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(54) **BATTERY PACK HAVING BLOW-OUT VALVE**

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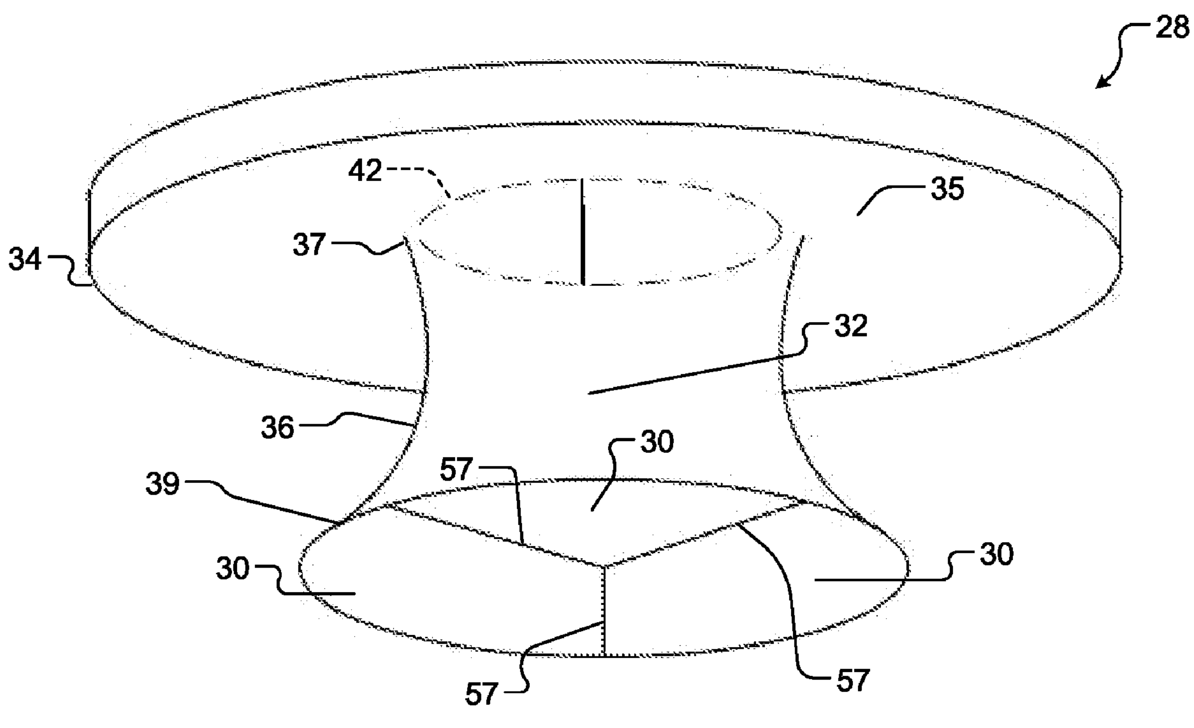
(57) **ABSTRACT**

A valve including an annular base defining a through-hole, a hollow throat section having a proximate end connected to the annular base at the through-hole and a distal end located away from the annular base, and a plurality of flexible members attached to the distal end that are configured to mate together to seal the aperture when the valve is in a closed position and configured to separate when the valve is in an open position. The plurality of flexible members are configured to separate when a pressure within the battery pack reaches a predetermined threshold, and in a closed position of the valve, the hollow throat section including the flexible members extends away from the through-hole in a negative z-direction, and in an open position of the valve the hollow throat section including the flexible members extend away from the through-hole in a positive z-direction.



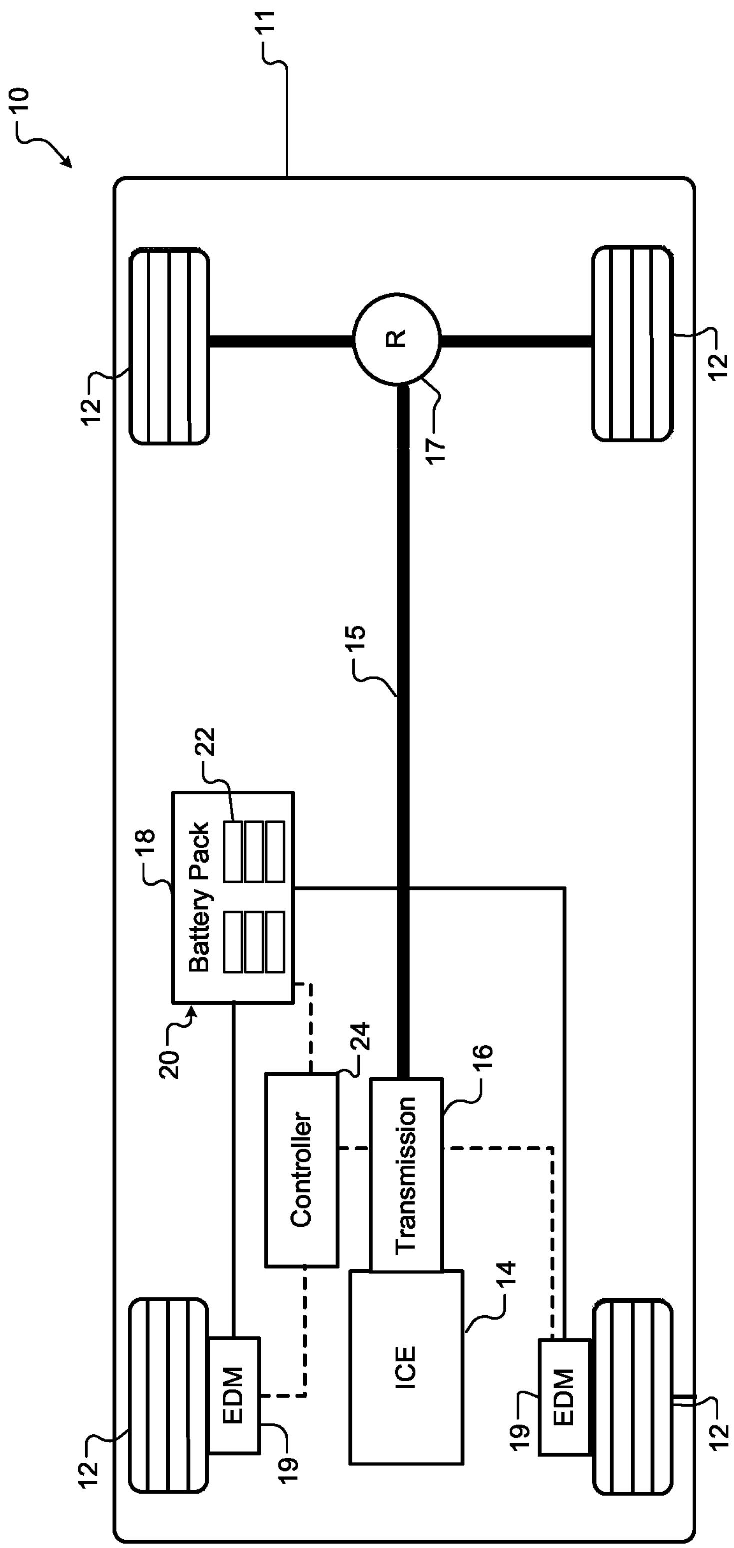

10
11
12
R
17
15
22
18
Battery Pack
20
24
Controller
16
Transmission
14
ICE
EDM
19

FIG. 1

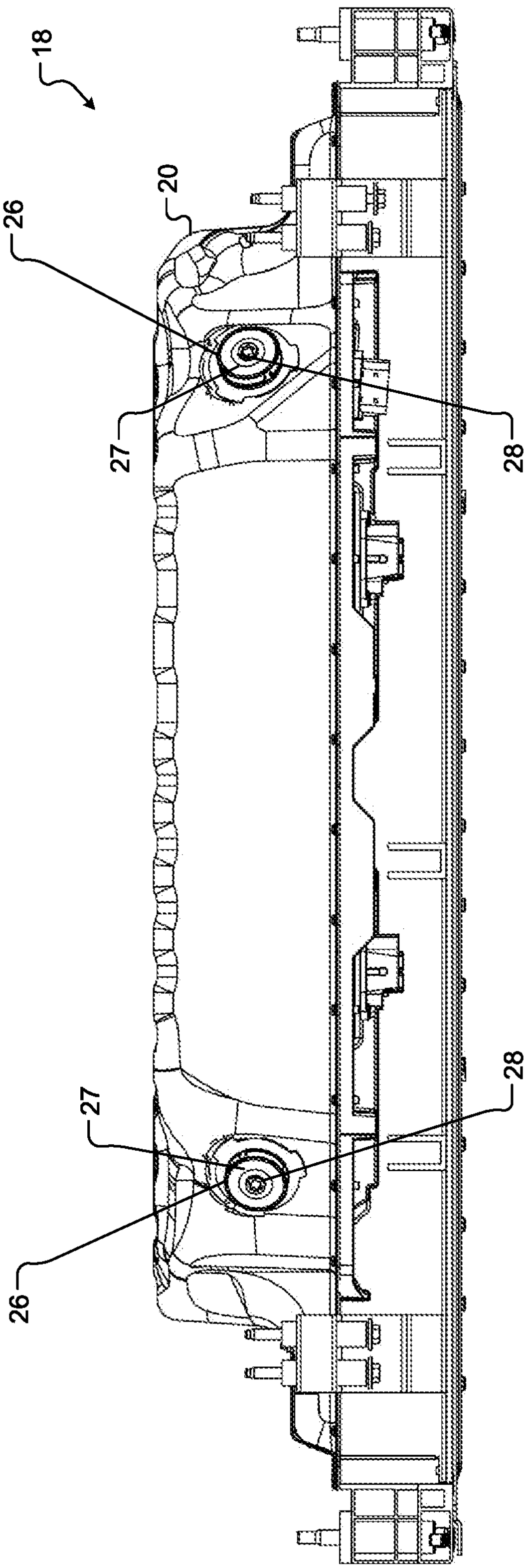


FIG. 2

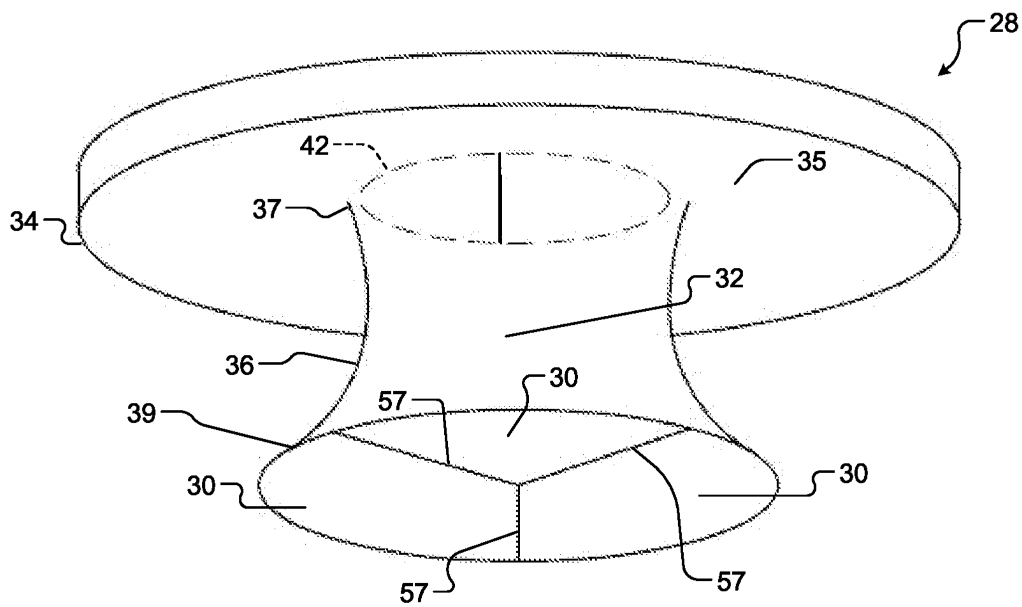


FIG. 3

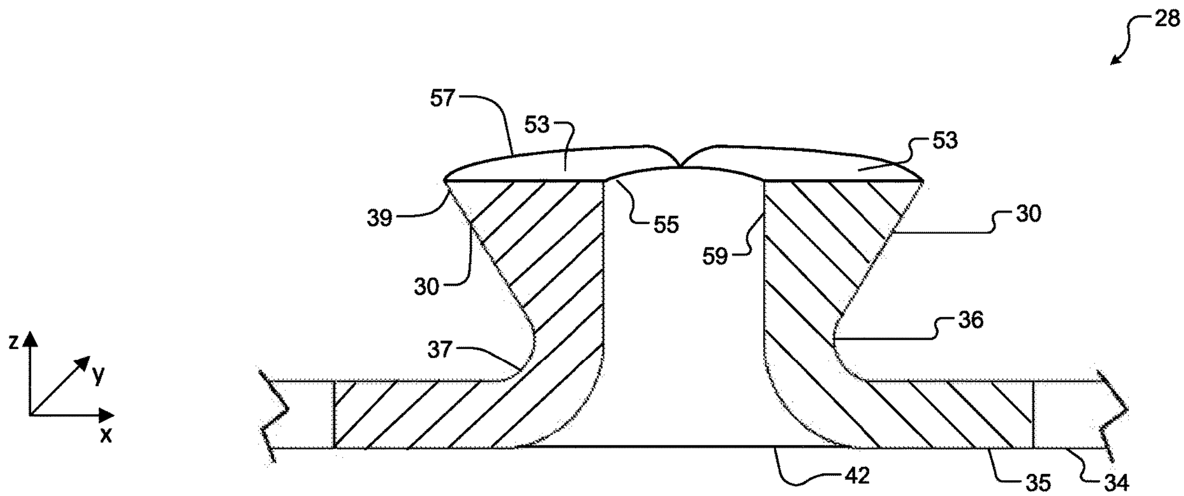

28
57
53
53
39
55
30
59
30
36
37
z
y
x
42
35
34

FIG. 4A

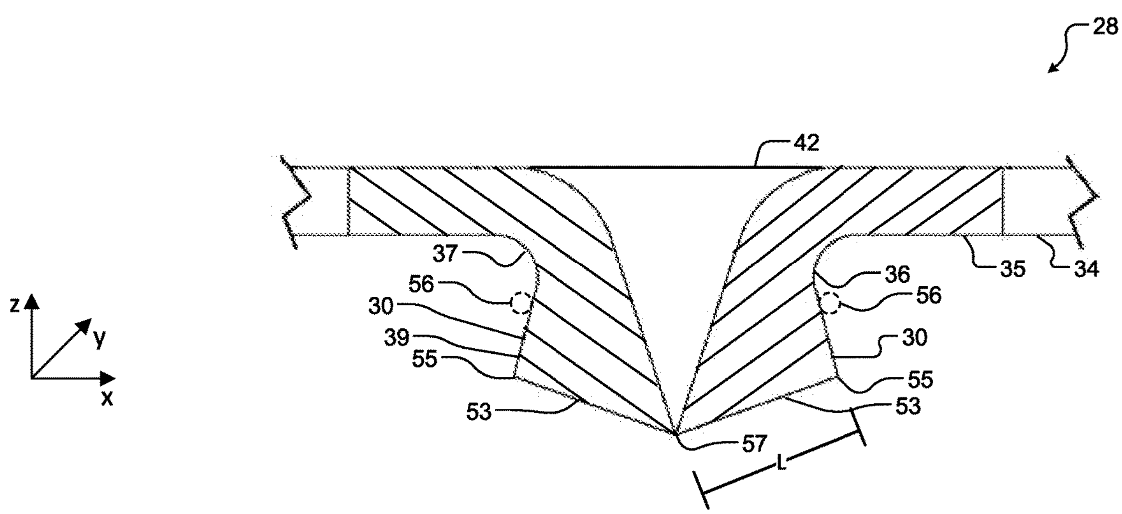

28
42
37
36
35
34
56
56
z
y
30
39
30
55
55
x
53
53
57
L

FIG. 4B

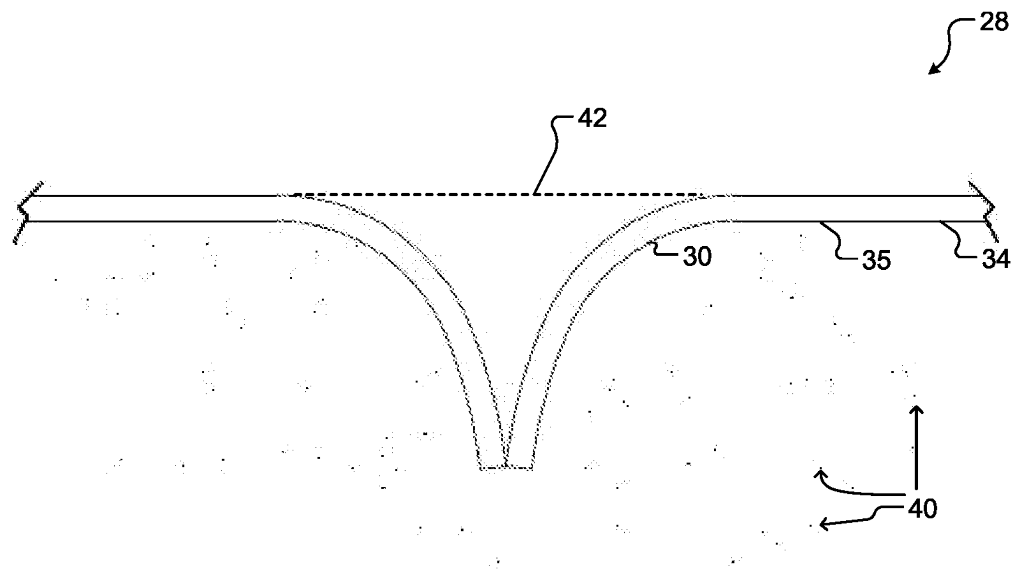


FIG. 5A

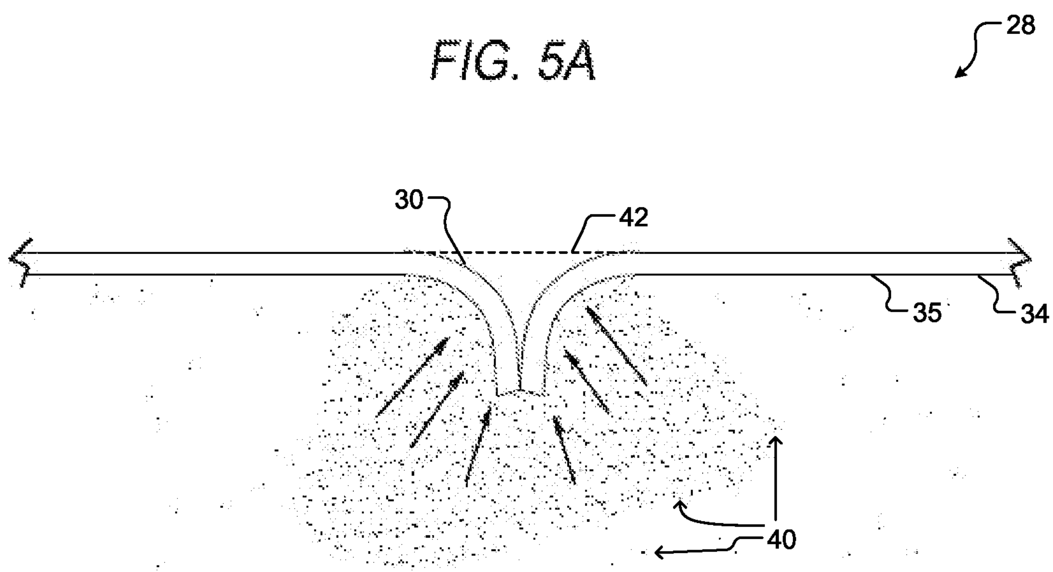


FIG. 5B

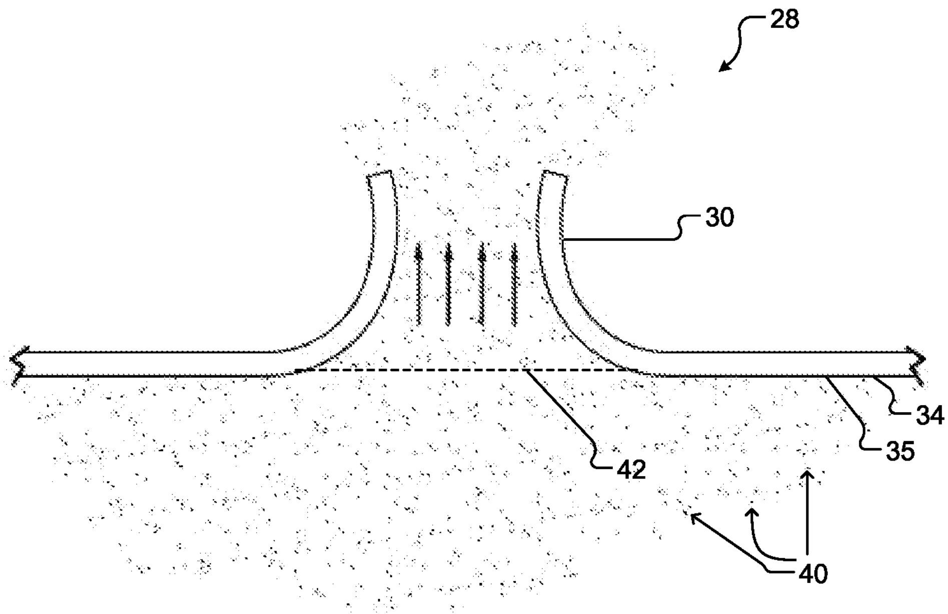


FIG. 5C

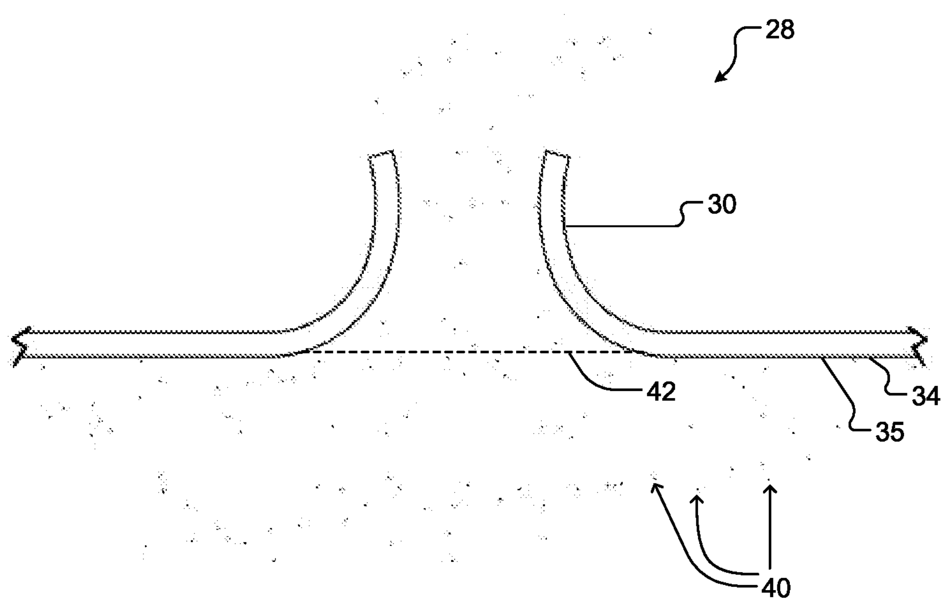


FIG. 5D

BATTERY PACK HAVING BLOW-OUT VALVE

FIELD

[0001] The present disclosure relates to battery back having a blow-out valve.

BACKGROUND

[0002] This section provides background information related to the present disclosure which is not necessarily prior art.

[0003] Vehicles with electric propulsion systems are becoming increasingly more common. Some electrically propelled vehicles include an electric drive motor at each wheel of the vehicle, and some electrically propelled vehicles include a front electric drive motor for rotating the front wheels of the vehicle and a rear electric drive motor for rotating the rear wheels of the vehicle. In either case, the electric drive motors receive power from a battery pack that includes a plurality of battery cells therein. Example battery cells include lithium-ion battery cells and lithium-metal battery cells.

[0004] Lithium-ion and lithium-metal battery cells sometimes undergo a process called thermal runaway during failure conditions. Thermal runaway may result in a rapid increase of battery cell temperature accompanied by the release of various gases, which, in turn, rapidly increase the pressure inside a battery housing. Accordingly, in the event of a thermal runaway, it is desirable that the vehicle include features that assist in the ventilation of the volatile gases that may otherwise increasingly pressurize the battery housing.

SUMMARY

[0005] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0006] According to a first aspect of the present disclosure, there is provided a valve configured for use with a battery pack having a discharge vent for discharging gases from the battery pack, the valve comprising an annular base located proximate the discharge vent and defining a through-hole; a hollow throat section having a proximate end connected to the annular base at the through-hole and a distal end located away from the annular base; and a plurality of flexible members attached to the distal end that are configured to mate together to seal the aperture when the valve is in a closed position and configured to separate when the valve is in an open position, wherein the plurality of flexible members are configured to separate when a pressure within the battery pack reaches a predetermined threshold, and in a closed position of the valve, the hollow throat section including the flexible members extends away from the through-hole in a negative z-direction, and in an open position of the valve the hollow throat section including the flexible members extend away from the through-hole in a positive z-direction.

[0007] According to the first aspect, each of the plurality of flexible members include edges that are configured to mate and form an interlocked seal when the valve is in the closed position.

[0008] According to the first aspect, the edges separate to open the interlocked seal when the valve is in the open position.

[0009] According to the first aspect, the predetermined threshold to open the valve is about 100 millibars.

[0010] According to the first aspect, each of the annular base, the throat section, and the plurality of flexible members are formed of an elastomeric material.

[0011] According to the first aspect, the elastomeric material is selected from the group consisting of a natural or synthetic rubber material, a silicone material, and polyurethane material.

[0012] According to the first aspect, each of the annular base, the throat section, and each of the plurality of flexible members form a monolithic structure.

[0013] According to a second aspect of the present disclosure there is provided a battery pack comprising a housing configured to support a plurality of battery cells; a plurality of discharge vents that are configured to discharge gases generated by at least one of the plurality of battery cells; and a valve provided in each of the discharge vents that is configured to open to permit the discharge gases to escape the housing through each of the discharge vents, wherein each of the valves includes an annular base located proximate the discharge vent and defining a through-hole; a hollow throat section having a proximate end connected to the annular base at the through-hole and a distal end located away from the annular base; and a plurality of flexible members attached to the distal end that are configured to mate together to seal the aperture when the valve is in a closed position and configured to separate when the valve is in an open position, wherein the plurality of flexible members are configured to separate when a pressure within the battery pack reaches a predetermined threshold, and in a closed position of the valve, the hollow throat section including the flexible members extends away from the through-hole in a negative z-direction, and in an open position of the valve the hollow throat section including.

[0014] According to the second aspect, each of the plurality of flexible members include edges that are configured to mate and form an interlocked seal when the valve is in the closed position.

[0015] According to the second aspect, the edges separate to open the interlocked seal when the valve is in the open position.

[0016] According to the second aspect, the predetermined threshold to open the valve is about 100 millibars.

[0017] According to the second aspect, each of the annular base, the throat section, and the plurality of flexible members are formed of an elastomeric material.

[0018] According to the second aspect, the elastomeric material is selected from the group consisting of a natural or synthetic rubber material, a silicone material, and polyurethane material.

[0019] According to the second aspect, each of the annular base, the throat section, and each of the plurality of flexible members form a monolithic structure.

[0020] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0021] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0022] FIG. **1** is a schematic view of a vehicle according to a principle of the present disclosure;

[0023] FIG. **2** is a perspective view of an example battery pack of the vehicle illustrated in FIG. **1**;

[0024] FIG. **3** is a perspective view of an example blow-out valve in a closed position according to a principle of the present disclosure;

[0025] FIG. **4**A is a cross-sectional view of the example blow-out valve in an open position;

[0026] FIG. **4**B is a cross-sectional view of the example blow-out valve in a closed position;

[0027] FIG. **5**A is a schematic cross-sectional representation of the example blow-out valve in a closed position when no pressure is being exerted thereon to open the blow-out valve;

[0028] FIG. **5**B is a schematic cross-sectional representation of the example blow-out valve in a closed position when pressure is beginning to be exerted thereon to open the blow-out valve;

[0029] FIG. **5**C is a schematic cross-sectional representation of the example blow-out valve in an open position when the pressure was exerted to an extent that opened the blow-out valve; and

[0030] FIG. **5**D is a schematic cross-sectional representation of the example blow-out valve in an open position where the pressure within the battery pack has been expelled.

[0031] Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

[0032] Example embodiments will now be described more fully with reference to the accompanying drawings. The example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0033] FIG. **1** schematically illustrates an example vehicle **10** according to the present disclosure. The example vehicle **10** includes a body **11** and a plurality of wheels **12**. In the illustrated embodiment, each front wheel **12** may be driven using a respective electric drive module **19** that receives electric power from a battery pack **18** having a housing **20** that encases a plurality of battery cells **22**. Thus, vehicle **10** may be a battery-powered electric vehicle. Example battery cells **22** include lithium-ion battery cells, lithium-metal battery cells, and combinations thereof. It should be understood, however, that other types of battery cells **22** known to one skilled in the art may be used, without limitation. Housing **20** is preferably formed of a rigid metal material (e.g., steel, aluminum, and the like) that is resistant to puncture and is non-flammable.

[0034] While the vehicle **10** is described above as being an electric vehicle, it should be understood that the teachings of the present disclosure can also be applicable to a hybrid vehicle having, in addition to the electric drive modules **19**, an internal combustion engine **14** and transmission **16** for providing power to rear wheels **12** via a driveshaft **15** that is connected to a differential **17** that is connected to the rear wheels **12**.

[0035] FIG. **1** illustrates two electric drive modules **19** such that each front wheel **12** can be driven by a single electric drive module **19**. It should be understood, however, that vehicle **10** may include a single electric drive module **19** for driving a pair of wheels **12** (e.g., for driving the pair of front wheels **12** or the pair of rear wheels **12**), or may include a pair of electric drive modules **19** with one of the electric drive modules **19** driving the front pair of wheels **12** and another of the electric drive modules **19** driving the rear pair of wheels **12**. Regardless of the configuration selected, it should be understood that electric drive modules **19** receive a voltage or current from battery pack **18** that is utilized by the electric drive module **19** to drive the wheels **12** of the vehicle **10**.

[0036] Vehicle **10** may also include a controller **24** in communication with each of the drive modules **19** and in communication with the battery pack **18**. Controller **24** may be used to control electric drive modules **19** to control a speed of vehicle **10**, and may also be used to monitor and/or communicate with various systems of vehicle such as, for example, an HVAC system (not shown), a vehicle braking system (not shown), and any other system that may be part of vehicle **10**.

[0037] As noted above, battery cells **22** may sometimes undergo a process called thermal runaway during failure conditions of the battery cell(s) **22**. Thermal runaway may result in a rapid increase of battery cell **22** temperature accompanied by the release of various gases. Example gases that may be released during a thermal runaway event include hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), and various hydrocarbons including, but not limited to, methane, ethane, ethylene, acetylene, propane, cyclopropane, and butane. As these gases are released and the temperature of battery pack **18** increases, the pressure within battery pack **18** also increases.

[0038] Now referring to FIG. **2**, it can be seen that housing **20** of battery pack **18** includes a plurality of discharge vents **26** that permit the pressure and gases to escape housing **20** during a thermal runaway event. In this regard, discharge vents **26** may each include a blow-out valve **28** that is closed when a pressure in the housing **20** is below a predetermined pressure, and that is configured to open when the predetermined gas pressure is generated within housing **20**. Blow-out valve **28** is a one-way valve that only permits gases to exit housing **20** when the predetermined pressure is generated in housing **20**.

[0039] For example, if the pressure within housing **20** reaches 100 millibars the blow-out valve **28** is configured to open and permit the gases within housing **20** to exit the battery pack **18** through discharge vent **26**. Discharge vents **26** may be in communication with various conduits (not shown) located in battery pack **18**, which direct the gases generated during the thermal runaway event to the discharge vents **26** and the blow-out valves **28** to be expelled from battery pack **18**. While only a pair of discharge vents **26** having blow-out valves **28** are illustrated in FIG. **2**, it should be understood that battery pack **18** may include a greater number of discharge vents **26** having blow-out valves **28** without departing from the scope of the present disclosure.

[0040] FIG. **3** illustrates an example blow-out valve **28** according to a principle of the present disclosure in the closed position. Blow-out valve **28** may be formed (e.g., molded) from an elastomeric material that is capable of deforming under pressure and returning to its original shape. Example elastomeric materials include, but are not limited to, natural or synthetic rubber materials, silicone materials, and polyurethane materials.

[0041] As illustrated in FIG. **3**, the blow-out valve **28** is formed (e.g., molded) as a continuous and unitary structure that may include an annular base **34** and a hollow throat section **36** defining a channel **32** extending outward from the annular base **34**. FIG. **3** illustrates blow-out valve **28** in a closed position. Annular base **34** includes an abutment surface **35** that is configured to abut against an annular surface **27** of discharge vent **26**, while throat section **36** is configured to be received within an elongated passage (not shown) provided in discharge vent **26**. Throat section **36** is configured to receive gases from an interior of battery pack **18** when a pressure within the interior of the battery pack **18** reaches a certain level (e.g., 100 millibars) that is sufficient to force a plurality of flexible members **30** to spread apart from each other and open the blow-out valve **28**, as will be described in more detail below.

[0042] Throat section **36** includes a first or proximate end **37** attached to annular base **34** at a through-hole **42** that permits gases to escape discharge vents **26** when blow-out valve **28** is open, and an opposite second or distal end **39** that includes, in the illustrated embodiment, three flexible members or flaps **30**. When blow-out valve **28** is closed, the flexible members **30** are in contact with each other as shown in FIG. **3** to form an interlocking seal at the distal end **39** that provides a fluid-tight barrier, and when blow-out valve **28** is open the flexible members **30** disengage from each other to open the blow-out valve **28** and permit the pressure within battery pack **18** to escape the discharge vent **26**. While three flexible members **30** are illustrated, it should be understood that the blow-out valve **28** may include a greater or lesser number of flexible members **30**, if desired. In any event, it should be understood that the structure of blow-out valve **28** enables flexible members **30** to be re-closed (i.e., but back into contact with each other) to re-use the blow-out valve **28** after gases have escaped from battery pack **18**.

[0043] Now referring to FIGS. **4**A and **4**B, blow-out valve **28** is illustrated in the open (FIG. **4**A) and closed (FIG. **4**B) positions. FIG. **4**A illustrates the blow-out valve **28** in an "as-molded" condition where blow-out valve **28** is open, and FIG. **4**B illustrates the blow-out valve **28** in an "inverted" and closed position where throat **36** and flexible members **30** are pressed through aperture **42** such that flexible members **30** are engaged with each other to form the interlocking seal. To assist in maintaining flexible members **30** in engagement when blow-out valve **28** is closed, a biasing ring or garter spring **56** may be placed about an outer perimeter of the throat **36**.

[0044] As shown in FIG. **4**A, flexible members **30** extends outward from annular base **34** in the positive z-direction when blow-out valve **28** is open. When blow-out valve **28** is closed as shown in FIG. **4**B, flexible members **30** and throat **36** are inverted to extend outward from annular base **34** in the negative z-direction. When flexible members **30** and throat **36** are inverted, an outer radial surface **57** of a respective flexible member **30** will contact the outer radial surfaces **57** of the other flexible members **30** to form the interlocked seal shown in FIG. **3**. When flexible members **30** are in the open position (FIG. **4**A), an inner radial surface **55** of the flexible members **30** collectively define a cylindrical outlet **59** that permits gases to escape blow-out valve **28**.

[0045] Flexible members **30** each include a planar surface **53** that, when blow-out valve **28** is in the closed position, can be impinged upon by the gases that may develop during a thermal runaway event. Once the force exerted by the gases on planar surface **53** has reached a predetermined threshold (i.e., 100 millibars), flexible members **30** may be forced in the positive z-direction where outer radial surfaces **57** disengage from each other and blow-out valve **28** is opened (FIG. **4**A). Flexible members **30** include planar surface **53** because a thickness of flexible members **30** increases from first end **37** to second end **39**.

[0046] As noted above, blowout valve **28** may optionally include a garter spring **56** (shown in FIG. **4**B) that can prevent blowout valve **28** from unnecessarily opening when in the inverted (i.e., closed) position. In this regard, if a negative pressure were to develop within battery pack **18**, a positive pressure located exterior to battery pack **18** may be sufficient to partially push outer radial surfaces **57** of flexible members **30** away from each other and permit ambient air, dust, and/or moisture to enter into the housing **20**. Due to the presence of garter spring **56**, however, the interlocked seal between the flexible members **30** in the closed position is maintained. The garter spring **56** may be formed from an elastomeric material, metal, or a combination of both. The garter spring **56** may wrap around the interlocked flexible members **30** and exert an inward radial force upon the flexible members **30** that maintains blowout valve **28** in the closed position when a negative pressure exists in housing **20**.

[0047] It should be understood that garter spring **56** does not prevent blowout valve **28** from opening upon reaching the predetermined threshold pressure described above. Indeed, garter spring **56** is designed to naturally slip off the blow-out valve **28** when flexible members **30** move from the closed to the open position.

[0048] FIGS. **5**A-**5**D schematically illustrate operation of blow-out valve **28**. FIG. **5**A depicts the blow-out valve **28** in the closed position where pressure within battery pack **18** is below the threshold (e.g., 100 millibars) required to open blow-out valve **28**. FIG. **5**B depicts the blow-out valve **28** under a pressure that is approaching the gas pressure threshold (e.g., 100 millibars), but where the gases (illustrated as particles **40** for ease of description) are depicted as dense and agitated. In this state, the flexible members **30** can be seen as beginning to deform, rolling upwards and away from the high pressure gas **40** pushing against it. FIG. **5**C depicts the blow-out valve **28** under pressure that has exceeded the gas pressure threshold required to open the blow-out valve **28***b* (e.g., 100 millibars), and the flexible members **30** having moved from the inverted state (FIGS. **5**A and **5**B) to the open state where the gases **40** are permitted to exit the battery pack **18** through vents **26** and the blow-out valves **28**, which rapidly equalizes the pressure in battery pack **18** as shown in FIG. **5**D. In this example, damage to the battery and electric vehicle may be avoided or at least substantially minimized. Once the gases have exited the battery pack **18**, the faulty cells **22** can be removed therefrom and the blow-out valves **28** may simply be pushed and inverted to once more form the interlocking seal between surfaces **57** of flexible members **30**.

[0049] The gas pressure threshold of that can trigger opening blow-out valves **28** may be determined by a length L of the planar surfaces **53** of the flexible members **30**, and the elasticity of the elastomer used to form the blow-out valves **28**. With respect to the length L, the force required to open the blow-out valve **28** is a product of pressure and the area over which it acts. The larger the length L the greater the amount of gas pressure required to move the blow-out valve **28** from the closed position to the open position. Various lengths L, and thus various gas pressure thresholds, are contemplated. In this regard, the threshold can be above or below 100 millibars, if desired.

[0050] The gas pressure threshold may be further determined by the elasticity of the elastomer. By adjusting the elasticity of the elastomer, the gas pressure threshold of the blow-out valve **28** may be decreased or increased, respectively. The more elastic material will open at lower pressures, while a less elastic material will require higher pressures.

[0051] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

What is claimed is:

1. A valve configured for use with a battery pack having a discharge vent for discharging gases from the battery pack, the valve comprising:

an annular base located proximate the discharge vent and defining a through-hole;

a hollow throat section having a proximate end connected to the annular base at the through-hole and a distal end located away from the annular base; and

a plurality of flexible members attached to the distal end that are configured to mate together to seal the aperture when the valve is in a closed position and configured to separate when the valve is in an open position,

wherein the plurality of flexible members are configured to separate when a pressure within the battery pack reaches a predetermined threshold, and

in a closed position of the valve, the hollow throat section including the flexible members extends away from the through-hole in a negative z-direction, and in an open position of the valve the hollow throat section including the flexible members extend away from the through-hole in a positive z-direction.

2. The valve according to claim **1**, wherein each of the plurality of flexible members include edges that are configured to mate and form an interlocked seal when the valve is in the closed position.

3. The valve according to claim **2**, wherein the edges separate to open the interlocked seal when the valve is in the open position.

4. The valve according to claim **1**, wherein the predetermined threshold to open the valve is about 100 millibars.

5. The valve according to claim **1**, wherein each of the annular base, the throat section, and the plurality of flexible members are formed of an elastomeric material.

6. The valve according to claim **5**, wherein the elastomeric material is selected from the group consisting of a natural or synthetic rubber material, a silicone material, and polyurethane material.

7. The valve according to claim **1**, wherein each of the annular base, the throat section, and each of the plurality of flexible members form a monolithic structure.

8. A battery pack comprising:

a housing configured to support a plurality of battery cells;

a plurality of discharge vents that are configured to discharge gases generated by at least one of the plurality of battery cells; and

a valve provided in each of the discharge vents that is configured to open to permit the discharge gases to escape the housing through each of the discharge vents,

wherein each of the valves includes an annular base located proximate the discharge vent and defining a through-hole;

a hollow throat section having a proximate end connected to the annular base at the through-hole and a distal end located away from the annular base; and

a plurality of flexible members attached to the distal end that are configured to mate together to seal the aperture when the valve is in a closed position and configured to separate when the valve is in an open position,

wherein the plurality of flexible members are configured to separate when a pressure within the battery pack reaches a predetermined threshold, and in a closed position of the valve, the hollow throat section including the flexible members extends away from the through-hole in a negative z-direction, and in an open position of the valve the hollow throat section including.

9. The battery pack according to claim **8**, wherein each of the plurality of flexible members include edges that are configured to mate and form an interlocked seal when the valve is in the closed position.

10. The battery pack according to claim **9**, wherein the edges separate to open the interlocked seal when the valve is in the open position.

11. The battery pack according to claim **8**, wherein the predetermined threshold to open the valve is about 100 millibars.

12. The battery pack according to claim **8**, wherein each of the annular base, the throat section, and the plurality of flexible members are formed of an elastomeric material.

13. The battery pack according to claim **12**, wherein the elastomeric material is selected from the group consisting of a natural or synthetic rubber material, a silicone material, and polyurethane material.

14. The battery pack according to claim **8**, wherein each of the annular base, the throat section, and each of the plurality of flexible members form a monolithic structure.

* * * * *