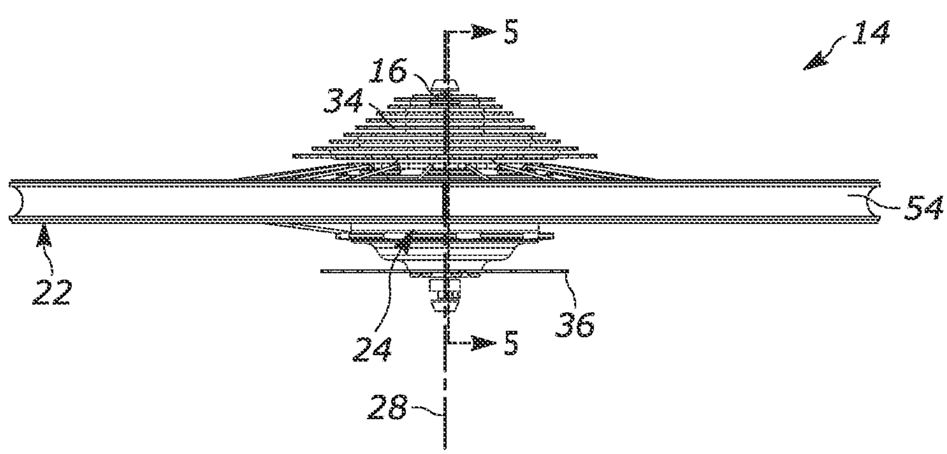

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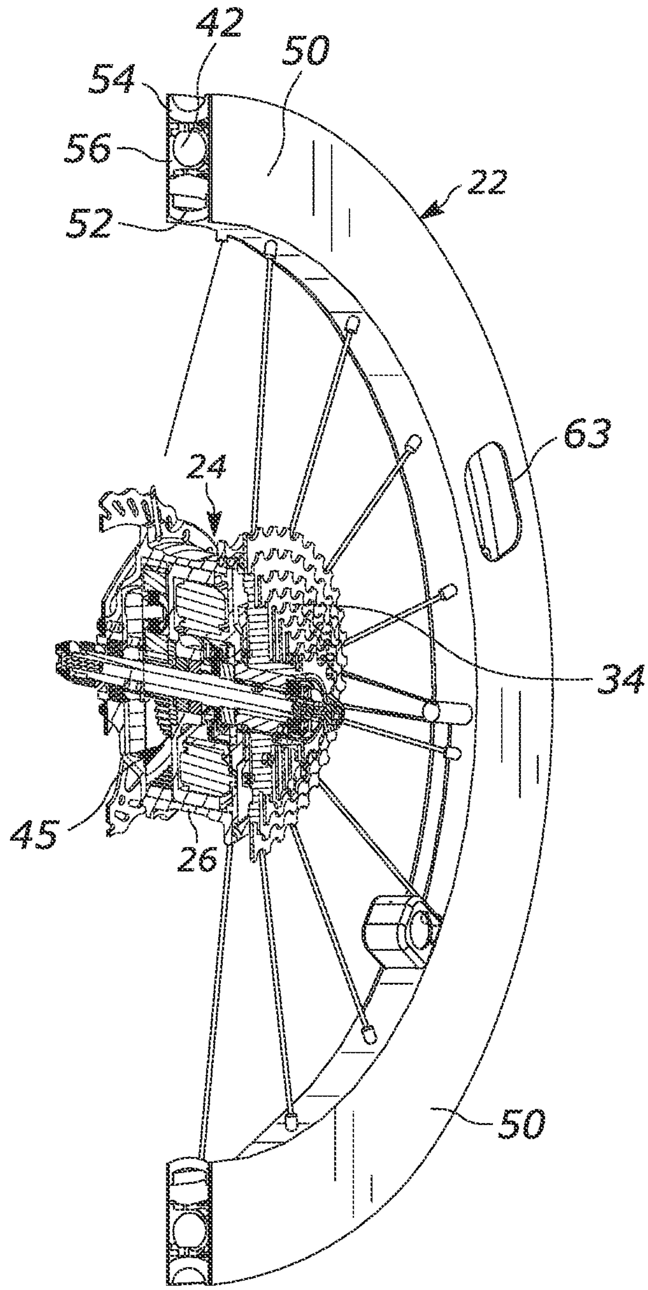

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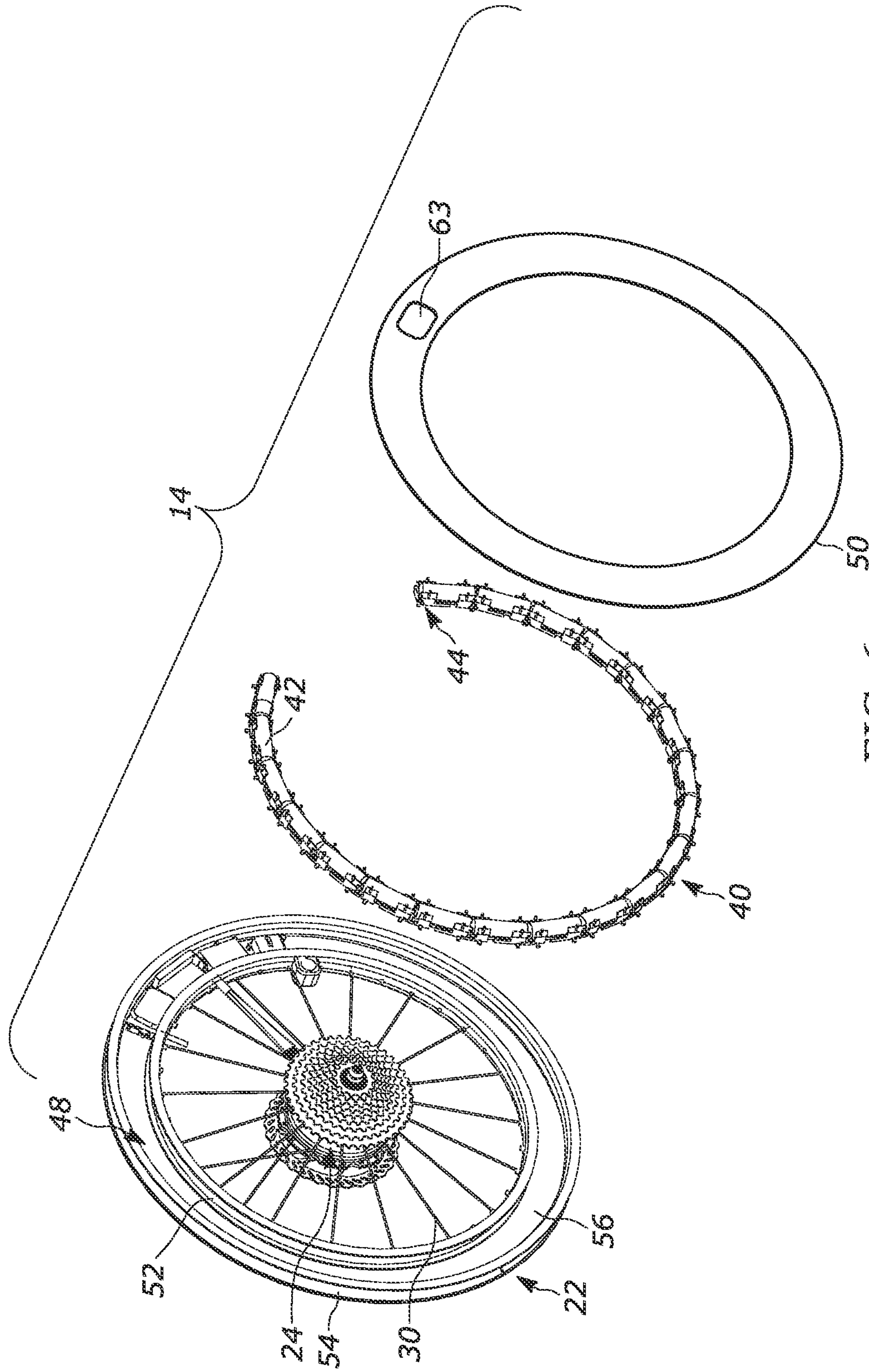

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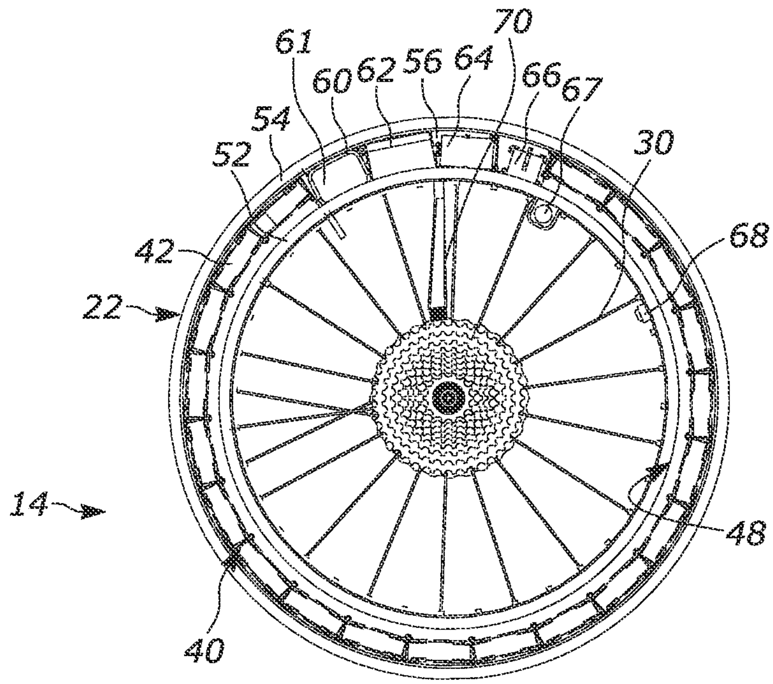

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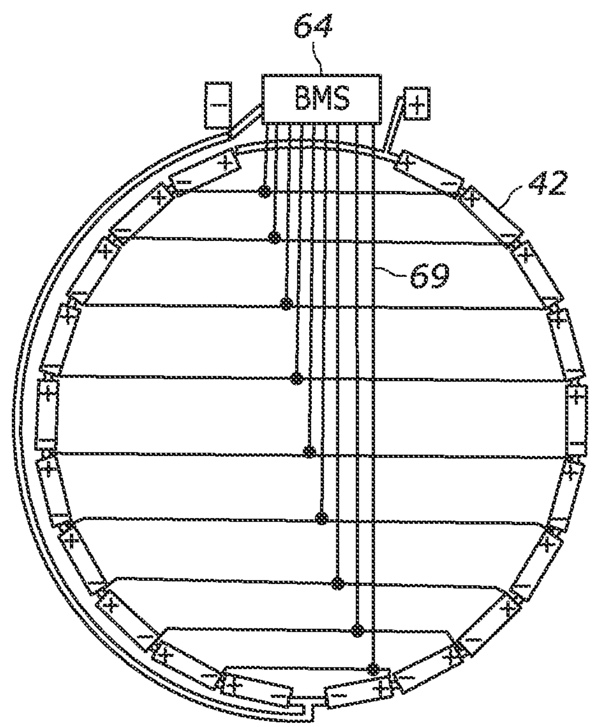

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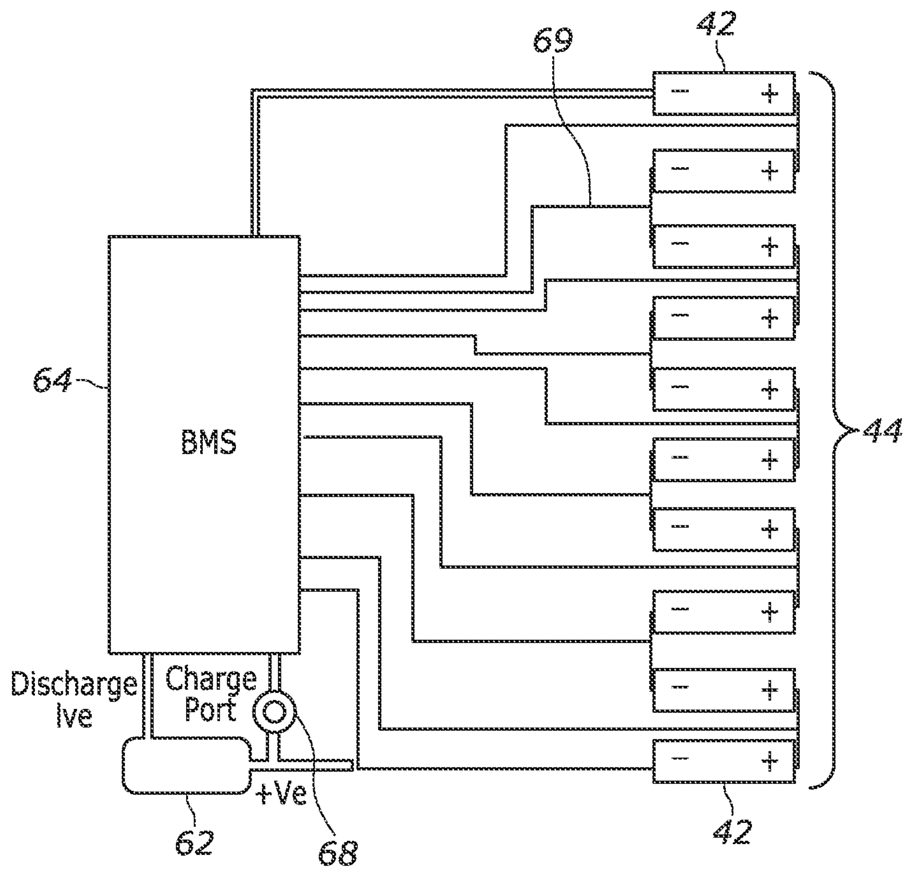

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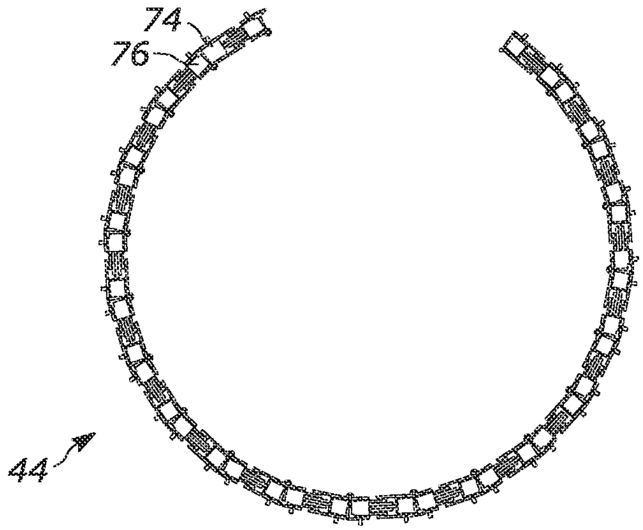

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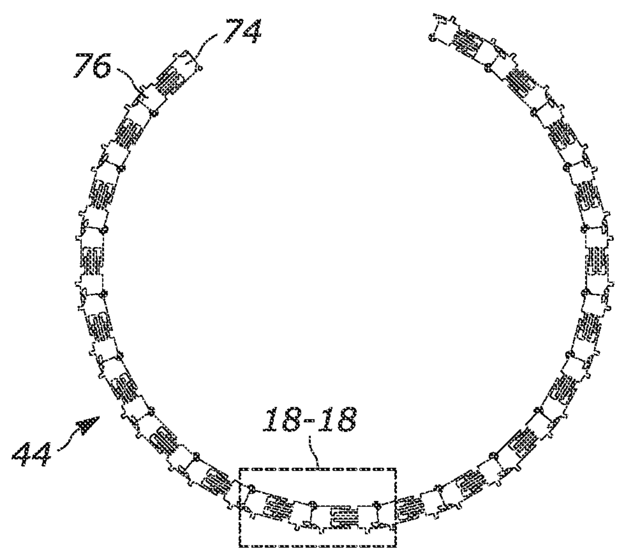

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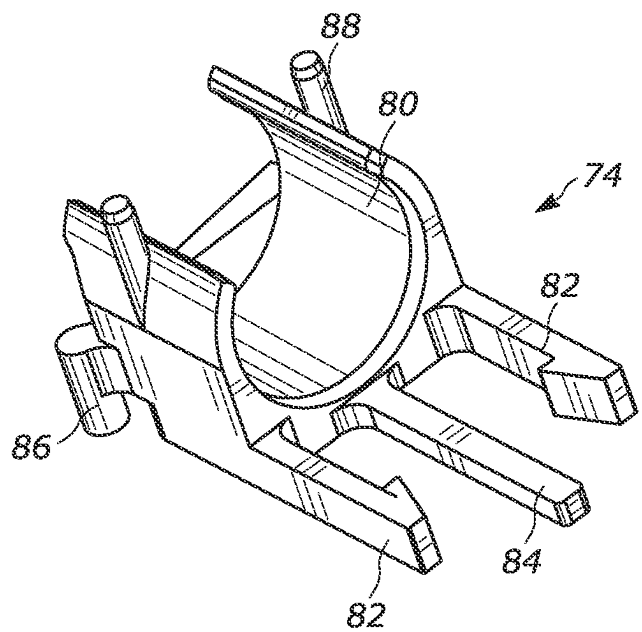

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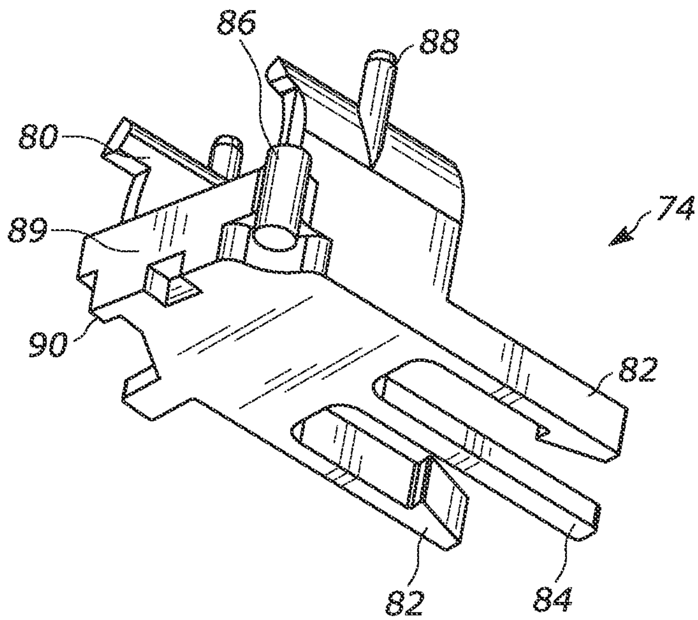

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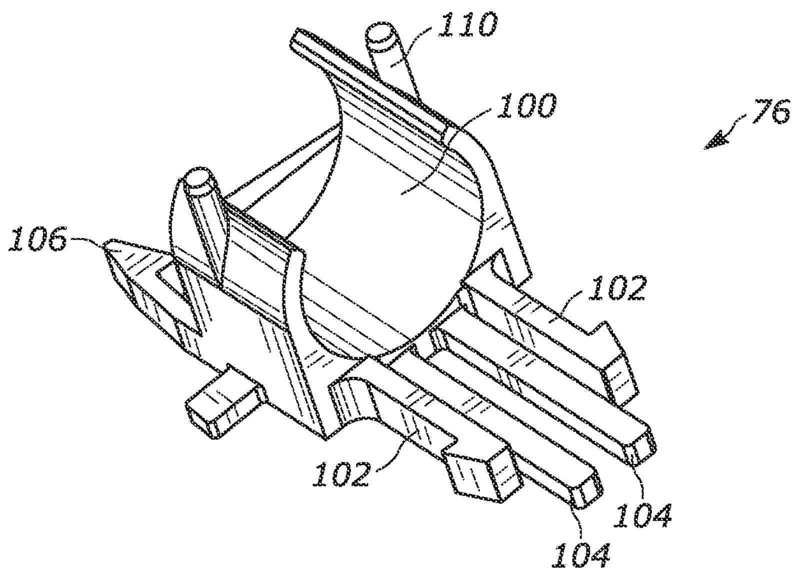
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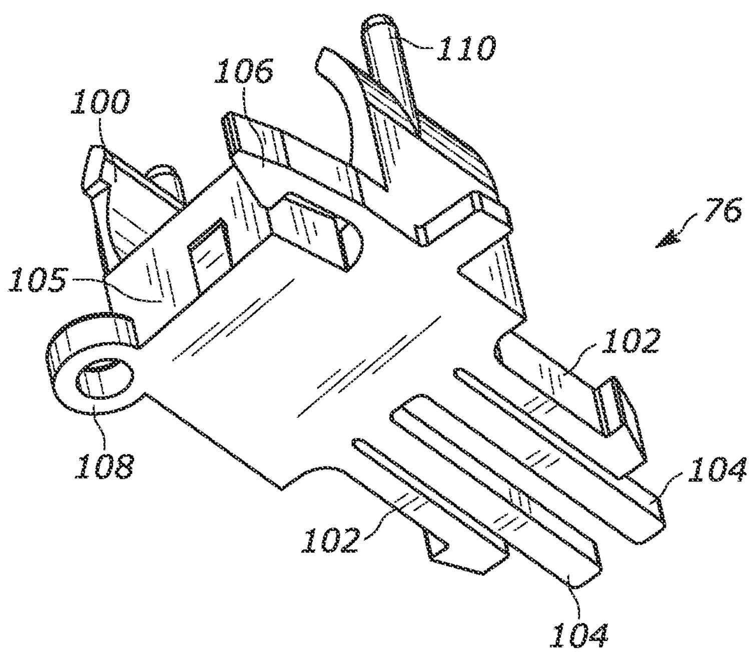
FIG. 14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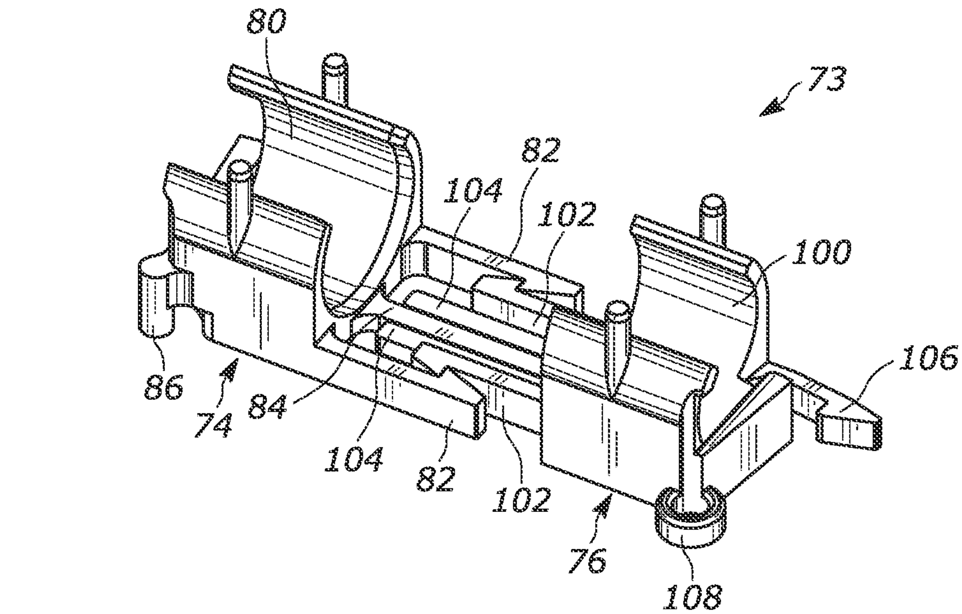
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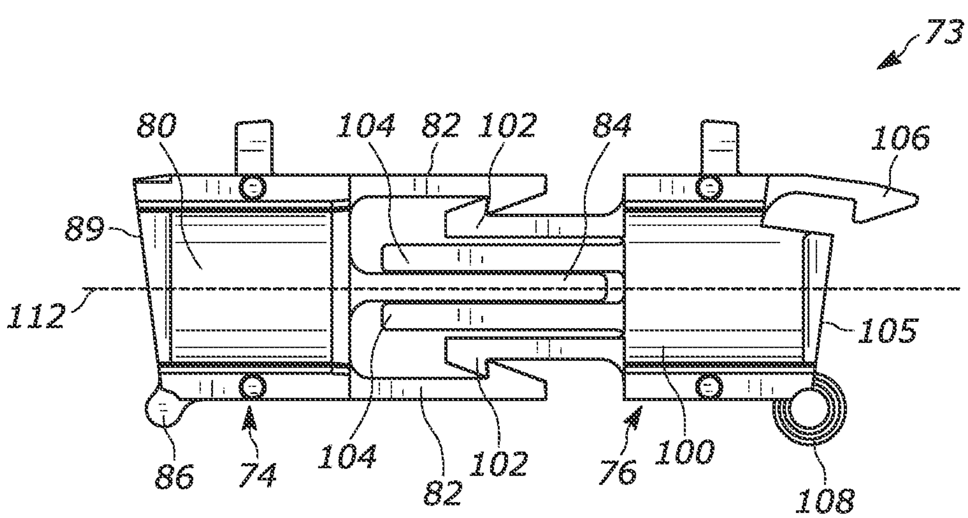
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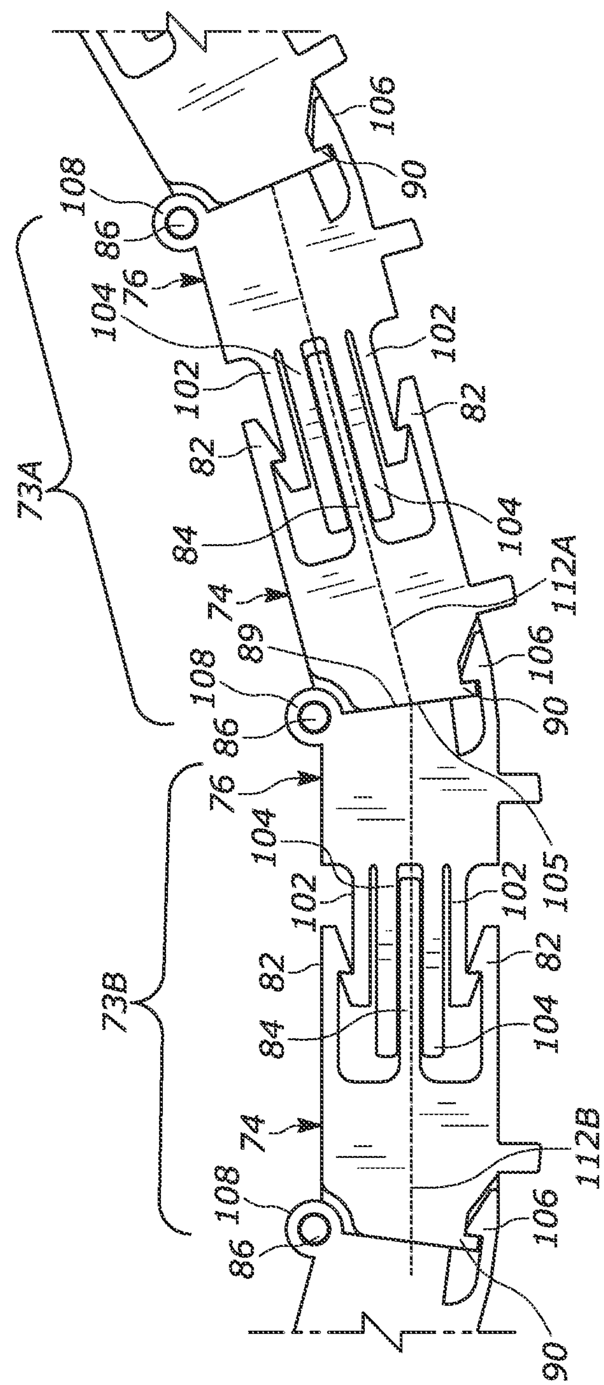

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FIG. 18

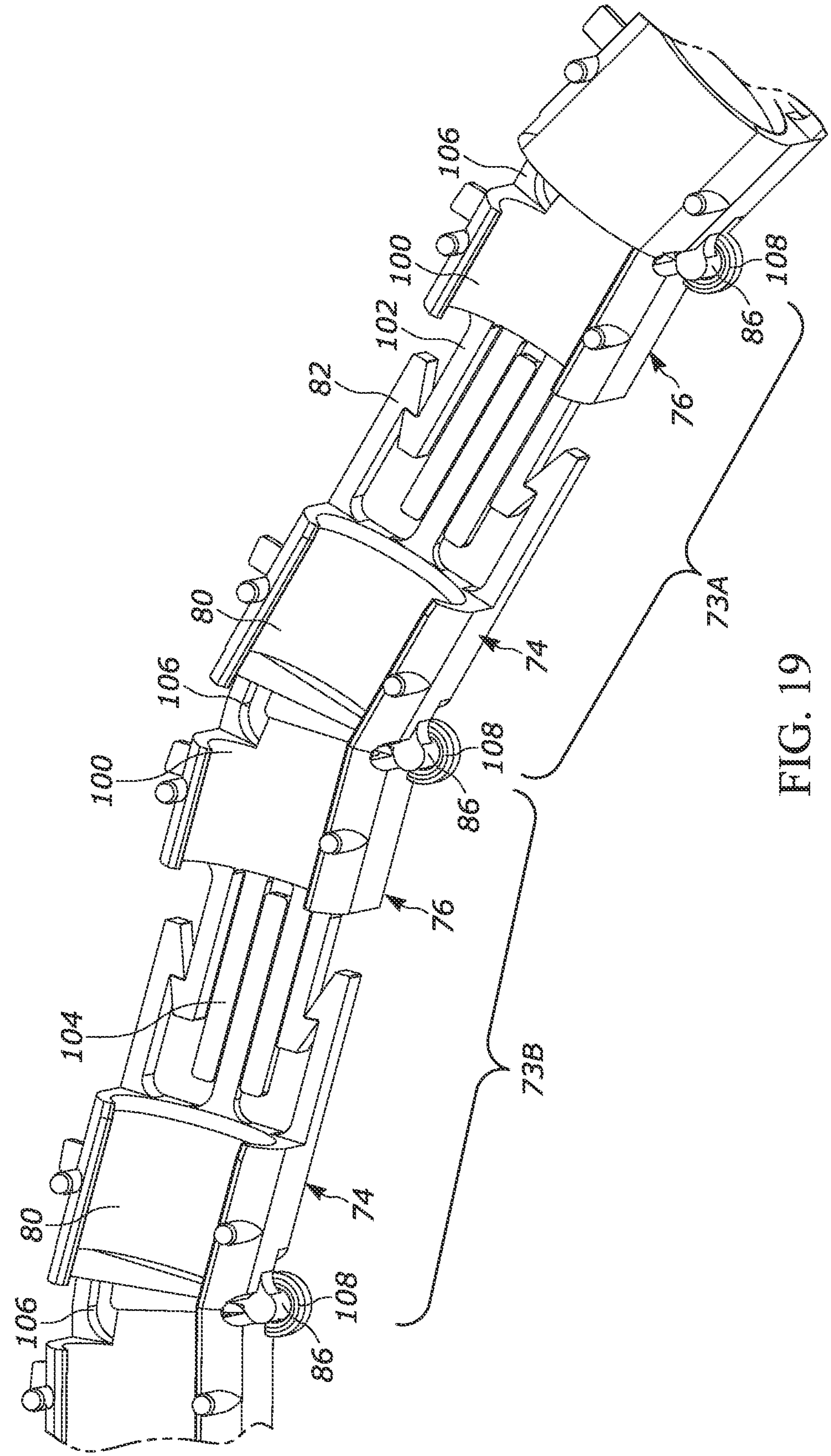
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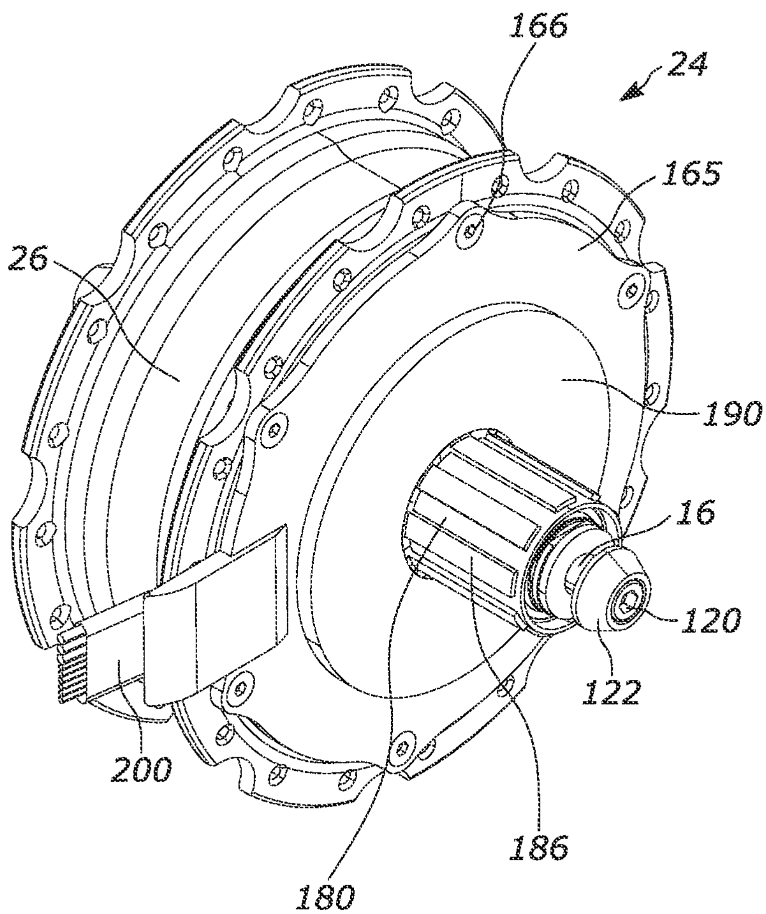
FIG. 19



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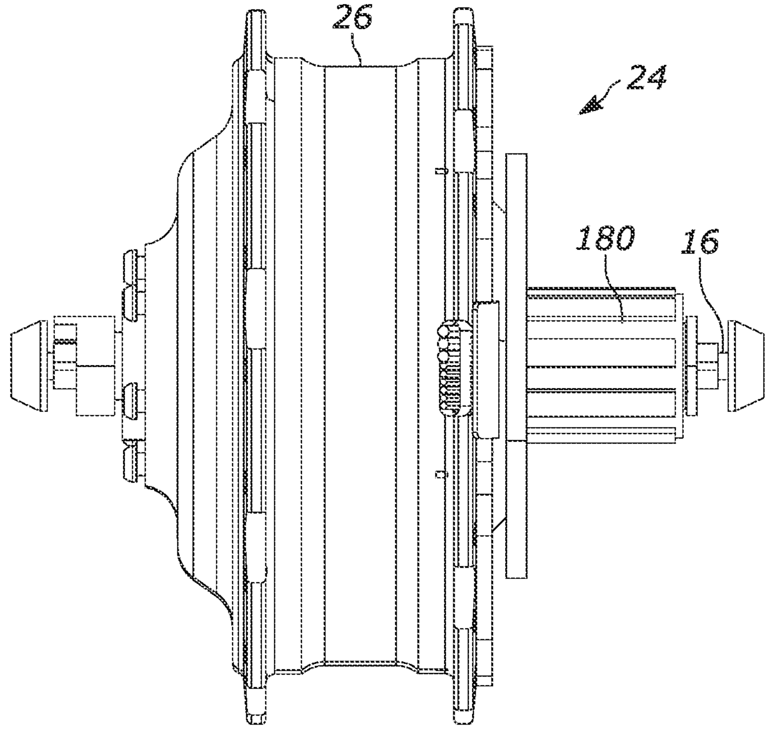

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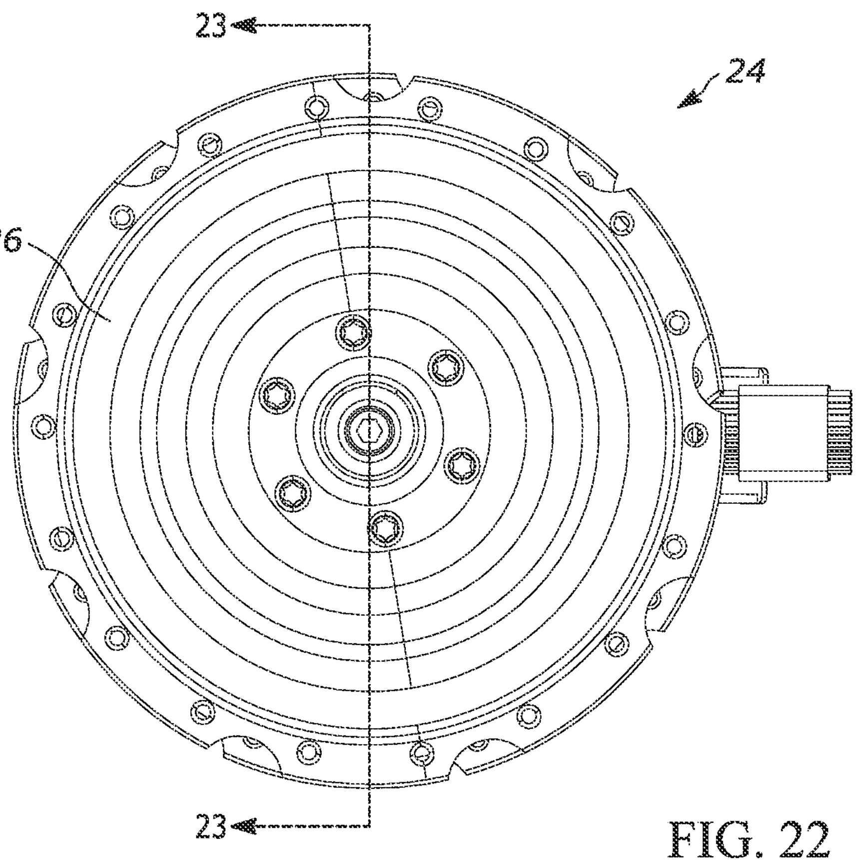

FIG. 22

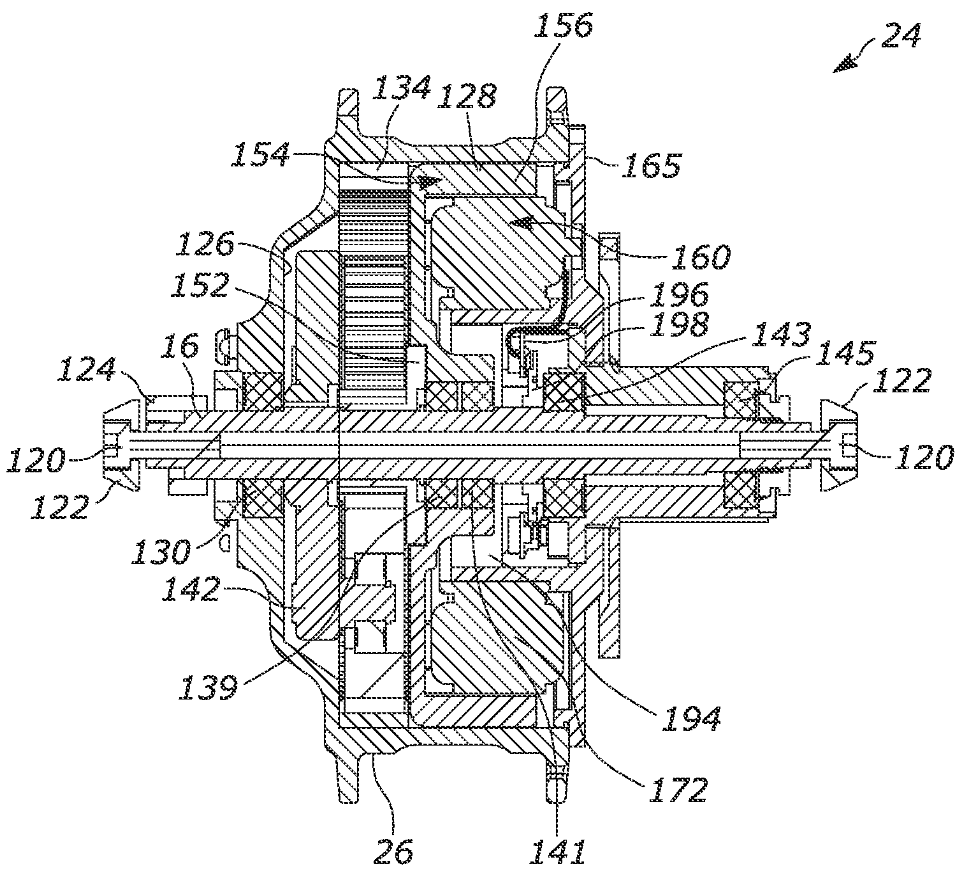
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FIG. 23

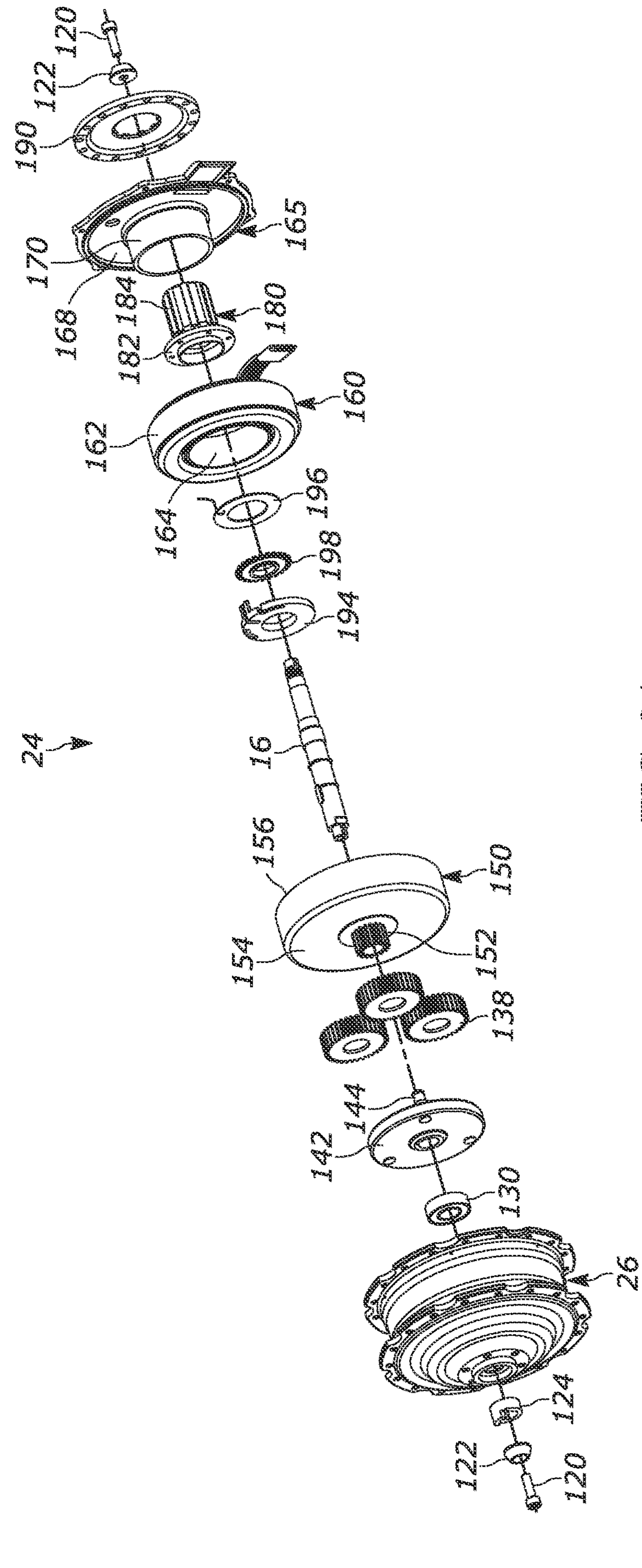
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FIG. 24

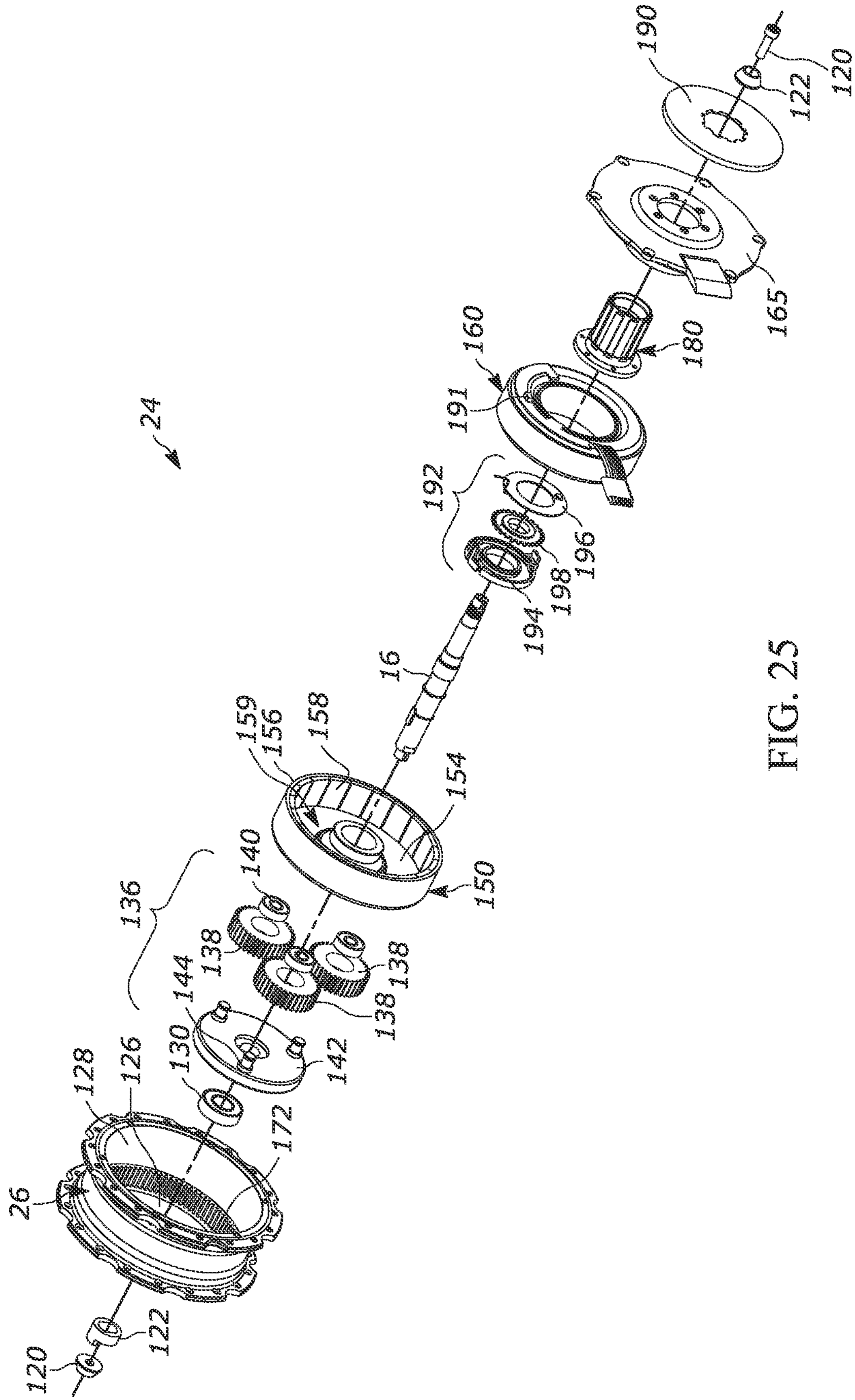
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FIG. 25

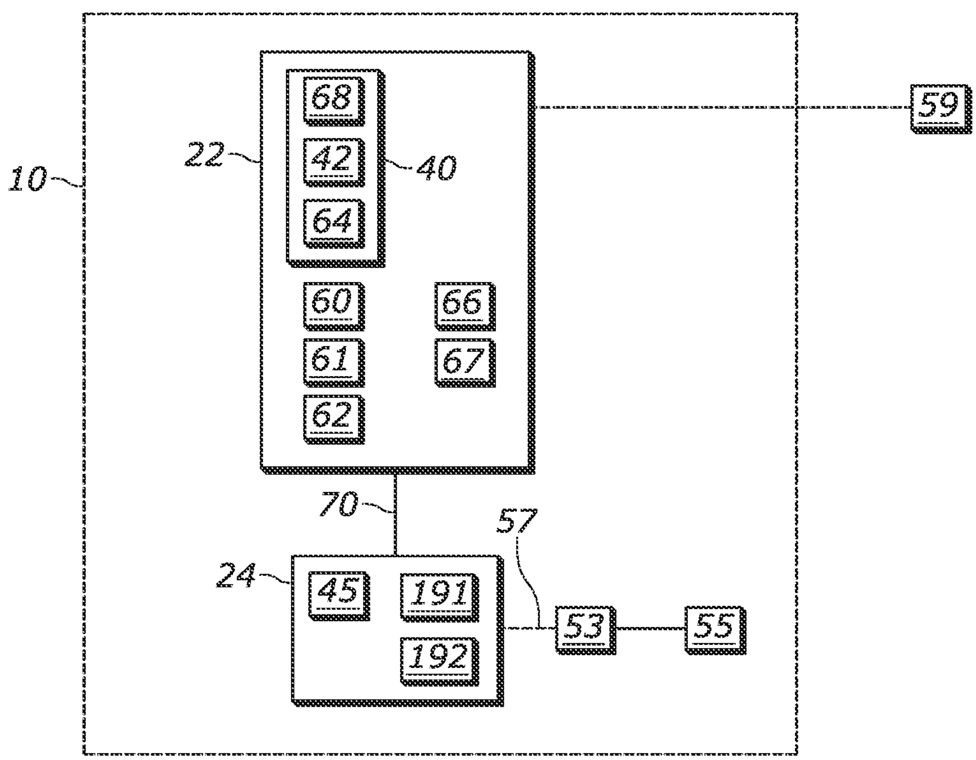

FIG. 26

BATTERY WHEEL ASSEMBLY

CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of and priority to U.S. Provisional Patent Application Ser. No. 63/260,547 filed Aug. 25, 2021, which is incorporated herein by reference in its entirety for all purposes.

FIELD OF THE INVENTION

The invention relates generally to wheel components. More particularly, the invention relates to wheel assemblies used in vehicles.

BACKGROUND

Electric bicycles use electric motors to provide powered propulsion assist to a user. The motor is typically mounted in the crank region at the base of the main frame, but can also be mounted in a hub of the front wheel or rear wheel. Power for the motor comes from one or more battery cells. With a crank region motor, the battery cells are typically mounted on or partially/completely in the frame of the bicycle to provide a convenient connection to the motor, whereas a hub mounted motor may be wired to a frame mounted battery or a battery mounted inside the hub itself adjacent to the motor. Unfortunately, mounting the battery in the hub can be problematic, for example, the battery is housed with and mounted directly adjacent to a motor, which generates significant heat during operation. The battery absorbs the motor heat, which reduces efficiency of the battery, and along with the battery's own generated heat that is trapped in the hub, causes diminishing battery performance. In addition, the hub itself must be large enough to accommodate both the battery and the motor.

Typically, electric bicycle hub motors use a fixed stator where the stator is fixed to a non-rotating axle attached to the bicycle frame. Rotation of the wheel is then sensed between the rotating hub shell and the axle—by means of a magnet in the hub shell and a Hall-effect sensor or reed switch mounted to the stator/axle. In addition, electric bikes, such as mid-drive electric bicycles typically include a rotation sensor about the wheel to send feedback via wiring to a frame-mounted controller to measure rotation between the axle and the hub shell. In most mid-drive electric bicycles, the Hall-effect sensor is mounted on the chain stay of the frame and a magnet is mounted to a spoke. Many modern systems use a Hall-effect sensor mounted onto the inside of a disc side dropout and the disc brake rotor has a magnet attached to it.

BRIEF SUMMARY

In at least some embodiments, a battery wheel assembly is provided that includes: a wheel comprising: an axle for securement to a vehicle, the axle having a central axle axis extending therethrough; a wheel rim; and a wheel hub interconnected with the wheel rim and rotatable about the central axle axis; and a battery pack comprising: a carrier wreath secured to the wheel rim; and a plurality of battery cells electrically interconnected and secured to the carrier wreath.

Further embodiments of the invention are disclosed herein. The invention is generally described for use with a bicycle, although in additional embodiments, the technology

of the invention can be utilized in numerous wheel applications, including those noted herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are disclosed with reference to the accompanying drawings and are for illustrative purposes only. The invention is not limited in application to the details of construction or the arrangement of the components illustrated in the drawings. The invention is capable of other embodiments or of being practiced or carried out in other various ways.

FIG. **1** is a side perspective view of an exemplary bicycle.

FIG. **2** is a first side perspective view of the wheel of the bicycle of FIG. **1** with the tire removed for clarity.

FIG. **3** is a second side perspective view of the wheel of FIG. **2**.

FIG. **4** is a top view of the wheel of FIG. **2**.

FIG. **5** is a cross-sectional view of the wheel taken along line **5-5** of FIG. **4**.

FIG. **6** is a partial exploded view of the wheel of FIG. **2**.

FIG. **7** is a first side view of the wheel of FIG. **2**, with the cover plate removed for clarity.

FIG. **8** is a schematic of an exemplary wiring configuration for the battery pack and the BMS for the wheel of FIG. **7**.

FIG. **9** is a schematic of another exemplary wiring configuration for the battery pack, the BMS, and the motor controller for the wheel of FIG. **7**.

FIG. **10** is a first side view of the carrier wreath of the wheel of FIG. **6**, shown without the battery cells installed.

FIG. **11** is a second side view of the carrier wreath of FIG. **10**.

FIG. **12** is a top perspective view of a primary carrier of the carrier wreath of FIG. **10**.

FIG. **13** is a bottom perspective view of the primary carrier of FIG. **12**.

FIG. **14** is a top perspective view of a secondary carrier of the carrier wreath of FIG. **10**.

FIG. **15** is a bottom perspective view of the secondary carrier of FIG. **14**.

FIG. **16** is perspective view of a carrier link formed by coupling the primary carrier to the secondary carrier.

FIG. **17** is top view of the carrier link of FIG. **16**.

FIG. **18** is a close-up second side view of the carrier wreath taken at **18-18** of FIG. **11**.

FIG. **19** is a rotated view of the carrier wreath shown in FIG. **18**.

FIG. **20** is a perspective view of the wheel hub of FIG. **1**, shown removed from the bicycle.

FIG. **21** is a rear view of the wheel hub of FIG. **20**.

FIG. **22** is a side view of the wheel hub of FIG. **20**.

FIG. **23** is a cross-sectional rear view of the wheel hub taken along lines **23-23** of FIG. **22**.

FIG. **24** is a first perspective exploded view of the wheel hub of FIG. **20**.

FIG. **25** is a second perspective exploded view of the wheel hub of FIG. **20**.

FIG. **26** is a block diagram illustrating an exemplary system configuration for the bike of FIG. **1**.

DETAILED DESCRIPTION

Referring to FIG. **1**, a perspective view of an exemplary bicycle **10** is provided that includes a frame **12** coupled to a wheel **14** having a tire **15** (only shown in FIG. **1**, for clarity purposes) and an axle **16** that is securable to the frame **12**.

In at least some embodiments, the frame **12** is a one-piece frame (e.g., a hard-tail), while in other embodiments the frame **12** can include a main frame coupled with a rear frame portion that is translatable relative to the main frame (e.g., a soft-tail/full suspension). In at least some embodiments, the wheel **14** is a rear wheel that is secured by the axle **16** to, for example, one or more dropouts **17** extending from the main frame or rear frame portion, while in other embodiments, the wheel **14** can be a front wheel secured by the axle **16** to a front fork **18** interconnected with a pair of handlebars **20**.

Referring to FIGS. **2-5**, the wheel **14** includes a wheel rim **22** interconnected with a wheel hub **24**. The wheel hub **24** includes a hub shell **26** and is connected with the axle **16** to rotate about a central axle axis **28** of the axle **16**. The wheel rim **22** is interconnected to the wheel hub **24** by a plurality of spokes **30**, which can be provided in numerous shapes, sizes, and materials. The spokes **30** can take many forms including individual metal spokes, as well as spokes **30** that are integrated with the wheel rim **22** and the hub shell **26**, rather than a separately coupled structure. In at least some embodiments, the spokes **30** can be a singular disc-shaped extension that extends radially from the hub shell **26** (e.g., form a continuous wall therebetween).

The bicycle **10** further includes a pedal crank **32** that is coupled with the wheel hub **24** (e.g., via chain and sprockets, etc.), thereby allowing an operator of the bicycle **10** to rotate the wheel hub **24** via a pedaling action on pedals **33** coupled to the pedal crank **32**. In at least some embodiments, the wheel hub **24** can be coupled with a gear cassette **34** as further described below, as well as a brake disc **36** for engagement with a brake caliper (not shown) to provide a stopping force to the wheel **14**. In at least some embodiments, other types of braking can be provided such as, a rim brake, a drum brake, or solely regenerative braking from the motor as is typical with electric (stand up/kick) scooters.

Referring to FIGS. **5** and **6**, wheel **14** is shown in cross-sectional and partially exploded views. The wheel **14** further includes an exemplary battery pack **40** that includes a plurality of battery cells **42** electrically coupled together and secured to a carrier wreath **44**, wherein the battery pack **40** is at least indirectly electrically coupled to a hub motor **45** used to provide a rotational force to the wheel **14**. In at least some embodiments, the battery pack **40** is sized and shaped to fit in a battery compartment **48** formed in the wheel rim **22**, wherein the battery compartment **48** is closable by a removable cover plate **50** sized to generally cover the opening exposing the battery compartment in the wheel rim **22**. Although in some embodiments the battery compartment **48** is a continuous compartment, in at least some embodiments, the battery compartment **48** can include multiple dividers separating adjacent portions thereof, such that the battery compartment **48** includes a plurality of divided compartments collectively forming the battery compartment. The cover plate **50** can in at least some embodiments, be a generally planar ring-shape, while in other embodiments other shapes and sizes, including various curvatures can be provided to at least in part, close or at least partially close the battery compartment **48**. In at least some embodiments, the battery compartment **48** is situated inside the wheel rim **22** and outside of the hub shell **26** (e.g., for a typical spoked rim), while in other embodiments the wheel rim **22** can be formed with the hub shell **26** as noted above.

The battery compartment **48** can take many forms and is sized and shaped to house the battery pack **40** within the wheel rim **22**, wherein in at least some embodiments, it is bounded by an inner ring **52**, an outer ring **54**, a rim sidewall **56**, and the cover plate **50**, while in other embodiments, the battery compartment **48** can include more or less walls or wall portions. In at least some embodiments, the outer ring **54** and inner ring **52** are formed separately and then secured (e.g., welding, adhesive bonding, mechanical fasteners, etc.) to the rim sidewall **56**, where in at least some embodiments, the rim sidewall **56** is shaped similar to the cover plate **50** (e.g., generally planar ring-shaped), while in other embodiments, the outer ring **54**, inner ring **52**, and rim sidewall **56** are integrally formed, while in still further embodiments, other configurations of forming and assembly can be used to provide wheel rim **22** having a desired strength and size. In addition, cover plate **50** can be secured at least indirectly to the outer ring **54** and/or inner ring **52** using various fastening methods, and as such can be removable for servicing, part replacement, etc., or permanently attached. Such fastening methods can include, for example, any combination of friction stir welded, ultrasonic welded, diffusion bonded, laser welded, laser brazed, adhesive bonding, film adhesive (high strength thin double-sided tape), heat activated adhesive that can unbonded at a temperature safe for the battery cells—for servicing, bolts, nuts, pins, split pins, roll pins, thread rolled—flow drilled holes, etc. In at least some embodiments, the fastening method can include threaded inserts and bolts or rivets (e.g., "blind" one sided pop rivets), and if the wheel rim **22** and cover plate **50** are composite—they can be "over wrapped" with composite (a layer of composite, such as glass fiber or CFRP woven tape with epoxy resin that is applied onto and over the edge of the cover plate and onto the wheel rim.

The wheel rim construction can be configured to provide the opportunity to replace an internal element or the battery pack either using bolts to attach the cover plate or using pop rivets to attach the cover plate, which can be drilled out and replaced. Also, if the wheel rim was damaged e.g., by an impact/pothole—the electronics and battery pack could be transferred to a new wheel rim. The various components of the wheel rim **22** can be formed using any of various types of materials (e.g., fiber reinforced plastic, carbon fiber, metal, etc.) and using any of various methods, such as injection molding, 3D printing, or casting (e.g., magnesium, aluminum, etc.). In addition, various components of the wheel rim **22** can be formed in whole or in part, integrally with the hub shell **26**.

Referring now to FIG. **7**, a side view of the wheel **14** is provided, with the cover plate **50** removed for clarity to expose the battery compartment **48**. In this view, the battery pack **40** can be seen situated inside the battery compartment **48**, above the inner ring **52** and below the outer ring **54**, noting that the outer ring **54** is sized and shaped to receive and seat the tire **15** thereover (e.g., circular in circumference and curved along its width), whereas the inner ring **52** is configured for securement to the wheel hub **24** (e.g., spokes **30**, etc.) and therefore can be similar to or vary in size and shape to the outer ring **54**. As seen in FIG. **7** the wheel **14** can further include other electronic devices housed at least partially in the battery compartment **48** for monitoring and controlling various aspects of the wheel **14**, such as the battery pack **40** and the hub motor **45**.

In at least some embodiments, the battery compartment **48** can receive one or more of, a local user interface **60**, a motor controller **62**, one or more Battery Management Systems (BMS) **64**, RFID and/or NFC circuits for communicating battery and/or other information to or from a user (e.g., via communication with a remote user interface **59**, such as a mobile phone, wireless user interface mounted on the frame **12**, etc.), a radio Frequency (RF) cutout **66**, and/or a master power ON/OFF switch **67**. In at least some embodiments, the motor controller **62** is secured to the wheel rim **22** (e.g., to the rim sidewall **56**) in a manner that allows the wheel rim **22** to serve as a heat sink, for example, metal-to-metal engagement therebetween, etc.). The BMS can also be mounted in a similar manner to utilize the wheel rim **22** as heat sink. Providing such a large heat sink (wheel rim) with good airflow therearound during operation allows these devices to run cool and efficiently and at high power levels for their size.

The Radio Frequency (RF) cutout **66** can be handlebar mounted remote power ON/OFF relay/switch. The local user interface **60** can provide user access to monitor and adjust various features using multiple buttons and/or an illuminated screen **61** (e.g., LCD) to control ON/OFF and adjust electronic assistance level (e.g., low, medium, high). The screen **61** can also display information such as the power level selected, battery status (e.g., 5 bar LED display, charging status, multi color LED, or battery percentage, remaining range in Miles/km, total distance ridden, trip distance, average speed, max speed, etc.). The screen **61** can be a touchscreen to receive user inputs, or a passive display.

A non-rotating power output can be provided to power other devices **55**, such as lights, etc. The power output can include a port provided to a stationary part of the bicycle **10** and receive power from the wheel hub **24**, such as via a DC-DC converter **53** (see FIG. **26**) providing a 12 VDC output that is wired to the wheel hub **24** using multi-pole rotary electrical connection **57** (e.g., slip ring configuration). An ON/OFF switch can be coupled with the power output that is accessible by the screen **61** or a separate discreet switch. In at least some embodiments, during operation, the screen **61** can be constantly illuminated (and master power ON/OFF switch **67** if desired) to provide increased visibility for other road users as they would spin when the bicycle **10** is being operated and create a ring of light—wherein the cover plate **50** can include a window **63** to provide screen visibility and to allow a user to conveniently access the local user interface **60**.

The motor controller **62** is a processor-based device that receives various inputs as discussed below and provides controlled power from the battery pack **40** to the hub motor **45** as required. Various types of motor controllers are well known and therefore not discussed in detail here. The BMS **64** is interconnected with the battery cells **42**. BMS devices are well known for sensing the voltage and/or current of the battery cells and provide monitoring for overvoltage, undervoltage, etc., as well as regulation of voltage and/or current provided to battery cells during use and the charging process.

Numerous wiring configurations of the battery cells **42** can be utilized. For example, as seen in FIG. **8**, to match the ring-shaped wheel rim **22**, the battery cells **42** can be positioned and electrically coupled in a circular configuration (e.g., a "sausage string") that can be easily fitted inside the battery compartment **48**. This circular configuration can prevent or limit overheating as the battery cells **42** are spaced apart and fixed in place around the wheel rim **22**. FIGS. **8** and **9** illustrate exemplary wiring configurations to electrically couple the battery cells **42**.

The battery cells **42** are electrically coupled to the motor controller **62** for powering the hub motor **45** situated in the wheel hub **24**. In at least some embodiments, the battery cells **42** are wired to provide a power output (+, −), and a charge port **68** is wired to the BMS **64** for recharging. The charge port **68** can take many forms, such as a typical female socket, an inductive wireless charging point, etc. Further, as shown, BMS cell balancing wires **69** can be connected at the positive terminal/connection between series connected pairs of battery cells **42**, or other desired connection points, the cell balancing wires **69** providing battery cell **42** monitoring at the various connection points along the battery pack **40**.

The battery cell wiring configuration shown in FIG. **9** illustrates the battery cells **42** connected directly in series, with BMS cell balancing wires **69** connected at the series connection of each battery cell **42**. The battery cells **42** can include any of various types of battery chemistry, such as Lithium Polymer, Nickel-metal Hydride, solid state, etc. In the case of some battery chemistry, the BMS **64** may not be desirable or necessary. Further, the battery cells **42** can take many forms, and in at least some embodiments, can be any of cylindrical, prismatic/rectangular, pouch cells, round, flat, arced, etc. The battery cells **42** and other electrical components can be electrically wired from the wheel rim **22** to the wheel hub **24** via one or more wires run along the spokes **30** or through a dedicated tube, such as exemplary cable tube **70** (see FIG. **7**), or a hollow spoke leg extending between the wheel rim **22** and wheel hub **24**. In at least some embodiments, the spokes could be used as individual conductors, eliminating/reducing separate wires running down the spokes—e.g., for high current/power phase wires, wherein the ends of the spokes would be insulated from each other. Minimizing the number of wires running between the wheel rim **22** and the wheel hub **24** can be achieved in many ways apparent to those skilled in the art.

Referring now to FIGS. **10** and **11** illustrating exemplary first and second side views of the carrier wreath **44** without the battery cells **42** installed. The carrier wreath **44** is configured to secure the battery cells **42** in a generally arced/curved manner to match the contour of the wheel rim **22**. To provide the curved arrangement and the versatility to secure a desired number of battery cells, a plurality of coupled carrier links **73** are utilized. More particularly, the carrier wreath **44** includes a plurality of carrier links **73**, wherein the carrier links **73** include a primary carrier **74** removably interconnected with a secondary carrier **76**. The carrier links **73** are each configured to secure a battery cell **42** and be coupled together in a generally circular manner.

Referring to FIGS. **12** and **13**, top and bottom perspective views of an exemplary primary carrier **74** are provided. In at least some embodiments, the primary carrier **74** includes a primary cell holder **80** that can be shaped and sized to securably engage a desired battery cell **42** (e.g., a curved C-shape to engage a cylindrical cell, a U-shape for a flatter cell, etc.). The primary carrier **74** can also include a plurality of primary clips **82** and a primary alignment bar **84**, all extending longitudinally away from the primary cell holder **80**. A pivot peg **86** is provided on an opposite side of the primary cell holder **80** and extends generally perpendicular to the primary clips **82**. A plurality of primary pillars **88** can be provided extending upwards from either side of the primary cell holder **80**, wherein the primary pillars **88** extend perpendicular to the primary clips **82** and are sized to abut with the cover plate **50**, such that when the cover plate **50** is secured in place it aids to secure the primary carrier **74** in place, and they can also help channel electrical wiring within the battery compartment **48**. The primary carrier **74** includes a primary end wall **89** that tapers in at least some embodiments. A carrier catch **90** can be provided, that in at least some embodiments is situated opposite the pivot peg **86** adjacent the primary end wall **89**, and in at least some embodiments is shaped as a protrusion that can be latched onto.

In at least some embodiments, the battery pack **40** is one piece forming a circle or partial circle, while in other embodiments, the battery pack **40** can include two or more separate curved groups of carrier links **73** and battery cells **42** wired together and configured to fit on opposing sides of the wheel rim **22**, wherein separate BMS's **64** can be used for each group.

Referring now to FIGS. **14** and **15**, top and bottom perspective views of an exemplary secondary carrier **76** are provided. In at least some embodiments, the secondary carrier **76** includes a secondary cell holder **100** that is shaped and sized similar to primary cell holder **80** to engage a battery cell **42**. As the secondary carrier **76** is configured to be engaged with the primary carrier **74** to form the carrier link **73**, the secondary carrier **76** includes several complementary features to facilitate the engagement. More particularly, in at least some embodiments, the secondary carrier **76** includes a plurality of secondary clips **102** and secondary alignment bars **104**, all extending longitudinally away from the secondary cell holder **100**. The secondary carrier **76** includes a secondary end wall **105** that in at least some embodiments is tapered. A carrier latch **106** is provided that in at least some embodiments, is situated on an opposite side of the secondary cell holder **100** and extends generally in an opposite longitudinal direction from the secondary clips **102**. A pivot ring **108** is provided that in at least some embodiments is situated adjacent the secondary end wall **105** and opposite the carrier latch **106** relative to the secondary end wall **105**. A plurality of secondary pillars **110** can be provided extending upwards from either side of the secondary cell holder **100**, providing the similar function as the primary pillars **88**.

Referring now to FIGS. **16** and **17**, the primary carrier **74** is shown coupled with the secondary carrier **76** to form the carrier link **73**. As the carrier link **73** is configured to engage a battery cell **42**, in at least some embodiments, the primary alignment bar **84** and secondary alignment bars **104** are straight with the primary alignment bar **84** being complementarily received between the secondary alignment bars **104** to align the primary carrier **74** and the secondary carrier **76**. The primary clips **82** are then aligned outside of the secondary clips **102**, with the primary clips **82** facing inward and the secondary clips **102** facing outward, such that pushing the primary carrier **74** into the secondary carrier **76** with the primary alignment bar **84** being received in between the secondary alignment bars **104**, causes the primary clips **82** to latch with the secondary clips **102**, noting that the forced alignment caused by the primary alignment bar **84** in between the secondary alignment bars **104** assists to keep the clips **82**, **102** in an engaged position. Once fully engaged, the primary carrier **74** and secondary carrier **76** form the carrier link **73**, which can be coupled with another carrier link **73**. Once the carrier link **73** is formed, the primary cell holder **80** and secondary cell holder **100** are aligned so as to receive, for example, a cylindrical battery cell. For reference, the carrier link **73** has a central longitudinal axis **112** (FIG. **17**) (e.g., extending through the primary alignment bar **84**).

Referring to FIGS. **18** and **19**, illustrating partial views of the carrier wreath **44** taken from FIG. **11**, a plurality of carrier links **73** are shown, wherein the coupling between the carrier links **73** occurs via insertion of the pivot peg **86** of a first carrier link (labeled **73**A for discussion purposes only) into the pivot ring **108** of a second carrier link (labeled **73**B for discussion purposes only), which pivotably links the carrier links **73**A and **73**B (forming a pivoting connection), once pivotably coupled, rotating the carrier links **73**A and **73**B about this pivot joint causes the carrier latch **106** to engage with the carrier catch **90**, thereby latching the carrier links **73**A and **73**B together (forming a latching connection). In at least some embodiments, the carrier latch **106** is sized and shaped to engage the carrier catch **90** when the end walls of the carrier links **73** (primary end wall **89** and secondary end wall **105**) abut. As the end walls **89**, **105** are tapered in the same direction (towards a center of the carrier wreath **44**), abutment of the end walls **89**, **105** offsets the central longitudinal axes (**112**A and **112**B for discussion purposes only) of the carrier links. The offset provides the curvature of the carrier wreath **44**, which can easily be modified by changing the tapering of the end walls **89**, **105** and length of the carrier latch **106**, noting that the carrier latch **106** has a chosen curvature and length sufficient to engage the carrier catch **90**. This manner of coupling the carrier links **73** can be repeated to accommodate all the battery cells **42** in the battery pack **40**. Once the carrier wreath **44** is assembled it can be placed into the battery compartment **48** with the battery cells **42** and all or some of the wiring being installed before or after insertion into the battery compartment **48**.

Referring now to FIGS. **20-25**, various views of the wheel hub **24** of FIG. **1** are provided. The wheel hub **24** is rotationally supported by the axle **16**, where in at least some embodiments, the axle **16** is securable to the frame **12** via a pair of axle bolts **120** and end caps **122**, one or more keyed washers **124** can also be utilized (shown in FIGS. **20-25** along with the wheel hub **24** for illustrative purposes, while in other embodiments, the axle **16** is a thru-axle design utilizing typical thru-axle hardware for securement to the frame **12**. For clarity, securement to the frame **12** is intended to include indirect securement, such as via securement to a rear frame portion on a soft-tail, a swing-arm, etc.

As best seen in FIG. **23**, the hub shell **26** includes a shell side wall **126** and a shell top wall **128**, which can be integrally formed, or fastened together. The shell side wall **126** is coupled to the axle **16** via a housing bearing **130** to allow rotation relative thereto. The shell top wall **128** is generally ring-shaped and includes a ring gear **132** (i.e., includes inner ring gear teeth **134** positioned circumferentially and extending inward towards the axle **16**). As best seen in FIGS. **24** and **25**, a planetary gear set **136** is housed inside the hub shell **26** and includes a plurality of planetary gears **138** (e.g., three gears with bearings **140**) coupled to a one-way clutch **142** (that includes bearing posts **144** for the planetary gears), wherein the planetary gears **138** are rotationally engaged with the ring gear **132** and the clutch is fixed to the axle **16** (e.g., keyed to prevent rotation therebetween). Various other bearings can be provided to allow rotation of other components around the axle **16**, such as bearings **139**, **141**, **143**, **145** (see FIG. **23**).

A rotor **150** is provided that is secured to or formed integrally with a sun gear **152**, wherein the sun gear **152** rotationally engages the planetary gears **138**, such that rotation of the rotor **150** at least indirectly causes rotation of the hub shell **26**. The rotor **150** includes a rotor side wall **154** and a rotor top wall **156**. A plurality of magnets **158** are secured circumferentially inside the rotor **150** along the rotor top wall **156** that, along with the rotor side wall **154**, form a stator cavity **159** for receiving a stator **160**, the stator **160** being ring-shaped having an outer surface **162** and an inner surface **164**. The rotor **150** and stator **160** form at least in part the hub motor **45**.

The stator **160** is engaged with a shell cover **165** to prevent the stator **160** from rotating relative to the shell cover **165**. The shell cover **165** is sized and shaped to be secured to the hub shell **26** using a plurality of fasteners **166** (e.g., screws, bolts, etc.). In at least some embodiments, the shell cover **165** includes a cover wall **168** radially extending from a cylindrical stator carrier **170**, wherein the stator carrier **170** is sized to receive thereover the inner surface **164** of the stator **160** and to provide a press-fit engagement (an adhesive can be used to further the engagement). This engagement provides a direct heat transfer path from the stator **160** to the shell cover **165** to ensure good heat conduction from the stator **160** to significantly enhance stator cooling, thereby allowing higher sustained power output from the hub motor **45**. Additionally, the stator may be potted in thermal epoxy, which in this design will also fill the gap between the stator **160** and the shell cover **165**, which will further improve the heat transfer from the stator (i.e., stator windings) to the shell cover **165**.

The stator **160** includes a plurality of stator windings **172** (FIG. **23**), situated between the outer surface **162** and inner surface **164**, which are energized by power from the motor controller **62**. The rotor **150** and stator **160** themselves form a version of an outrunner motor configuration, wherein energizing the stator windings **172** creates a rotational force on the magnets **158** that surround the stator **160**, although in a typical outrunner configuration used on a bicycle, a stator would be fixed relative to a bicycle frame to prevent rotation, thereby causing a rotational force on a rotor to rotate the rotor relative to the frame to rotate a hub. In contrast, in the disclosed invention, the stator **160** is fixed to the hub shell **26**, which is rotationally supported about the axle **16**. When the stator **160** is energized, a first rotational force is applied to the rotor **150** to push it in a first direction, but since the rotor **150** and stator **160** are both rotatable about the axle **16**, an opposing second rotational force is applied to the stator **160**. Rotation of the rotor **150** turns the sun gear **152**, which turns the planetary gears **138** engaged with the ring gear **132**, thereby causing both the rotor **150** and stator **160** to provide rotational forces to the hub shell **26**.

Allowing the rotor **150** and stator **160** to both apply rotational forces to the hub shell **26** has numerous advantageous, for example, any electrical motor torque ripple generated by the motor controller **62** or vibration from the planetary gear meshing inconsistency is transferred between the magnets **158** via the electromagnetic force from the stator **160** to the stator/hub shell/wheel combination. This torsional vibration is dissipated in an improved way as the hub shell/wheel, which has a high torsional moment of inertia due to the mass of the battery pack **40** in the rim, can absorb that torsional vibration, and as the wheel **14** is connected to a road surface via the rubber tire **15**, it can dampen any remaining vibration. The result of this is a very smooth quiet ride as the torque ripple and gear mesh vibration is not directly transferred as a torsional vibration via the axle **16** to frame **12** and the rider/user. Additionally, the relative speed of the rotor and stator are higher by a multiple of one divided by the planetary gear ratio for a set planetary gear ratio (vs a fixed stator)—which allows the hub motor **45** to run more efficiently at low hub RPM/bike speed (as motor efficiency increases versus RPM at low RPM's). This increased rotor-stator relative RPM also results in more overall motor power produced at a set hub RPM/bike speed by a multiple of one divided by the planetary gear ratio—e.g., if the gear ratio is 1:5 the rotor-stator relative RPM is 6/5 (sixth-fifths) the hub shell rpm. Therefore, the overall power output is hence 6/5 (sixth-fifths) the power output vs a fixed stator (given a constant torque generated between the rotor/stator for both variants).

The wheel hub **24** further includes a freehub body **180**. Various types of freehub body configurations are known for use with coupling a hub to a rider input and can be adapted for use herein. In at least some embodiments, the freehub body **180** includes a flange **182** extending from a shaft **184** having radially extending ribs **186** sized and spaced to complementarily receive and engage the gear cassette **34**. The flange **182** is secured to the shell cover **165**, such as using a plurality of fasteners (not shown for clarity), while in other embodiments, the freehub **180** can include other features.

Various sensors can be utilized to provide information to the motor controller to selectively supply the desired amount of power to the hub motor **45**, so that in at least some embodiments, the wheel **14** can operate autonomously, with no electrical control signals being provided outside of the wheel **14** if desired. For example, in at least some embodiments, a freewheel sensor disc **190** can be engaged with the shaft **184** (e.g., slots that receive the ribs **186**) to rotate an embedded magnet simultaneously with the gear cassette **34**, the rotation of the magnet can be sensed by a freewheel sensor **191** (FIG. **25**) positioned on the stator **160** to monitor the user pedaling motion (speed and direction) provided via a chain and sprocket coupling with the gear cassette **34**. In at least some embodiments, the freewheel sensor disc **190** and freewheel sensor **191** can be configured for optical sensing instead of magnetic sensing.

Other exemplary sensors can include a shell rotation sensor assembly **192** that can be mounted within the stator carrier **170**, to measure the rotation and direction of the hub shell **26** relative to the axle **16**. The shell rotation sensor assembly **192** can include a shell rotation sensor housing **194** for positioning a shell rotation sensor **196** adjacent to an axle disc **198** and securing the shell rotation sensor **196** to the stator carrier **170**, wherein the axle disc **198** is fixed to the axle **16**, and the shell rotation sensor **196** rotates with the stator carrier **170** to sense rotation of the stator **160** relative to the axle **16** (e.g., via magnetic or optical sensing). The use of magnetic-based sensors as discussed herein can easily be replaced with other known sensor technologies (e.g., optical sensors, etc.) to perform similar functions. In at least some embodiments, the stator **160** includes a stator interface **199** (see FIG. **25**), which can be mounted on the side of the stator **160** for example, and which is electrically coupled along with one or more various sensors to the motor controller **62**. The stator interface **199** can include one or more circuit components, such as processor, that are mounted on a circuit board with one or more input/output connectors for receiving and/or providing power and/or sensor data. In at least some embodiments, the shell rotation sensor **196** is electrically coupled to the stator interface **199**. A stator electrical connector **200** is provided external of the hub shell **26** for connection with the motor controller **62** and/or local user interface **60** in the wheel rim **22**. FIG. **26** provides a system block diagram illustrating an exemplary configuration for the bicycle **10**.

In addition, in at least some embodiments, various components can be consolidated into a single microchip and/or onto a single printed circuit board (e.g., the motor controller, BMS, etc.). Such consolidation can increase reliability, while decreasing overall part count, cost, wiring, and connectors, noting that typical sealed connectors commonly found on electric bikes are subject to flexing and breaking over time, so such reduction can be beneficial.

In at least some embodiments, after connecting the various components (e.g., battery cells **42**, motor controller **62**, BMS **64**, etc.) together that will go into the battery compartment, they can be potted (encapsulated, in resin) with thermal epoxy to form a rigid ring, which is then mounted in the battery compartment **48** using various known types of fastening, such as bonding, high strength double sided tape, bolts, clips, etc. Alternatively, the potting can occur after the components have been installed inside the battery compartment **48**, wherein such post-installation potting can nullify the need for the cover plate **50** to be readily removable. Potting can provide waterproofing and limit vibration damage to the wired connections.

The wheel **14** has been shown as a wheel for a bicycle **10** for exemplary purposes, although in various other embodiments, the aforementioned components, such as the battery pack **40** encircling a rim and the hub motor **45** with rotating stator and rotor can be utilized alone or jointly with wheel designs from other types of vehicles, and as such, it shall be understood that the invention can be utilized for use with, for example, wheelchairs, bicycle trailers, trailers, carts, hand carts, stand up scooters, sit down scooters/mopeds, monowheels, unicycles, tractors, strollers/joggers, tricycles, quadricycles, Light Electric vehicles, trains, trams, robots, All-Terrain Vehicles and Utility Vehicles (ATVs and UTVs), cable-cars, motorcycles, cars, etc. In addition, various non-vehicle applications, such as winch pulleys, etc. can also incorporate one or more of the aforementioned aspects of the invention.

It will be understood by those skilled in the art that one or more aspects of this invention can meet certain objectives, while one or more other aspects can lead to certain other objectives. Other objects, features, benefits and advantages of the invention will be apparent in the descriptions of the disclosed embodiments, and will be readily apparent to those skilled in the art. Such objects, features, benefits and advantages will be apparent from the above as taken in conjunction with the accompanying figures and all reasonable inferences to be drawn therefrom. Although the invention has been herein described in what is perceived to be the most practical and preferred embodiments, it is to be understood that the invention is not intended to be limited to the specific embodiments set forth above. Rather, it is recognized that modifications may be made by one of skill in the art of the invention without departing from the spirit or intent of the invention.

What is claimed is:

1. A battery wheel assembly comprising:

a wheel comprising:

- an axle for securement to a vehicle, the axle having a central axle axis extending therethrough;
- a wheel rim; and
- a wheel hub interconnected with the wheel rim and rotatable about the central axle axis; and

a battery pack secured to the wheel rim comprising:

- a carrier wreath having a plurality of carrier links selectably interconnected; and
- a plurality of battery cells electrically interconnected and secured to the carrier wreath.

2. The battery wheel assembly of claim **1**, wherein each of the plurality of carrier links includes a primary carrier and a secondary carrier selectably coupled together.

3. The battery wheel assembly of claim **2**, wherein the primary carrier includes a primary cell holder and a plurality of primary clips extending longitudinally, and the secondary carrier includes a secondary cell holder and a plurality of secondary clips extending longitudinally, and wherein the plurality of primary clips engage the plurality of secondary clips to couple the primary carrier and the secondary carrier together, and the primary cell holder and secondary cell holder secure at least one of the plurality of battery cells.

4. The battery wheel assembly of claim **3**, wherein the primary carrier includes a primary alignment bar extending longitudinally with the plurality of primary clips, and the secondary carrier includes a plurality of secondary alignment bars extending longitudinally with the plurality of secondary clips and spaced to receive the primary alignment bar therebetween.

5. The battery wheel assembly of claim **4**, wherein the primary carrier includes a tapered primary end wall, and the secondary carrier includes a tapered secondary end wall.

6. The battery wheel assembly of claim **5**, wherein the primary carrier includes a carrier catch and the secondary carrier includes a carrier latch.

7. The battery wheel assembly of claim **6**, wherein the primary carrier includes a pivot peg and the secondary carrier includes a pivot ring.

8. The battery wheel assembly of claim **1**, wherein the plurality of carrier links includes a first carrier link having a first central longitudinal axis and a second carrier link having a second central longitudinal axis, and wherein the plurality of battery cells includes a first battery cell and a second battery cell.

9. The battery wheel assembly of claim **8**, wherein the first carrier link and the second carrier link are coupled together via a pivotable connection and a latching connection.

10. The battery wheel assembly of claim **9**, wherein the pivotable connection includes a pivot peg and a pivot ring, and wherein the pivot peg extends from one of the first carrier link or second carrier link and is received in the pivot ring extending from the other of the first carrier link or second carrier link.

11. The battery wheel assembly of claim **10**, wherein the latching connection includes a carrier latch and a carrier catch, and wherein the carrier latch extends from one of the first carrier link or second carrier link and is engageable with the carrier catch situated on the other of the first carrier link or second carrier link.

12. The battery wheel assembly of claim **11**, wherein the first carrier link has a tapered first end wall and the second carrier link has a tapered second end wall, and wherein when the first carrier link and the second carrier link are coupled together, the tapered first end wall and the tapered second end wall are in abutment such that the first central longitudinal axis is offset from the second central longitudinal axis.

13. The battery wheel assembly of claim **12**, wherein the first battery cell is secured to the first carrier link and the second battery cell is secured to the second carrier link.

14. The battery wheel assembly of claim **13**, wherein the battery pack is electrically coupled to a motor controller secured to the wheel rim, and wherein the motor controller is electrically coupled to a hub motor situated in the wheel hub.

15. The battery wheel assembly of claim **14**, wherein a battery management system is electrically coupled to the plurality of battery cells.

16. The battery wheel assembly of claim **15**, wherein the wheel rim further includes a battery compartment.

17. The battery wheel assembly of claim **16**, wherein the battery pack, battery management system, and motor controller are situated in the battery compartment.

18. The battery wheel assembly of claim **17**, wherein the wheel rim further includes a removable cover plate.

19. The battery wheel assembly of claim **18**, wherein the wheel rim further includes a screen situated in the battery compartment and visible via a window in the removable cover plate.

20. A battery wheel assembly comprising:
- a wheel comprising:
  - an axle for securement to a vehicle, the axle having a central axle axis extending therethrough;
  - a wheel rim; and
  - a wheel hub interconnected with the wheel rim and rotatable about the central axle axis;
- a hub motor situated in the wheel hub;
- a battery pack secured to the wheel rim and at least indirectly coupled electrically to the hub motor, the battery pack comprising:
  - a carrier wreath; and
  - a plurality of battery cells electrically interconnected and secured to the carrier wreath; and
- a battery management system secured to the wheel rim and electrically coupled to the plurality of battery cells, wherein a motor controller is electrically coupled to the hub motor and secured to the wheel rim.

21. The battery wheel assembly of claim **20**, wherein the wheel rim further includes a battery compartment.

22. The battery wheel assembly of claim **21**, wherein the battery pack, battery management system, and motor controller are situated in the battery compartment.

23. The battery wheel assembly of claim **22**, wherein the wheel rim further includes a cover plate.

24. The battery wheel assembly of claim **23**, wherein the wheel rim further includes a screen situated in the battery compartment and visible via a window in the cover plate.

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