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Kollar et al.

(54) **PLUG ASSEMBLY FOR OPENING AND CLOSING A DRAIN HOLE**

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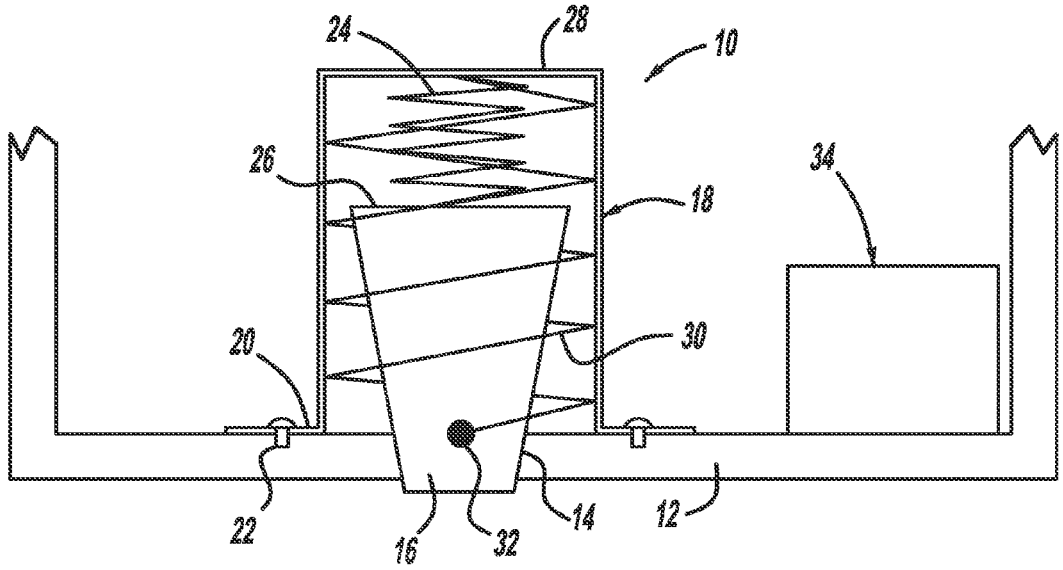
CPC *F16K 31/025* (2013.01)

(57) **ABSTRACT**

A drain plug assembly that has particular application for sealing a drain hole in a battery compartment on a vehicle. The plug assembly includes a plug that inserted into the drain hole and a cover covering the plug. The plug assembly also includes a first shape memory alloy (SMA) wire having ends attached to the cover and a middle portion attached to the plug and a second SMA wire having ends attached to the cover and a middle portion attached to the plug. The plug assembly also includes a mechanical hinge attached to the plug and the cover, wherein the first SMA wire is actuated to flip the hinge to position the plug in a closed position to close the drain hole and the second SMA wire is actuated to flip the hinge to position the plug in an open position to open the drain hole.



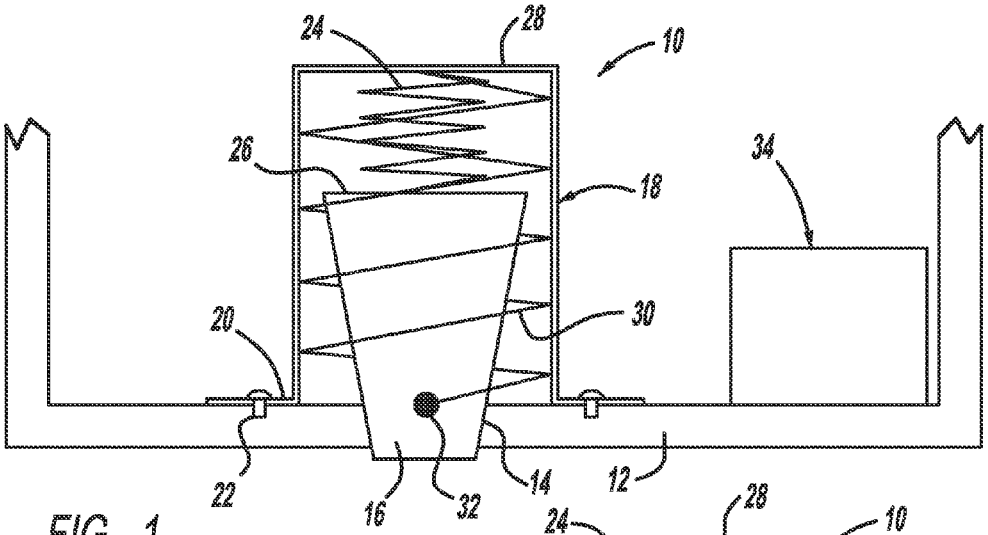


FIG - 1

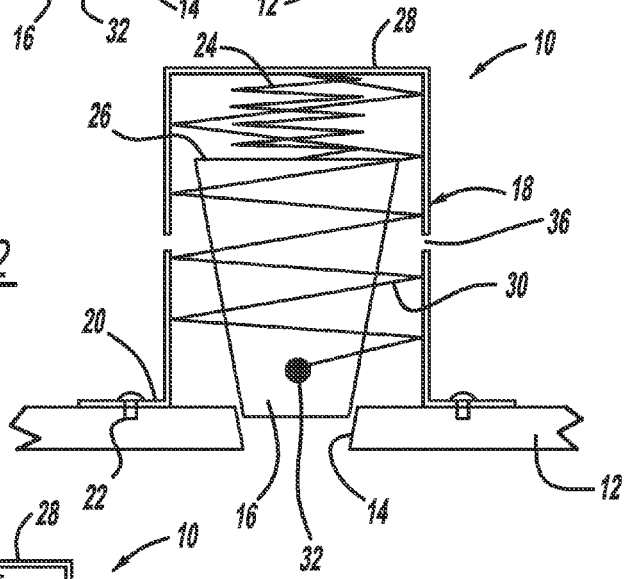


FIG - 2

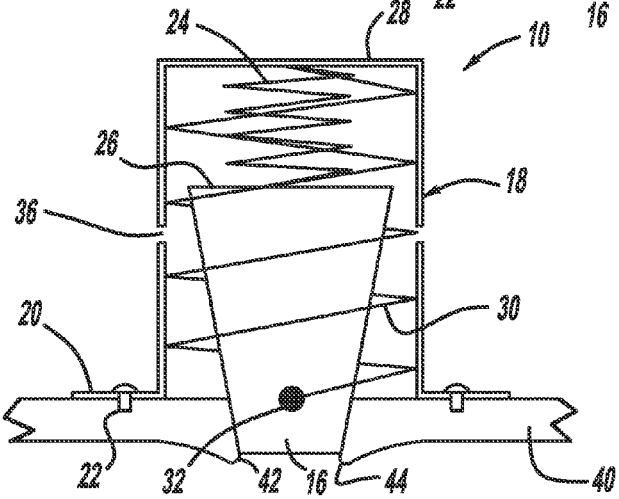


FIG - 3

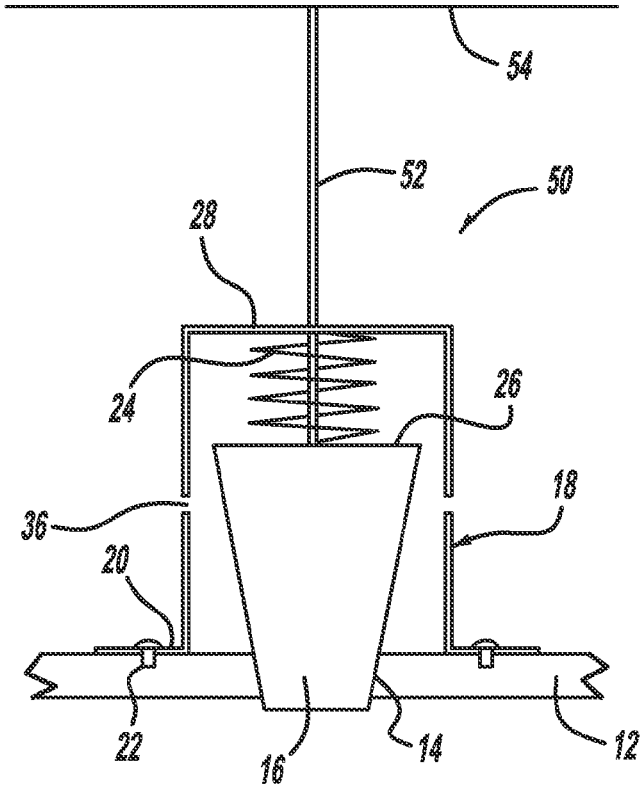

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FIG - 4

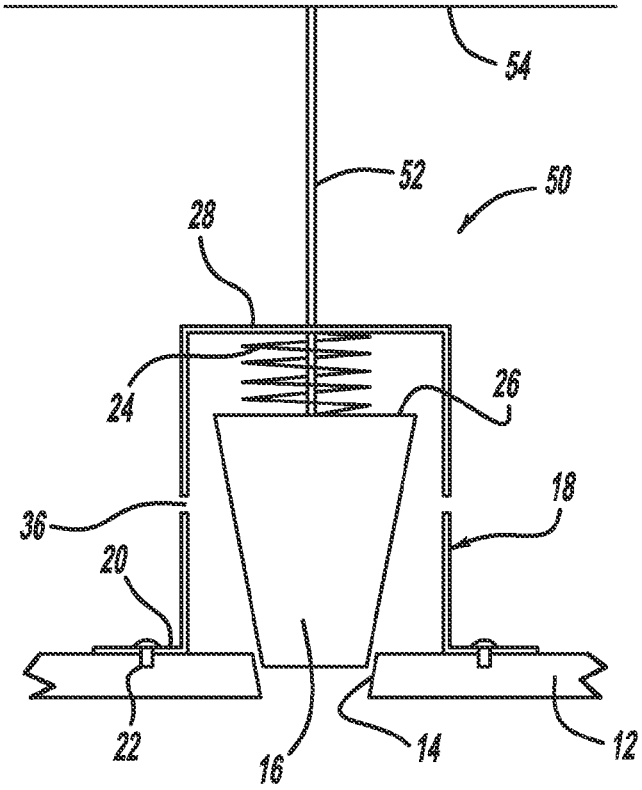
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FIG - 5

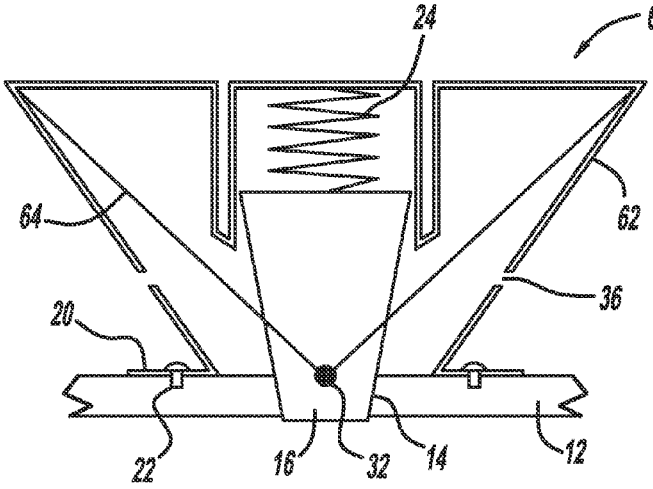

FIG - 6

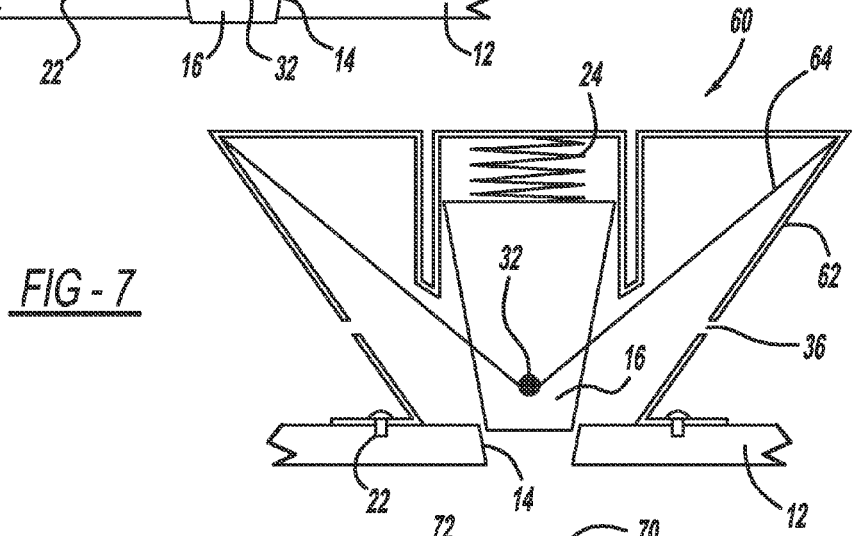

FIG - 7

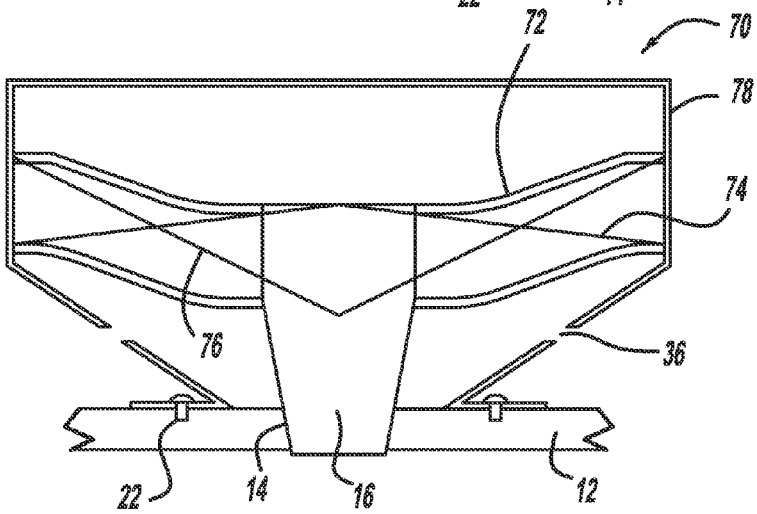

FIG - 8

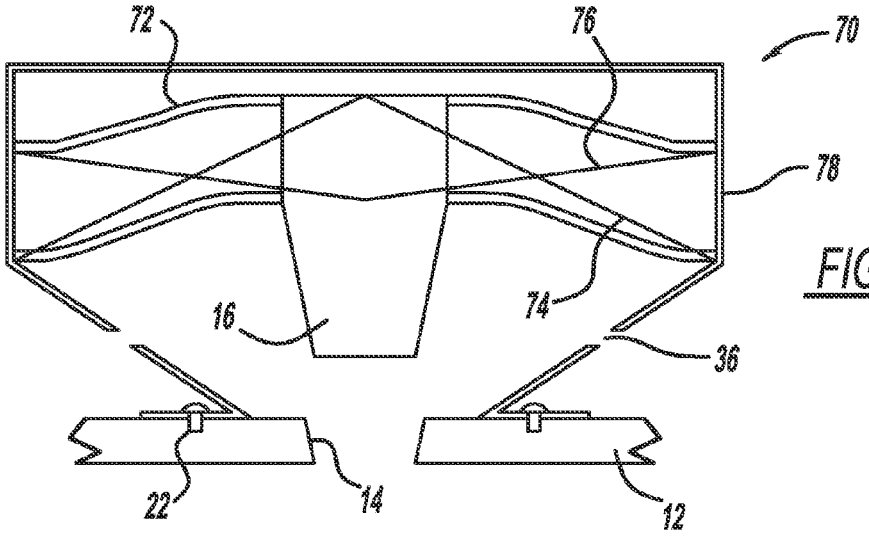

FIG - 9

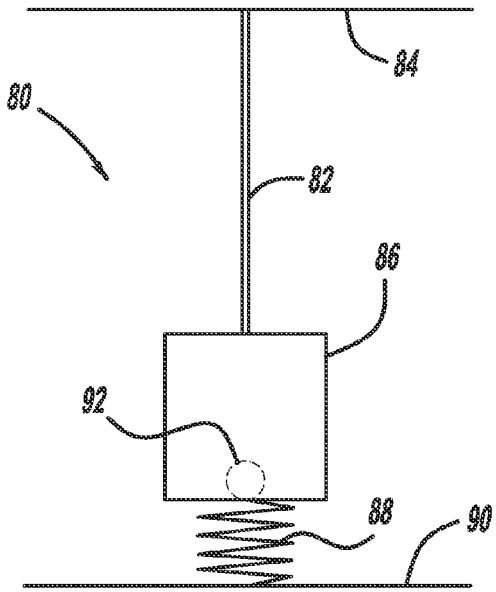

FIG - 10

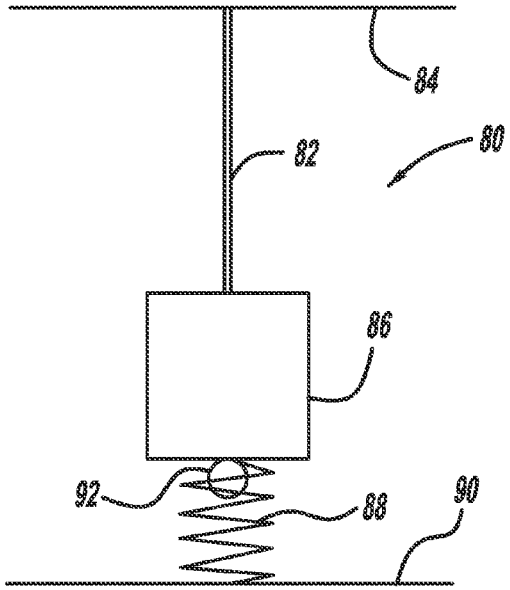

FIG - 11

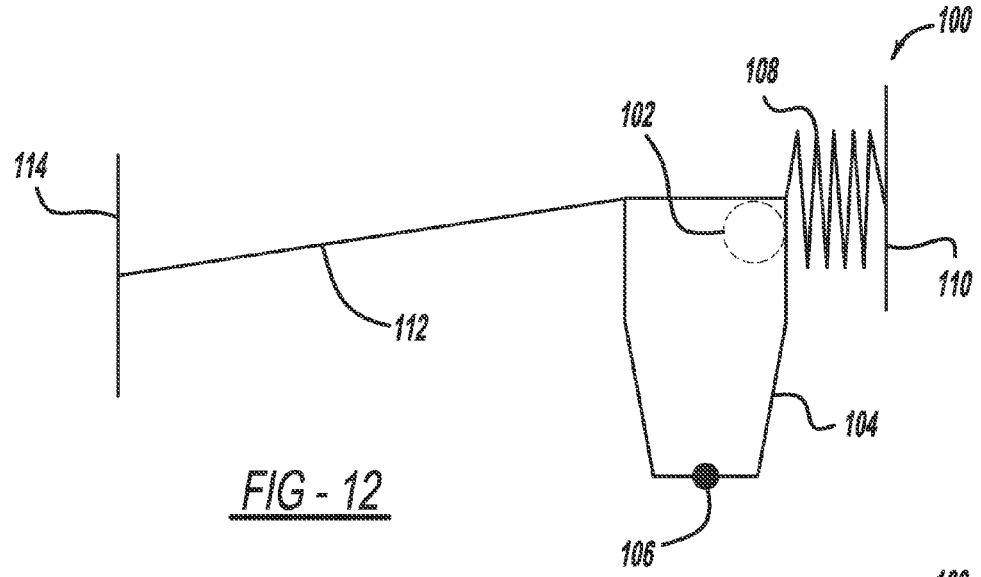

FIG - 12

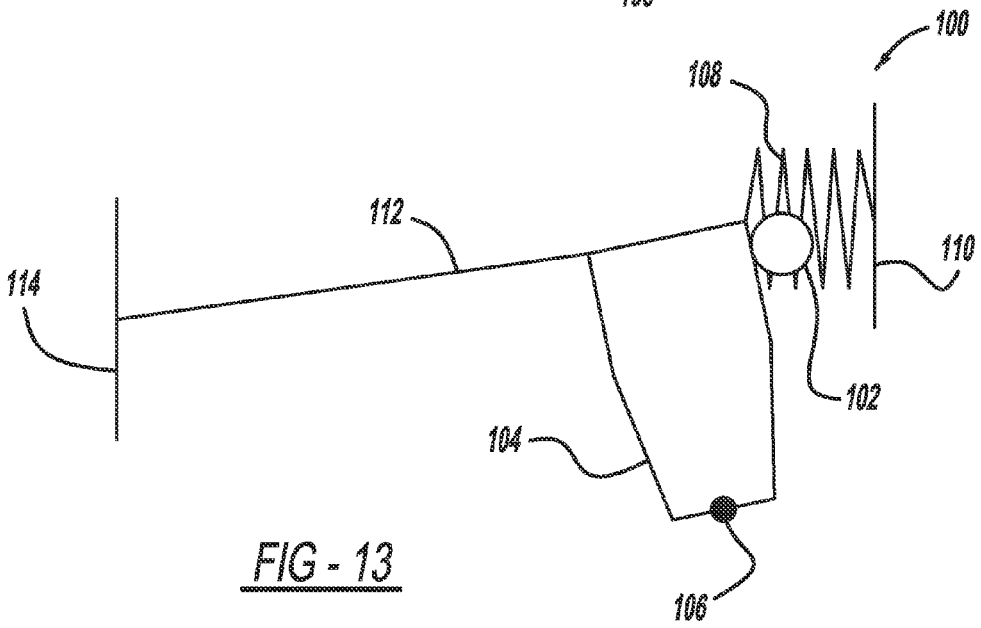

FIG - 13

PLUG ASSEMBLY FOR OPENING AND CLOSING A DRAIN HOLE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Divisional application of U.S. patent application Ser. No. 12/913,224, filed Oct. 27, 2010, titled "Active Drain Plug for High Voltage Battery Applications".

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates generally to a drain plug for an enclosure and, more particularly, to a drain plug assembly for a battery enclosure that employs a shape memory alloy (SMA) device for actuating the drain plug.

[0004] 2. Discussion of the Related Art

[0005] Electric vehicles are becoming more and more prevalent. These vehicles include hybrid vehicles, such as the extended range electric vehicles (EREV) that combine a battery and a main power source, such as an internal combustion engine, fuel cell systems, etc., and electric only vehicles, such as the battery electric vehicles (BEV). All of these types of electric vehicles employ a high voltage battery that includes a number of battery cells. These batteries can be different battery types, such as lithium ion, nickel metal hydride, lead acid, etc. A typical high voltage battery system for an electric vehicle may include a large number of battery cells or modules including several battery cells to meet the vehicle power and energy requirements.

[0006] The high voltage battery on an electric vehicle is typically mounted to a support member and covered with a suitable protective cover that provides a number of functions. For example, the cover is a protective cover in that it prevents the battery cells from being damaged as a result of collision with other objects. Further, the cover provides electrical insulation from the high voltage of the battery to protect individuals and users.

[0007] Various sources may cause fluids to accumulate within the battery enclosure. Because the vehicle battery is a high voltage battery, it is desirable to remove or drain any fluids that may have accumulated in the enclosure. In order to provide this drainage, the lower support structure on which the battery pack is mounted typically includes a drain plug that is inserted into an opening in the wall of the enclosure, which can be removed to drain the fluid that accumulates in the enclosure. For example, it is known in the art to provide a flexible plug in a drain hole that is provided at a desirable location in the battery pack enclosure. In one design, the drain hole is about 20 mm in diameter.

[0008] Because of the high voltage environment, it is typically necessary that any fluid that has accumulated in the battery enclosure that requires the plug be removed be performed by a trained service technician where the vehicle needs to be taken to a reputable service center. Further, it is sometimes difficult to know if fluid has accumulated in the battery enclosure, requiring such a trip to the service center. Also, the known plugs that are inserted into the drain hole of the battery enclosure often times leak themselves where water from driving through a wet environment may enter the enclosure through the drain hole around the plug.

SUMMARY OF THE INVENTION

[0009] The present disclosure describes a drain plug assembly that has particular application for sealing a drain hole in a high voltage battery compartment on a vehicle. The plug assembly includes a plug that is inserted into the drain hole and a cover covering the plug. The plug assembly also includes a first shape memory alloy (SMA) wire having a first end attached to one side of the cover, a second end attached to an opposite side of the cover and a middle portion attached to the plug, and a second SMA wire having a first end attached to one side of the cover, a second end attached to an opposite side of the cover and a middle portion attached to the plug. The plug assembly also a mechanical hinge attached to the plug and the cover, where the first SMA wire is actuated to flip the hinge to position the plug in a closed position to close the drain hole and the second SMA wire is actuated to flip the hinge to position the plug in an open position to open the drain hole, and where the first and second SMA wires are actuated by applying a current to the wires.

[0010] Additional features of the present invention will become apparent from the following description and appended claims, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a side plan view of a plug assembly for sealing a drain hole where the plug is in the closed position;

[0012] FIG. **2** is a side plan view of the plug assembly shown in FIG. **1** where the plug in the open position;

[0013] FIG. **3** is a side plan view of the plug assembly shown in FIG. **1** where the drain hole includes an anti-splash guard feature;

[0014] FIG. **4** is a side plan view of another plug assembly for sealing a drain hole where the plug is in the closed position;

[0015] FIG. **5** is a side plan view of the plug assembly shown in FIG. **4** where the plug in the open position;

[0016] FIG. **6** is a side plan view of another plug assembly for sealing a drain hole where the plug is in the closed position;

[0017] FIG. **7** is side plan view of the plug assembly shown in FIG. **6** where the plug is in the open position;

[0018] FIG. **8** is a side plan view of another plug assembly for sealing a drain hole where the plug is the closed position;

[0019] FIG. **9** is a side plan view of the plug assembly shown in FIG. **8** where the plug is in the open position;

[0020] FIG. **10** is a side plan view of another plug assembly for sealing a drain hole where the plug is in the closed position;

[0021] FIG. **11** is a side plan view of the plug assembly shown in FIG. **10** where the plug is in the open position;

[0022] FIG. **12** is a side plan view of another plug assembly for sealing a drain hole where the plug is in the closed position; and

[0023] FIG. **13** is a side plan view of the plug assembly shown in FIG. **12** where the plug is in the open position.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0024] The following discussion of the embodiments of the invention directed to a plug assembly for sealing a drain hole, where the plug assembly employs an SMA device, is merely exemplary in nature, and is in no way intended to limit the

invention or its application or uses. For example, the plug assembly of the invention has particular application for sealing a drain hole in a high voltage battery enclosure on a vehicle. However, as will be appreciated by those skilled in the art, the plug assembly of the invention may have other applications, such as boat hulls.

[0025] FIG. **1** is a side plan view of a plug assembly **10** mounted to a wall **12** having a drain hole **14**. In the non-limiting embodiment being discussed herein, the wall **12** is a bottom plate, or other suitable structure, of an enclosure for a high voltage battery **34** on a vehicle. The plug assembly **10** includes a plug **16**, shown in the closed position, that is made of suitable resilient material and appropriately shaped to fit within the drain hole **14** to provide a suitable seal. FIG. **2** is a side plan view of the plug assembly **10** where the plug **16** is shown in the open position to remove fluids from the enclosure. The drain hole **14** and the plug **16** have a corresponding conical shape so that when the plug **16** is inserted into the drain hole **14** it conforms to the shape of the hole **14** to provide the desired sealing. Further, the shape of the plug **16** and the drain hole **14** allows the plug **16** to provide a self centering feature within the hole **14** so that the plug **16** is properly aligned in the hole **14**. Further, as the plug **16** wears over time, it's conically shape allows it to sink deeper into the hole **14** to continue to provide the desired sealing.

[0026] The plug assembly **10** also includes an outer cover **18** having an edge flange **20** that is mounted to an inside surface of the wall **12** by suitable bolts **22**. The cover **18** includes suitable openings, slots, holes, etc., represented generally by reference number **36**, that allow fluid that accumulates within the enclosure to flow through the cover **18** and out of the drain hole **14**.

[0027] The plug assembly **10** also includes a helical return spring **24** having one end mounted to, or in contact with, a top end **26** of the plug **16** and opposite end mounted to, or in contact with, a top plate **28** of the housing **18**. The plug assembly **10** also includes a helical wound shape memory alloy (SMA) device **30** having a first end mounted to an attachment point **32** at an end of the plug **16** proximate the hole **14** and an opposite end mounted to, or in contact with, the top plate **28** so that the plug **16** is generally positioned within the SMA device **30**, as shown. The SMA device **30** is made of a suitable shape memory alloy, discussed in more detail below, that performs the desired function discussed herein.

[0028] Shape memory alloys are well known to those skilled in the art and provide a number of desirable features. Suitable shape memory alloy materials include nickel-titanium based alloys, indium-titanium based alloys, nickel-aluminum based alloys, nickel-gallium based alloys, copper based alloys (e.g., copper-zinc alloys, copper-aluminum alloys, copper-gold, and copper-tin alloys), gold-cadmium based alloys, silver-cadmium based alloys, indium-cadmium based alloys, manganese-copper based alloys, iron-platinum based alloys, iron-platinum based alloys, iron-palladium based alloys, and the like. The alloys can be binary, ternary, or any higher order so long as the alloy composition exhibits a shape memory effect, e.g., change in shape orientation, damping capacity, and the like. For example, a nickel-titanium based alloy is commercially available under the trademark NITINOL from Shape Memory Applications, Inc.

[0029] Shape memory alloys exhibit a one-way shape memory effect, an intrinsic two-way effect, or an extrinsic two-way shape memory effect depending on the alloy composition and processing history. The two phases that occur in shape memory alloys are often referred to as martensite and austenite phases. The martensite phase is a relatively soft and easily deformable phase of the shape memory alloys, which generally exists at lower temperatures. The austenite phase, the stronger phase of shape memory alloys, occurs at higher temperatures. Shape memory materials formed from shape memory alloy compositions that exhibit one-way shape memory effects do not automatically reform, and depending on the shape memory material design, will likely require an external mechanical force to reform the shape orientation that was previously exhibited. Shape memory materials that exhibit an intrinsic shape memory effect are fabricated from a shape memory alloy composition that will automatically reform themselves.

[0030] The temperature at which the shape memory alloy remembers its high temperature form when heated can be adjusted by slight changes in the composition of the alloy and through heat treatment. In nickel-titanium shape memory alloys, for example, it can be changed from above about 100° C. to below about −100° C. The shape recovery process occurs over a range of just a few degrees and the start or finish of the transformation can be controlled to within a degree or two depending on the desired application and alloy composition. The mechanical properties of the shape memory alloy vary greatly over the temperature range spanning their transformation, typically providing the shape memory material with shape memory effects as well as high damping capacity. The inherent high damping capacity of the shape memory alloys can be used to further increase the energy absorbing properties.

[0031] In this embodiment, an electrical current is applied to the SMA device **30** to cause it to change its state as a result of the heat generated therein. When the current is applied, the SMA device **30** contracts against the bias of the return spring **24** so that the plug **16** is drawn up into the cover **18** and out of the drain hole **14**, as shown in FIG. **2**. A discussion of when the control for the plug assembly **10** performs this operation will be provided below.

[0032] It is possible that dirt, mud and other debris from the road way may enter and clog the drain hole **14** and limit the fluid flow from the enclosure through the hole **14**. Further, obstacles hitting the plug **16** can cause it to lift up out of the hole **14** against the bias of the spring **24**, thus allowing water or other fluids to enter the enclosure through the hole **14**. In order to help prevent these detrimental effects from occurring, the wall **12** can be modified. FIG. **3** is a side plan view of the plug assembly **10** being used in an enclosure having a wall **40** with a drain hole **42** that has been modified to include an annular feature **44**. The feature **44** extends down from the plug **16** and prevents obstacles and debris from hitting the plug **16**.

[0033] The helical wound SMA device **30** in the plug assembly **10** is one non-limiting embodiment for providing an SMA actuated plug. FIG. **4** is a side plan view of a plug assembly **50** similar to the plug assembly **10**, where like elements are defined by the same reference number, and where the plug **16** is in the closed position. FIG. **5** is a side plan view of the plug assembly **50** where the plug **16** is in the open position. In this design, the helical wound SMA device **30** has been replaced with a straight wire SMA device **52** that has one end attached to the top surface **26** of the plug **16** and an opposite end attached to a mounting plate **54**. The mounting plate **54** may or may not be within the battery enclosure.

As above, when the SMA device **52** is heated, it contracts and shortens its length, which pulls the plug **16** up against the bias of the spring **24** to open the drain hole **14**, as shown in FIG. **5**.

[0034] FIG. **6** is a side plan view of a plug assembly **60** similar to the plug assembly **10**, where like elements are identified by the same reference numeral, and where the plug **16** is in the closed position. FIG. **7** is a side plan view of the plug assembly **60** showing the plug **16** in the open position. In this design, the cover **18** has been replaced with a cover **62** having a conical configuration and the helical wound SMA device **30** has been replaced with a bow-string SMA device **64**. This configuration of the cover **62** allows the bow-string type SMA device **64** to be connected at upper corners of the cover **62** to accommodate a bow-string operation. One end of the device **64** is attached to an upper attachment point of the cover **62** and an opposite end of the device **64** is attached to an opposite edge of the cover **62**, where a middle point of the device **64** is attached to the attachment point **32**. When the SMA device **64** is in its non-actuated state with no electrical current flow therethrough, shown in FIG. **6**, the bias of the spring **24** forces the plug **16** into the hole **14**. When the device **64** is heated by a flow of electrical current, its length is shortened due to the shape memory effect, which causes the plug **16** to move upward against the bias of the string **24** to open the hole **14**.

[0035] FIG. **8** is a side plan view of a plug assembly **70** similar to the plug assembly **10**, where like elements are identified by the same reference numeral, and where the plug **16** is in the closed position. FIG. **9** is a side plan view of the plug assembly **70** with the plug **16** in the open position. In this design, the plug assembly **70** includes a mechanical hinge **72** that attaches the plug **16** to the inside of a cover **78**. The hinge **72** can be any device, or assembly of components, and be made of any material suitable for the purposes discussed herein. The hinge **72** flips from the closed position shown in FIG. **8** to the open position shown in FIG. **9**, and back, when SMA devices **74** and **76** are actuated.

[0036] The SMA device **74** is a wire that includes one end attached to one side of the cover **78** and an opposite end attached to an opposite side of the cover **78**, where a center part of the device **74** is securely mounted to a top end of the plug **16** in any suitable manner so that the device **74** has a general upward pointing configuration, as shown. Likewise, the SMA device **76** is a wire that includes one end attached to one side of the cover **78** and an opposite end attached to an opposite side of the cover **78**, where a center part of the device **76** is securely mounted to the plug **16** at a central location so that the device **76** has a general downward pointing configuration, as shown. When the plug **16** is in the closed position, and it is desirable to open the drain hole **14**, current is applied to the device **76**, which causes it to contract and causes the hinge **72** to flip from the closed position to the open position. Once the plug **16** is in the open position, then the current to the device **76** is turned off. Likewise, when the plug **16** is in the open position and it is desirable to close the drain hole **14**, current is applied to the SMA device **74**, which causes it to contract and flip the hinge **72** to the closed position, where the plug **16** is positioned within the drain hole **14**. Once the plug is in the closed position, then the current to the device **74** is turned off.

[0037] FIG. **10** is a side plan view of a plug assembly **80**, which employs a straight wire SMA device **82**. One end of the device **82** is attached to a first mounting structure **84** and an opposite end of the device **82** is attached to a plug **86**. A return spring **88** is also attached to the plug **86** and a second mounting structure **90**. When the SMA device **82** is not being actuated by a current flow, the bias of the return spring **88** causes the plug **86** to be positioned over a drain hole **92** so that it is closed. When current is applied to the SMA device **82**, causing it to contract, the plug **86** slides away from the drain hole **92** against the bias of the return spring **88**, as shown in FIG. **11**.

[0038] FIG. **12** is a plan view of a plug assembly **100** that is also applicable to open and close a drain hole **102**, such as a drain hole in a battery enclosure. The plug assembly **100** includes a plug **104** that is pivotally mounted to a suitable structure at a pivot point **106**. A return spring **108** includes one end coupled to an opposite end of the plug **104** from the pivot point **106** and an opposite end to a support structure **110**. The plug assembly **100** also includes a wire SMA device **112** having one end coupled to an end of the plug **104** opposite to the pivot point **106** and an opposite end mounted to an SMA device attachment structure **114**. When the SMA device **112** is not actuated, the bias of the spring **108** causes the plug **104** to pivot at the pivot point **106** and close the drain hole **102**. However, when it is desirable to open the drain hole **102**, a current is applied to SMA device **112** causing it to shrink and pivot the plug **104** at the pivot point **106** to open the drain hole **102**, as shown in FIG. **13**.

[0039] The various plug assemblies discussed above can include a suitable controller (not shown) that automatically opens the drain hole **14** at a desirable time to drain any fluid out of the battery enclosure that may have accumulated therein. For example, the controller may determine that the vehicle is parked, the vehicle speed is zero and, for an electrical vehicle, determine that the battery is being charged. In this condition, it would be relatively safe to open the drain hole **14**, where the controller may automatically provide current to any one of the SMA devices discussed above to cause the plug **16** to be put in the open position. Other control features may be employed, such as determining whether the vehicle is on a level plane through a level sensor. Further, to save complexity and cost of the controller, the plug assembly can be designed so that the SMA device is actuated whenever the vehicle is in charging using a simple circuit. The particular design may include a feature to only actuate the SMA device when the vehicle is charging and possibly pulse the SMA device when the vehicle starts to make sure the plug **16** is set properly.

[0040] In a more sophisticated design, suitable sensors can be provided to determine if fluid has accumulated in the enclosure, and if so, cause the SMA device to be activated to open the drain hole under certain conditions. The various plug assemblies can be designed to detect if the drain hole **14** is blocked using the SMA device which can detect overload conditions. Further, the SMA device may be able to detect that it is in a fluid environment as a result of its characteristics as opposed to being in air environment. Further, in freeze conditions, a trickle current can be provided to the SMA device to cause it and other elements to melt before it is actuated. Further, wicking cords can be employed to bring fluid from other places in the enclosure to the drain hole.

[0041] The foregoing discussion disclosed and describes merely exemplary embodiments of the present invention. One skilled in the art will readily recognize from such discussion and from the accompanying drawings and claims that various changes, modifications and variations can be made therein

without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A plug assembly for opening and closing a drain hole, said plug assembly comprising:

a plug that seals the drain hole when the plug is inserted into the drain hole;

a cover covering the plug;

a first shape memory alloy (SMA) wire having a first end attached to one side of the cover, a second end attached to an opposite side of the cover and a middle portion attached to the plug; and

a second SMA wire having a first end attached to one side of the cover, a second end attached to an opposite side of the cover and a middle portion attached to the plug, wherein the first SMA wire is actuated to position the plug in a closed position to close the drain hole and the second SMA wire is actuated to position the plug in an open position to open the drain hole, and wherein the first and second SMA wires are actuated by applying a current to the wires.

2. The plug assembly according to claim **1** further comprising a mechanical hinge attached to the plug and the cover, said first SMA wire is actuated to flip the hinge to position the plug in the closed position and the second SMA wire is actuated to flip the hinge to position the plug in the open position.

3. The plug assembly according to claim **2** wherein the first SMA wire is attached to a top end of the plug and the second SMA wire is attached to a middle portion of the plug.

4. The plug assembly according to claim **1** wherein the cover includes at least one opening.

5. The plug assembly according to claim **1** wherein the plug and the drain hole are tapered.

6. The plug assembly according to claim **1** wherein the drain hole includes an anti-splash guard rim that extends down from the plug.

7. The plug assembly according to claim **1** wherein the drain hole is in an enclosure that houses a battery.

8. The plug assembly according to claim **7** where the battery is a high voltage battery for an electric vehicle.

9. A plug assembly for opening and closing a drain hole in an enclosure that houses a battery, said plug assembly comprising:

a plug that seals the drain hole when the plug is inserted into the drain hole;

a cover covering the plug;

a first shape memory alloy (SMA) wire having a first end attached to one side of the cover, a second end attached to an opposite side of the cover and a middle portion attached to the plug;

a second SMA wire having a first end attached to one side of the cover, a second end attached to an opposite side of the cover and a middle portion attached to the plug; and

a mechanical hinge attached to the plug and the cover, wherein the first SMA wire is actuated to flip the hinge to position the plug in a closed position to close the drain hole and the second SMA wire is actuated to flip the hinge to position the plug in an open position to open the drain hole, and wherein the first and second SMA wires are actuated by applying a current to the wires.

10. The plug assembly according to claim **9** wherein the first SMA wire is attached to a top end of the plug and the second SMA wire is attached to a middle portion of the plug.

11. The plug assembly according to claim **9** wherein the cover includes at least one opening.

12. The plug assembly according to claim **9** wherein the plug and the drain hole are tapered.

13. The plug assembly according to claim **9** wherein the drain hole includes an anti-splash guard rim that extends down from the plug.

14. The plug assembly according to claim **9** where the battery is a high voltage battery for an electric vehicle.

15. A plug assembly for opening and closing a tapered drain hole in an enclosure that houses a high voltage battery for an electric vehicle, said plug assembly comprising:

a tapered plug that seals the drain hole when the plug is inserted into the drain hole, wherein the drain hole includes an anti-splash guard rim that extends down from the plug;

a cover covering the plug;

a first shape memory alloy (SMA) wire having a first end attached to one side of the cover, a second end attached to an opposite side of the cover and a middle portion attached to the plug;

a second SMA wire having a first end attached to one side of the cover, a second end attached to an opposite side of the cover and a middle portion attached to the plug; and

a mechanical hinge attached to the plug and the cover, wherein the first SMA wire is actuated to flip the hinge to position the plug in a closed position to close the drain hole and the second SMA wire is actuated to flip the hinge to position the plug in an open position to open the drain hole, and wherein the first and second SMA wires are actuated by applying a current to the wires.

16. The plug assembly according to claim **15** wherein the first SMA wire is attached to a top end of the plug and the second SMA wire is attached to a middle portion of the plug.

17. The plug assembly according to claim **15** wherein the cover includes at least one opening.

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