US008857167B2

(12) **United States Patent**
Johnson et al.

(10) **Patent No.: US 8,857,167 B2**
(45) **Date of Patent: Oct. 14, 2014**

(54) **INTEGRAL ACCUMULATOR/RESERVOIR SYSTEM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 891 days.

(21) Appl. No.: **12/932,808**

(22) Filed: **Mar. 7, 2011**

(65) **Prior Publication Data**

US 2011/0219761 A1 Sep. 15, 2011

Related U.S. Application Data

(60) Provisional application No. 61/311,188, filed on Mar. 5, 2010.

(51) **Int. Cl.**
F15B 1/26 (2006.01)
F15B 1/16 (2006.01)

(52) **U.S. Cl.**
CPC ***F15B 1/26*** (2013.01); *F15B 2201/4053* (2013.01); *F15B 2201/3152* (2013.01); ***F15B 1/165*** (2013.01); *F15B 2201/4155* (2013.01); *F15B 2201/205* (2013.01)
USPC **60/414**; 138/30

(58) **Field of Classification Search**
USPC 60/414, 418; 138/26, 30
See application file for complete search history.

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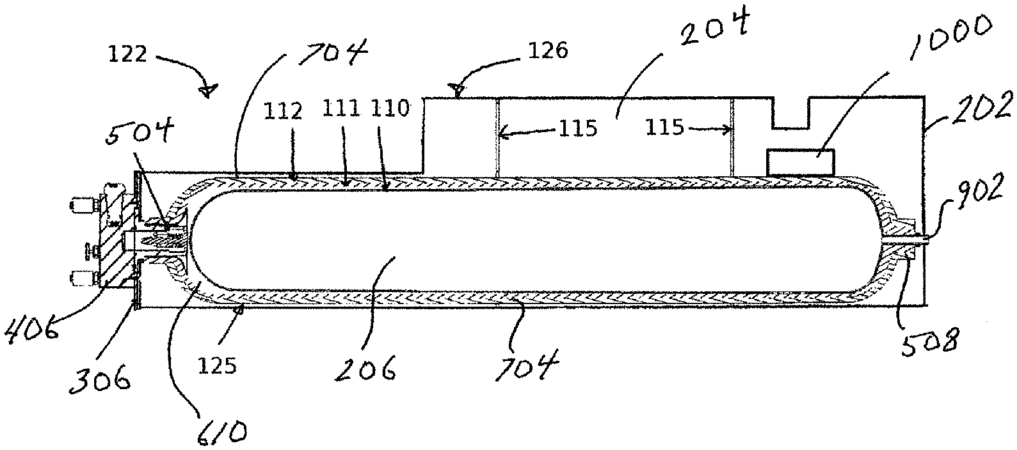
(57) **ABSTRACT**

An integral accumulator/reservoir system including a low pressure vessel having a low-pressure vessel wall defining a low-pressure vessel cavity; a high-pressure accumulator having a high-pressure accumulator wall defining a high-pressure accumulator cavity, the high-pressure accumulator being disposed in the low-pressure vessel cavity, the high-pressure accumulator wall including an aluminum layer; a flexible bladder, the flexible bladder being disposed in the high-pressure accumulator cavity; and a sensor module operably connected to the aluminum layer.

20 Claims, 9 Drawing Sheets



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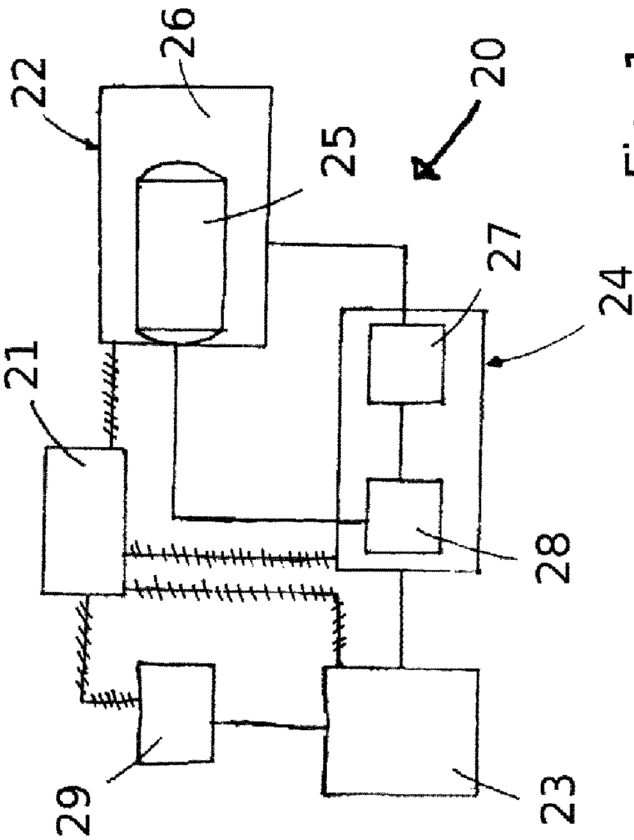


Fig. 1

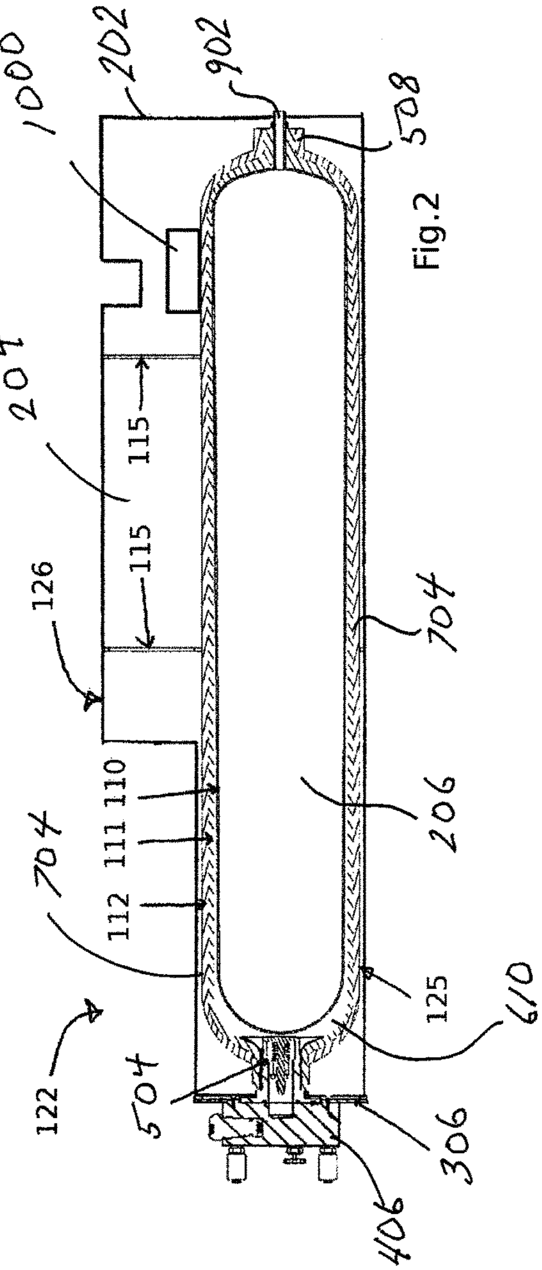

1000
202
902
508
204
115
115
126
704
704
206
110
111
112
125
610
122
504
306
406

Fig.2

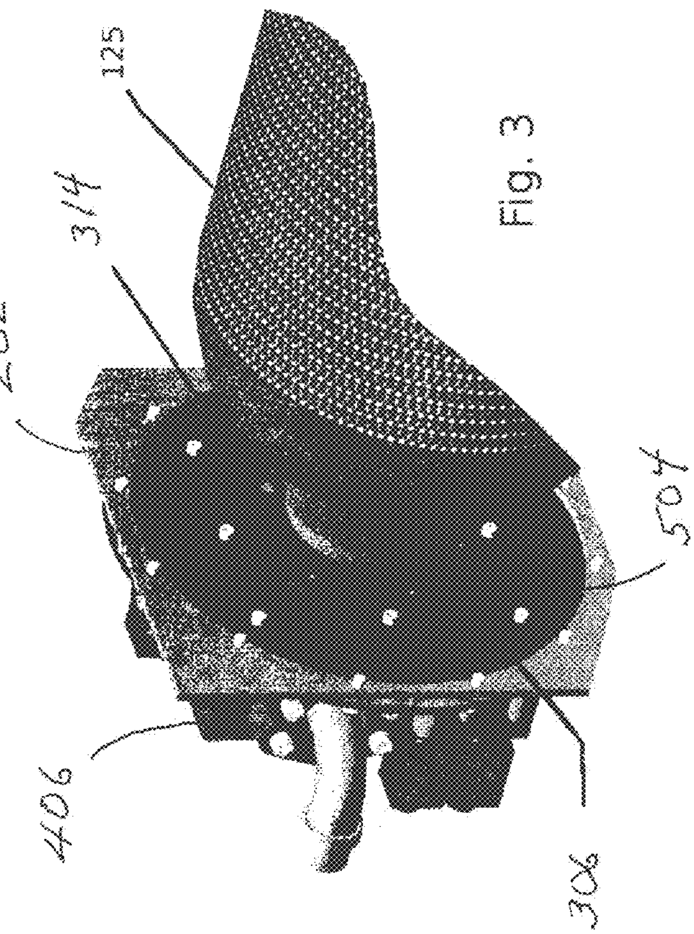


Fig. 3

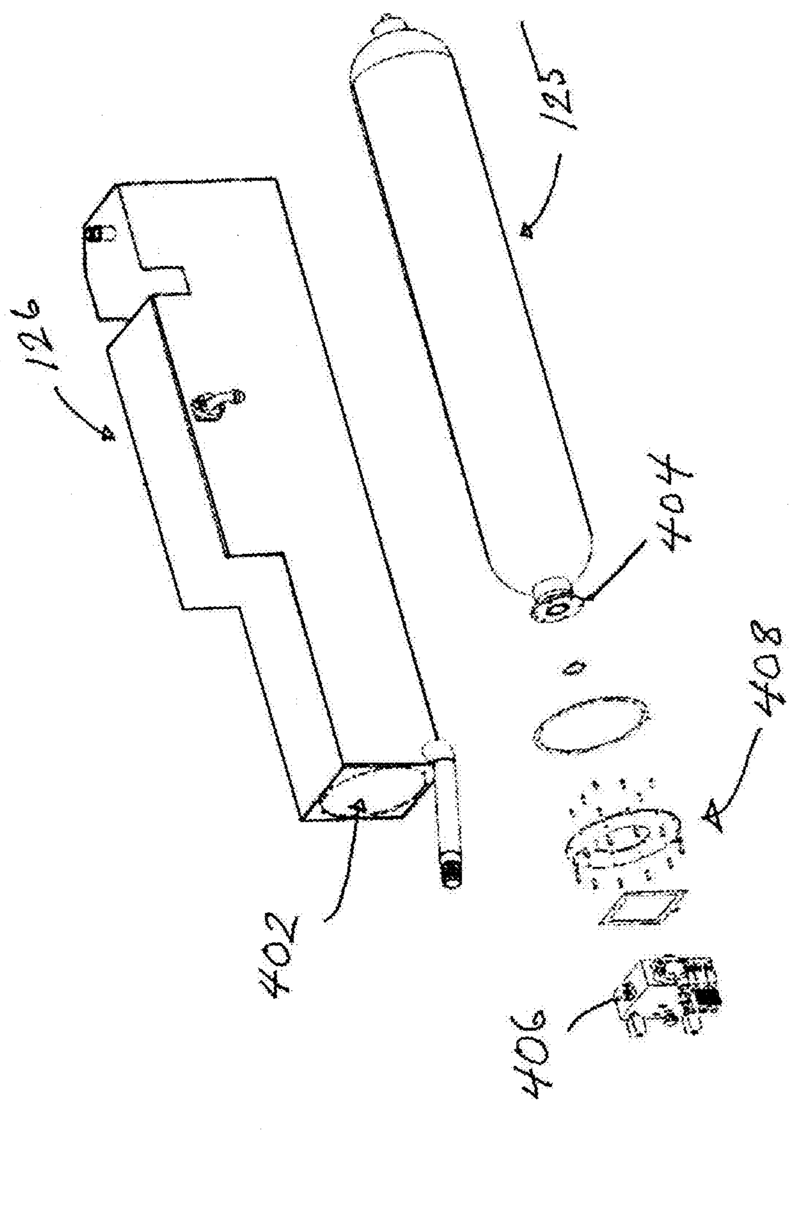


Fig. 4

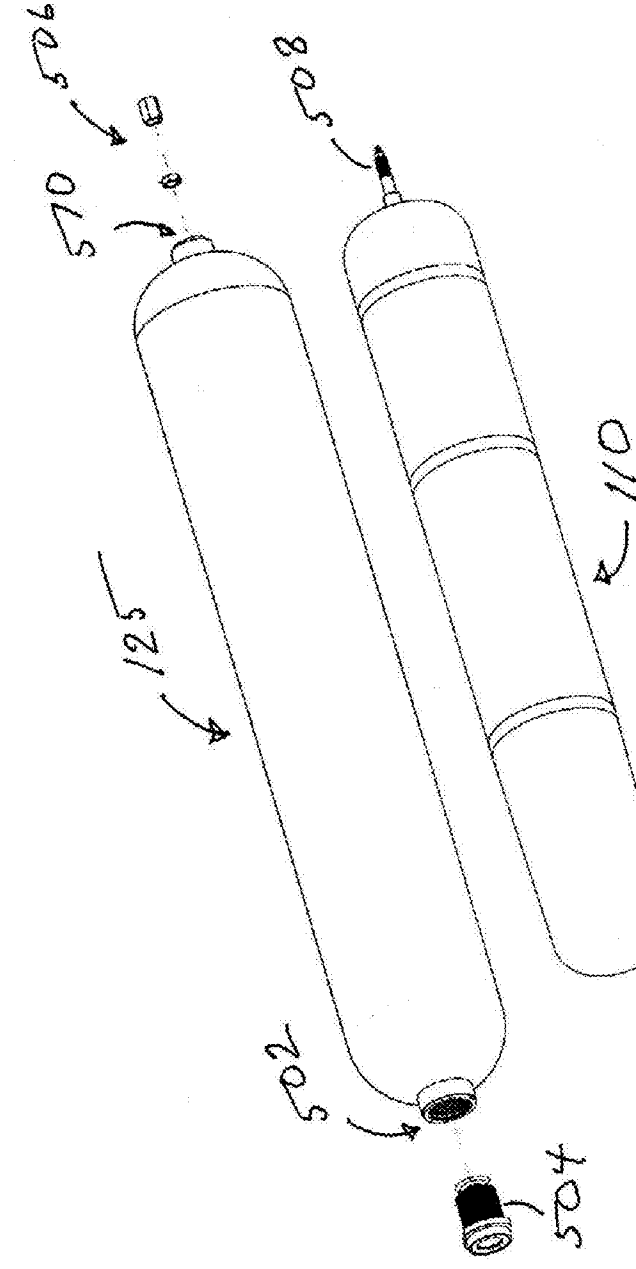


Fig. 5

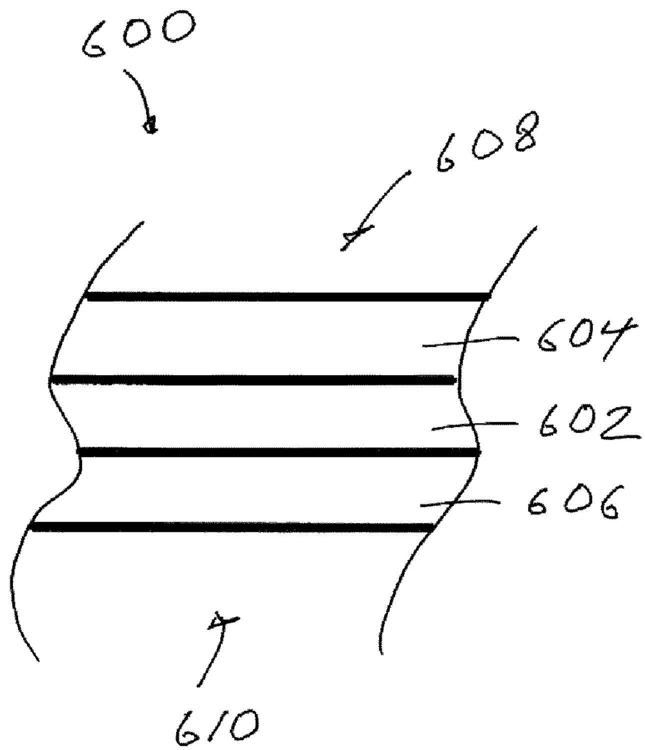


Fig. 6

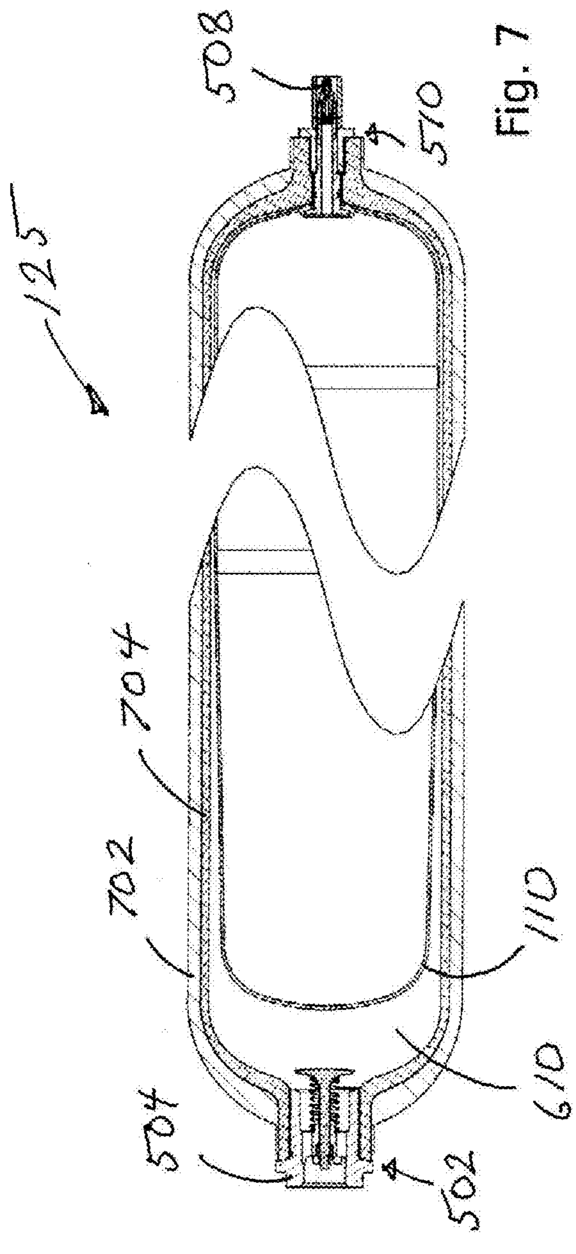
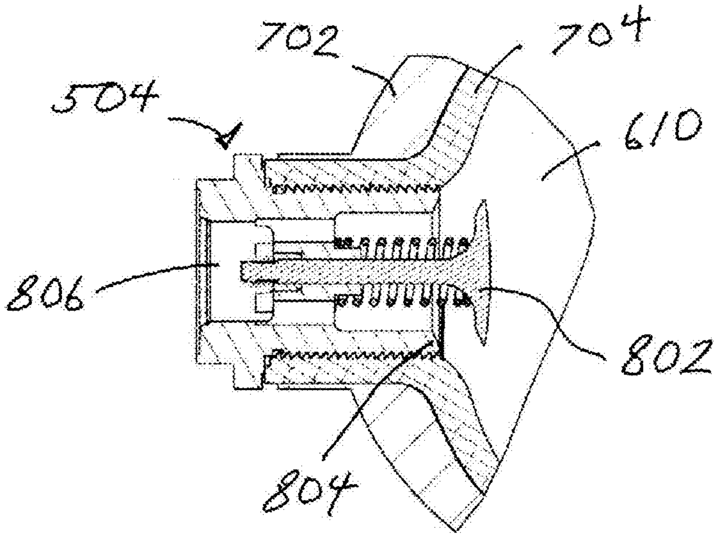
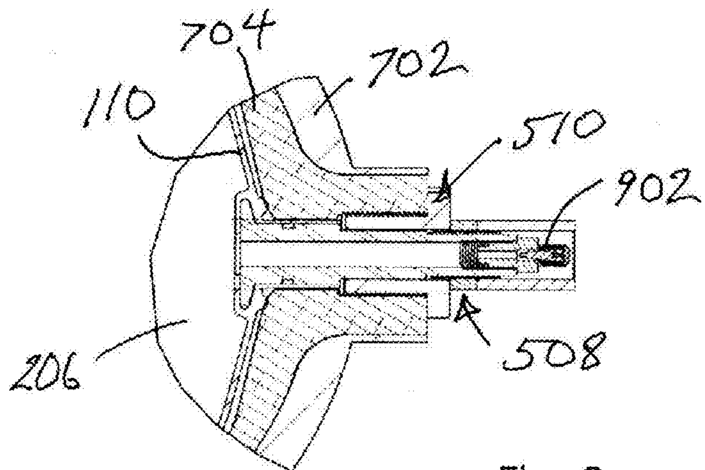


Fig. 7



Fig, 8



Fig, 9

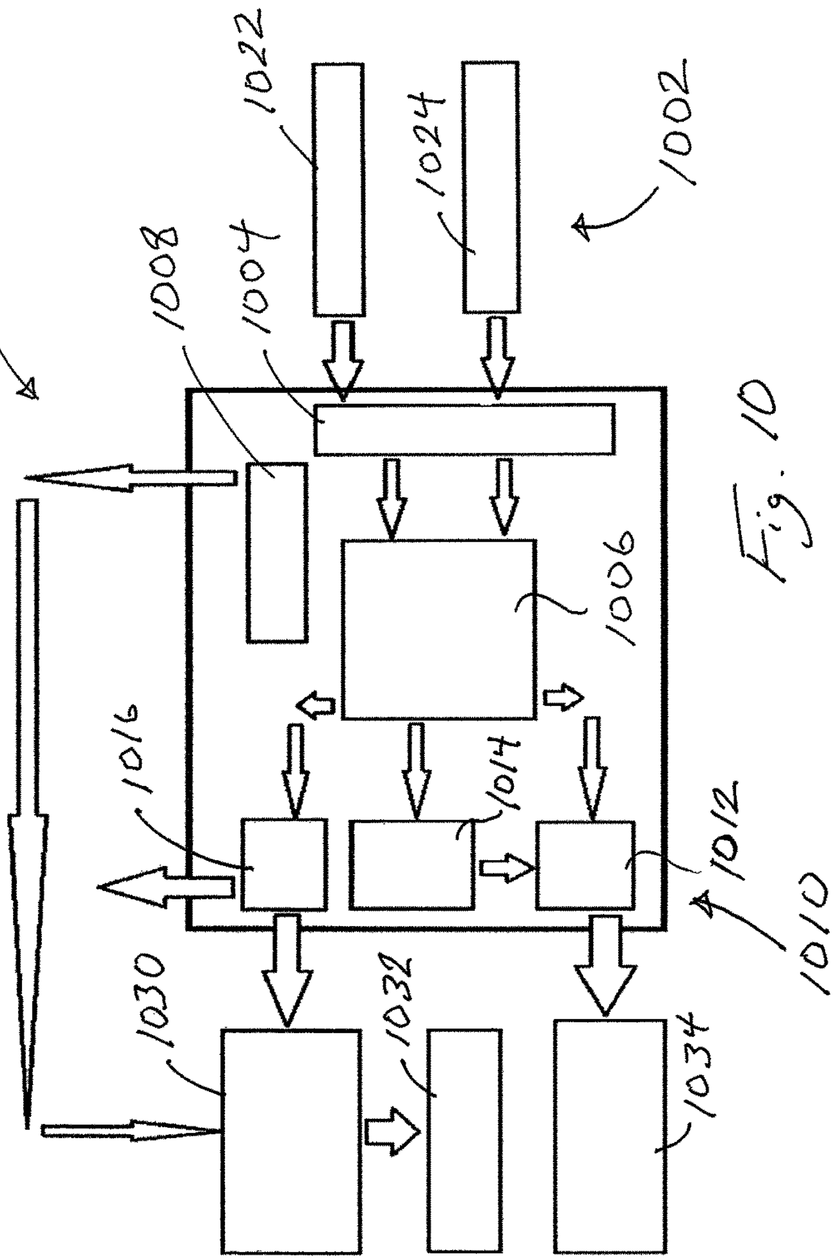

1000
1002
1004
1006
1008
1010
1012
1014
1016
1022
1024
1030
1032
1034

Fig. 10

INTEGRAL ACCUMULATOR/RESERVOIR SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. Provisional Application Ser. No. 61/311,188 filed Mar. 5, 2010, the complete subject matter of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The technical field of this disclosure is braking energy regeneration systems for hybrid hydraulic vehicles, particularly, integral accumulator/reservoir system for hybrid hydraulic vehicles.

BACKGROUND

Hybrid hydraulic systems for vehicles harness the lost kinetic energy that occurs during braking of a vehicle. Kinetic energy is captured by a power transfer system, and subsequently stored as potential energy in an accumulator. This potential energy is later transferred very quickly to kinetic energy which used to accelerate the vehicle, thereby improving fuel efficiency. The accumulator systems store a large amount of energy. Typical accumulator systems include a separate accumulator tank and a separate reservoir tank. Unfortunately, this configuration of accumulator and reservoir tanks presents problems.

Because of the large amount of potential energy stored in the accumulator systems, such systems must be designed to avoid uncontrolled release of the potential energy. One approach has been to make the walls of the accumulators thick enough that catastrophic failure becomes virtually impossible. Unfortunately, this increases the mass of the accumulator system and can negate any energy savings from the energy recovery since the acceleration of the vehicle must also accelerate the massive accumulator. The separate accumulator and reservoir tank configuration also presents a problem, because the separate tanks require more space on the chassis of the vehicle, thus decreasing available room for passengers, cargo, or other components.

It would be desirable to have an integral accumulator/reservoir system that would overcome the above disadvantages.

SUMMARY OF THE INVENTION

One aspect of the invention provides an integral accumulator/reservoir system, the system including a low pressure vessel having a low-pressure vessel wall defining a low-pressure vessel cavity; a high-pressure accumulator having a high-pressure accumulator wall defining a high-pressure accumulator cavity, the high-pressure accumulator being disposed in the low-pressure vessel cavity, the high-pressure accumulator wall including an aluminum layer; a flexible bladder, the flexible bladder being disposed in the high-pressure accumulator cavity; and a sensor module operably connected to the aluminum layer.

Another aspect of the invention provides a braking energy regeneration system for use with a vehicle prime mover, the system including a power transfer module operably connected to the vehicle prime mover; a hydraulic pump system operably connected to the power transfer module, the hydraulic pump system having an axial piston pump in fluid com-

munication with a fixed displacement pump; an integral accumulator/reservoir system operably connected to the hydraulic pump system, the integral accumulator/reservoir system having a high-pressure accumulator, a low-pressure vessel, and a flexible bladder; and a control system operably connected to the vehicle prime mover, the power transfer module, the hydraulic pump system, and the integral accumulator/reservoir system. The fixed displacement pump is in fluid communication with the low-pressure vessel, the fixed displacement pump is in fluid communication with the axial piston pump, and the axial piston pump is in fluid communication with the high-pressure accumulator. The integral accumulator/reservoir system includes the low pressure vessel having a low-pressure vessel wall defining a low-pressure vessel cavity; the high-pressure accumulator having a high-pressure accumulator wall defining a high-pressure accumulator cavity, the high-pressure accumulator being disposed in the low-pressure vessel cavity, the high-pressure accumulator wall including an aluminum layer; the flexible bladder being disposed in the high-pressure accumulator cavity; and a sensor module operably connected to the aluminum layer.

The foregoing and other features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiments, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention, rather than limiting the scope of the invention being defined by the appended claims and equivalents thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a braking energy regeneration system with an integral accumulator/reservoir system made in accordance with the present invention.

FIG. **2** is a cross section side view of an integral accumulator/reservoir system made in accordance with the present invention.

FIG. **3** is an isometric view of a mounting plate and bleed back port for an integral accumulator/reservoir showing made in accordance with the present invention.

FIG. **4** is an exploded view of a low pressure vessel and high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention.

FIG. **5** is an exploded view of a high-pressure accumulator and flexible bladder for an integral accumulator/reservoir system made in accordance with the present invention.

FIG. **6** is a detailed cross-section view of a wall for a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention.

FIG. **7** is a cross section side view of a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention.

FIG. **8** is a detailed cross-section view of a poppet valve for a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention.

FIG. **9** is a detailed cross-section view of a fill valve for a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention.

FIG. **10** is a block diagram of a control system for a sensor module for use with a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention.

DETAILED DESCRIPTION

FIG. **1** is a block diagram of a braking energy regeneration system with an integral accumulator/reservoir system made in accordance with the present invention. The braking energy regeneration system **20** is a closed-loop system including an automatic control system **21**, an integral accumulator/reservoir system **22**, a power transfer module **23**, and a hydraulic pump system **24**. The hydraulic pump system **24** includes a fixed displacement pump **27** in fluid communication with an axial piston pump **28**. The power transfer module **23** performs the function of a torque converter in a vehicle, exchanging power with the vehicle prime mover **29**. As indicated by the hatched lines, the control system **21** is operably connected to each of the integral accumulator/reservoir system **22**, the power transfer module **23**, hydraulic pump system **24**, and the vehicle prime mover **29**. The control system **21** can be a microcontroller operably connected to a variety of vehicle systems that allows the microcontroller to collect data inputs and provide the appropriate signals to each system. The braking energy regeneration system **20** can also include other control valves (not shown) operably connected to the control system **21** to manage hydraulic flow as desired for a particular application.

The integral accumulator/reservoir system **22** is a tank-in-tank system with a high-pressure accumulator **25** enclosed within a low pressure vessel **26**. The low pressure vessel **26** is in fluid communication with a small fixed displacement pump **27** within the hydraulic pump system **24**; the fixed displacement pump **27** is in fluid communication with the axial piston pump **28**; and the high-pressure accumulator **25** is in fluid communication with an axial piston pump **28** within the hydraulic pump system **24**. Thus, there is a hydraulic flow path between the low-pressure vessel **26** and the high-pressure accumulator **25**. The incorporation of the high-pressure accumulator **25** within the low pressure vessel **26** conserves space on the vehicle chassis and provides a barrier around the high-pressure accumulator **25**. In one embodiment, the high-pressure accumulator **25** is also in fluid communication with the low pressure vessel **26** through an emergency relief valve. In case of an emergency, such as a vehicle crash or a potential tank failure, the pressure in the high-pressure accumulator **25** can be relieved to the low pressure vessel **26** through the emergency relief valve by the emergency relief valve in response to an emergency signal.

The high-pressure accumulator **25** exchanges energy with the vehicle through the axial piston pump **28** and the power transfer module **23**. When the vehicle brakes, the power transfer module **23** drives the axial piston pump **28**, increasing the pressure in the high-pressure accumulator **25** by pumping hydraulic fluid into the high-pressure accumulator **25** and compressing the gas in the flexible bladder. When the vehicle accelerates, the pressure from the high-pressure accumulator **25** drives the axial piston pump **28**, releasing the energy to the vehicle through the power transfer module **23**. The fixed displacement pump **27** is operably connected to the low-pressure vessel **26** to provide hydraulic fluid to the axial piston pump **28** during braking to compress the gas in the flexible bladder and two receive hydraulic fluid from the axial piston pump **28** during acceleration as the pressure on the gas in the flexible bladder is released. Those skilled in the art will appreciate that the braking energy regeneration system **20** can be controlled by the control system **21** to operate in different modes as desired for a particular application.

In one embodiment, the braking energy regeneration system **20** is for use with a vehicle prime mover **29** and includes a power transfer module **23** operably connected to the vehicle prime mover **29**; a hydraulic pump system **24** operably connected to the power transfer module **23**, the hydraulic pump system **24** having an axial piston pump **28** in fluid communication with a fixed displacement pump **27**; an integral accumulator/reservoir system **22** operably connected to the hydraulic pump system **24**, the integral accumulator/reservoir system **22** having a high-pressure accumulator **25**, a low-pressure vessel **26**, and a flexible bladder (not shown); and a control system **21** operably connected to the vehicle prime mover **29**, the power transfer module **23**, the hydraulic pump system **24**, and the integral accumulator/reservoir system **22**. The fixed displacement pump **27** is in fluid communication with the low-pressure vessel **26**, the fixed displacement pump **27** is in fluid communication with the axial piston pump **28**, and the axial piston pump **28** is in fluid communication with the high-pressure accumulator **25**. The integral accumulator/reservoir system **22** includes the low pressure vessel **26** having a low-pressure vessel wall defining a low-pressure vessel cavity; the high-pressure accumulator **25** having a high-pressure accumulator wall defining a high-pressure accumulator cavity, the high-pressure accumulator being disposed in the low-pressure vessel cavity; and the flexible bladder, the flexible bladder being disposed in the high-pressure accumulator cavity. The high-pressure accumulator wall includes an aluminum layer, a carbon/epoxy layer exterior to the aluminum layer, and a plastic layer interior to the aluminum layer and adjacent to the flexible bladder.

FIG. **2** is a cross section side view of an integral accumulator/reservoir system made in accordance with the present invention. The integral accumulator/reservoir system **122** includes a low pressure vessel **126** completely enclosing a high-pressure accumulator **125**, which encloses a flexible bladder **110**. The low pressure vessel **126** has a low-pressure vessel wall **202** defining a low-pressure vessel cavity **204**, and the high-pressure accumulator **125** has a high-pressure accumulator wall defining a high-pressure accumulator cavity **610**. The high-pressure accumulator **125** is disposed in the low-pressure vessel cavity **204**, and the flexible bladder **110** is disposed in the high-pressure accumulator cavity **610**. The high-pressure accumulator wall **704** includes an aluminum layer **111**, a carbon/epoxy layer **112** exterior to the aluminum layer **111**, and a plastic layer (not shown) interior to the aluminum layer **111** and adjacent to the flexible bladder **110**. Supports **115** can be used to maintain placement of the high-pressure accumulator **125** within the low-pressure vessel **126**. A sensor module **1000** can be used to monitor the high-pressure accumulator **125** with a strain gauge, temperature sensor, or the like. In one embodiment, the sensor module **1000** is bonded to the aluminum layer **111**. The sensor module **1000** can include multiple arrays of sensors attached to various points on the high-pressure accumulator **125**. The sensor module **1000** can be in communication with the control system of the braking energy regeneration system.

Fill valve **902** of the fill valve assembly **508** passes through the low-pressure vessel wall **202**, connecting the flexible bladder cavity **206** with the exterior of the integral accumulator/reservoir system **122**. The fill valve **902** can be used to precharge the flexible bladder **110** with a gas such as nitrogen. Poppet valve assembly **504** connects the high-pressure accumulator cavity **610** to the manifold assembly **406** through the low-pressure vessel wall **202**. The manifold assembly **406** provides flow paths for hydraulic fluid to the low-pressure vessel **126** and high-pressure accumulator **125**.

FIG. **3** is an isometric view of a mounting plate and bleed back port for an integral accumulator/reservoir showing made in accordance with the present invention.

The mounting plate **306** connects the poppet valve assembly **504** to the low-pressure vessel walls **202**. The poppet valve assembly **504** is in fluid communication with the manifold assembly **406** and the high-pressure accumulator **125**. A bleed back port **314** is in fluid communication with the manifold assembly **406** to allow high-pressure leakage of hydraulic fluid to drain into the low-pressure vessel. The bleed back port **314** can also be used in connection with an emergency relief valve release pressure from the high-pressure accumulator **125** to the low-pressure vessel **126**. In case of an emergency, such as a vehicle crash or potential tank failure, the emergency relief valve can be opened. In one embodiment, the emergency relief valve is the poppet valve itself.

FIG. **4** is an exploded view of a low pressure vessel and high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention. The low-pressure vessel **126** receives the high-pressure accumulator **125** through the low-pressure vessel opening **402**. A manifold assembly **406** provides flow paths to the low-pressure vessel **126** and high-pressure accumulator **125**. Gasket/flange assembly **408** provides an interface and seal between the low-pressure vessel opening **402**, the poppet valve assembly flange **404**, and the manifold assembly **406**.

The low-pressure vessel **126** can be any lightweight vessel operable to receive low-pressure hydraulic fluid, such as hydraulic fluid up to 100 psi, for example. In one embodiment the low-pressure vessel **126** can be made of welded aluminum. In another embodiment, the low-pressure vessel **126** can be formed of a single piece of blow molded high-density polyethylene (HDPE). Those skilled in the art will appreciate that the low-pressure vessel **126** can be made of any lightweight material to maintain a low mass for the integral accumulator/reservoir system.

The high-pressure accumulator **125** can be any accumulator operable to receive high-pressure hydraulic fluid, such as hydraulic fluid up to 6000 psi, for example. The high-pressure accumulator **125** can be sized to provide the desired energy storage and pressure. In one embodiment the high-pressure accumulator **125** has an interior volume in the high-pressure accumulator cavity of about 6000 cubic inches and a length of about 73 inches.

The wall of the high-pressure accumulator **125** can include an aluminum layer, a carbon/epoxy layer exterior to the aluminum layer, and a plastic layer interior to the aluminum layer and adjacent to the flexible bladder. The aluminum layer can be part of an aluminum vessel, such as a cylindrical tank. In one embodiment, the aluminum is heat treated to permit microcracks to form under fatigue, rather than permitting catastrophic failure. The microcracks allow detectable leakage of hydraulic fluid from the high-pressure accumulator **125**. The carbon epoxy layer is also porous, so the hydraulic fluid leaks from the high-pressure accumulator **125** into the low-pressure vessel **126**.

The carbon/epoxy layer can include carbon fiber windings set in an epoxy bed. In one embodiment, the quantity and orientation of the carbon fiber windings in the carbon/epoxy layer are selected so that the carbon/epoxy layer can carry about 60% of the pressure load of the high-pressure accumulator **125**. For example, long fibers of the epoxy winding can be wound radially about the aluminum vessel.

The plastic layer can act as a liner inside of the aluminum shell. In one embodiment, the plastic layer is a rotomolded plastic liner formed of high-density polyethylene (HDPE). In one embodiment, the plastic layer is rotomolded in place inside the aluminum shell. Because of its elasticity, the plastic layer increases the number of pressure cycles the high-pressure accumulator **125** can withstand. The plastic layer also increases the lifetime of the flexible bladder by providing a very smooth surface that the flexible bladder can slide against.

In one embodiment, the wall of the high-pressure accumulator **125** can also include a nonstructural fiberglass layer exterior to the carbon/epoxy layer. The nonstructural fiberglass layer allows users to detect if the high-pressure accumulator has suffered any impact or has been excessively abraded.

FIG. **5** is an exploded view of a high-pressure accumulator and flexible bladder for an integral accumulator/reservoir system made in accordance with the present invention. The high-pressure accumulator **125** receives the flexible bladder **110** through the poppet valve accumulator opening **502**. The flexible bladder **110** is secured in the high-pressure accumulator **125** at fill valve accumulator opening **510** with threaded assembly **506** secured to fill valve assembly **508**. The fill valve of the fill valve assembly **508** is used to precharge the flexible bladder **110** with a gas such as nitrogen, which stores the energy when the high-pressure accumulator cavity is charged with hydraulic fluid.

The poppet valve in the poppet valve assembly **504** prevents the flexible bladder **110** from pushing out of the high-pressure accumulator cavity when the flexible bladder **110** is precharged with gas. The poppet valve assembly **504** is threaded complementary to the poppet valve accumulator opening **502** for ease of installation of the flexible bladder **110**. The threading allows use of a larger diameter poppet valve accumulator opening, compared to an anti-extrusion style valve. In one embodiment, the diameter of the poppet valve accumulator opening **502** is 3 inches, which allows a full thickness bladder to be inserted into the high-pressure accumulator. The larger opening permits use of a full thickness flexible bladder, avoiding problems with gas permeation through the bladder and extending the life of the bladder.

The flexible bladder **110** can be made of any flexible material compatible with the hydraulic fluid. In one embodiment, the flexible bladder **110** has a thickness of 0.125 inches to provide reasonable resistance to gas permeation. A thick flexible bladder **110** is desirable to prevent the gas from diffusing through the wall of the flexible bladder **110**. Gas diffusion reduces the precharge of gas in the flexible bladder **110** and also requires the flexible bladder **110** to be filled more often.

FIG. **6** is a detailed cross-section view of a wall for a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention. The high-pressure accumulator wall of the high-pressure accumulator includes an aluminum layer **602**, a carbon/epoxy layer **604** exterior to the aluminum layer **602**, and a plastic layer **606** interior to the aluminum layer **602** and adjacent to the flexible bladder. Both of the carbon epoxy layer **604** and the plastic layer **606** are exposed to hydraulic fluid. The carbon epoxy layer **604** is exposed to the low-pressure vessel cavity **608**, and the plastic layer **606** is exposed to the high-pressure accumulator cavity **610** and the flexible bladder.

The aluminum layer **602** can be part of an aluminum vessel, such as a cylindrical tank. In one embodiment, the aluminum is heat treated to permit microcracks to form under fatigue, rather than permitting catastrophic failure. The microcracks allow detectable leakage of hydraulic fluid from the high-pressure accumulator **125**. The carbon epoxy layer is also porous, so the hydraulic fluid leaks from the high-pressure accumulator **125** into the low-pressure vessel **126**. In one embodiment, the aluminum layer **602** is made of 7075 aluminum and has a thickness of 0.75 inches, which provides adequate structural strength and can be formed to the required shape.

The carbon/epoxy layer **604** can include carbon fiber windings set in an epoxy bed. In one embodiment, the quantity and orientation of the carbon fiber windings in the carbon/epoxy layer are selected so that the carbon/epoxy layer can carry about 60% of the pressure load of the high-pressure accumulator **125**. For example, long fibers of the epoxy winding can be wound radially about the aluminum vessel. In one embodiment, the carbon/epoxy layer **604** is made of ultra high modulus carbon and epoxy consisting of epichlorohydrin and bisphenol-A, and has a thickness of between 0.25 and 1.5 inches, depending on vessel size and pressure rating.

The plastic layer **606** can act as a liner inside of the aluminum shell. In one embodiment, the plastic layer is a rotomolded plastic liner formed of high-density polyethylene (HDPE). In one embodiment, the plastic layer is rotomolded in place inside the aluminum shell. Because of its elasticity, the plastic layer increases the number of pressure cycles the high-pressure accumulator **125** can withstand. The plastic layer also increases the lifetime of the flexible bladder by providing a very smooth surface that the flexible bladder can slide against. In one embodiment, the plastic layer **606** is made of high density polyethylene plastic and has a thickness of 0.0625 inches.

In one embodiment, the wall of the high-pressure accumulator **125** can also include a nonstructural fiberglass layer exterior to the carbon/epoxy layer. The nonstructural fiberglass layer allows users to detect if the high-pressure accumulator has suffered any impact or has been excessively abraded. In one embodiment, the nonstructural fiberglass layer is made of any available long stranded fiberglass and has a thickness of 0.01 inches, so that an impact to the high-pressure accumulator **125** easily destroys the fiberglass layer but protects the carbon layer underneath.

FIG. **7** is a cross section side view of a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention. In this example, the high-pressure accumulator **125** has a nonstructural fiberglass layer **702** exterior to a high-pressure accumulator wall **704**, which defines the high-pressure accumulator cavity **610**. The poppet valve assembly **504** is threaded into the poppet valve accumulator opening **502** defined by the high-pressure accumulator wall **704**. The fill valve assembly **508** is threaded into the fill valve accumulator opening **510** and secures the flexible bladder **110** within the high-pressure accumulator cavity **610**.

FIG. **8** is a detailed cross-section view of a poppet valve for a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention. The poppet valve assembly **504** includes a poppet valve stem **802** biased towards the high-pressure accumulator cavity **610** and a poppet valve seat **804**. When the flexible bladder is precharged, but no pressurized hydraulic fluid is present in the high-pressure accumulator cavity **610**, the flexible bladder presses against the poppet valve stem **802** and seats the poppet valve stem **802** on the poppet valve seat **804**. This closes the poppet valve assembly **504** to prevent the flexible bladder from passing through the poppet valve port **806**. When pressurized hydraulic fluid is present in the high-pressure accumulator cavity **610**, the flexible bladder is compressed and hydraulic fluid is free to pass in and out of the poppet valve port **806**.

In one embodiment, the poppet valve stem **802** is attached to an actuator which can close the poppet valve in response to a shut off signal, stopping flow through the threaded poppet valve assembly **504** into or out of the high-pressure accumulator cavity **610**. This can be used to prevent vehicle movement by preventing flow of hydraulic fluid to and from the integral accumulator reservoir system in the braking energy regeneration system. The shut off signal can be generated locally on the vehicle or remotely.

FIG. **9** is a detailed cross-section view of a fill valve assembly for a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention. The fill valve assembly **508** is threaded into the fill valve accumulator opening **510** and secures the flexible bladder **110** within the high-pressure accumulator cavity. The flexible bladder **110** is precharged with a gas through the fill valve **902**. The fill valve **902** can have a readily available fitting, such as a Schraeder valve. In one embodiment, the flexible bladder **110** can be charged to working pressure with nitrogen.

FIG. **10** is a block diagram of a control system for a sensor module for use with a high-pressure accumulator for an integral accumulator/reservoir system made in accordance with the present invention. The sensor module **1000** can be operably connected to the aluminum layer of the high-pressure accumulator wall to monitor the high-pressure accumulator. In one embodiment, the sensor module **1000** is bonded to the aluminum layer of the high-pressure accumulator.

The sensor module **1000** can be a self-contained unit applied to the high-pressure accumulator. The sensor module **1000** physically can include all the components on a very small printed circuit board. Other components can include Wheatstone bridges for small signal measurement, current drivers for valve actuation in the poppet assembly, appropriate communications chip, wireless communications devices, batteries, and required power circuitry. The sensor module **1000** can optionally be powered from an off-module power source, such as the vehicle battery and/or alternator, when power demands are too large for an onboard power source. The optional communication interface **1010** can communicate locally or remotely over the Internet using standard protocols such as Wi-Fi, Bluetooth, Zigbee, CAN, GSM, CDMA or the like.

The sensor module **1000** includes a sensor **1002**, an analog-to-digital converter **1004** operably connected to the sensor **1002**, a central processing unit **1006** operably connected to the analog-to-digital converter **1004**, and a communication interface **1010** operably connected to the central processing unit **1006**. The sensor **1002** can include one or more strain gauges **1022**, one or more temperature sensors **1024**, combinations thereof, or the like. The communication interface **1010** can include a wireless transceiver **1016**, a CAN/BUS communication chip **1014**, and/or a physical connector **1012**. The sensor module **1000** can also include global positioning system/Global System for Mobile Communications (GPS/GSM) interface **1008** and/or an optional display (not shown). The optional display can be a locally available LCD display providing information about the sensor module **1000** and/or the integral accumulator/reservoir system.

In one embodiment, the sensor **1002** is one or more strain gauges **1022** operable to detect strain in the aluminum layer of the high-pressure accumulator wall. When the sensor **1002** is a strain gauge, the central processing unit **1006** can use the detected strain to calculate parameters for the high-pressure accumulator such as the number of pressure cycles experienced, the maximum pressure experienced, the pressure history, or the like. Firmware on the central processing unit **1006** can provide functions which correlate the values from the strain gauges into meaningful pressure, cycle, and volume numbers. When the central processing unit **1006** detects or calculates a condition that could lead to a potential failure of the high-pressure accumulator, the central processing unit **1006** can alert operators over the display, through the communication interface **1010**, and/or can initiate automatic action to relieve pressure in the high-pressure accumulator. Examples of conditions that could be of concern include number of pressure cycles reaching accumulator end-of-life or excessive pressure loading. The strain gage can also be used to calculate the pressure or fluid volume in the high-pressure accumulator tank.

In another embodiment, the sensor **1002** can be one or more temperature sensors **1024** operable to detect the temperature of the aluminum layer. When the sensor **1002** is a temperature sensor, the central processing unit **1006** can use the detected temperature to calculate parameters for the high-pressure accumulator such as tank fluid pressure, tank fluid volume, or the like. The detected temperature at the aluminum layer also indicates the temperature of the hydraulic fluid and gas inside the high-pressure accumulator because the aluminum layer is thermally conductive. The temperature sensor **1024** can be any sort of temperature sensing device, such as a thermocouple, thermistor, silicon, or other electric temperature sensing device. The detected Temperature can be used to determine the pressure and/or volume of the hydraulic fluid in the high-pressure accumulator through a correlation such as the ideal gas law and/or thermodynamic tables.

The analog-to-digital converter **1004** can be any suitable converter for changing an analog signal from the sensor **1002** to a digital signal, as required for the central processing unit **1006**. The central processing unit **1006** can be in a processor operable to carry out instructions and manage data for the sensor module **1000**. In one example, the central processor unit **1006** can be a microprocessor. The central processing unit **1006** can also include or be associated with memory and/or storage for the instructions and data.

The communication interface **1010** can include a wireless transceiver **1016**, a CAN/BUS communication chip **1014**, and/or a physical connector **1012**, implemented as one or more integrated circuits. The wireless transceiver **1016** can communicate wirelessly with devices external to the sensor module **1000**. Those skilled in the art will appreciate that the wireless transceiver **1016** can operate over various protocols such as Wi-Fi, Bluetooth, Zigbee, CAN, GSM, CDMA or the like. The wireless transceiver **1016** can communicate locally or over a long distance. In one embodiment, the wireless transceiver **1016** exchanges information with the central processing unit **1006** and provides information to an accumulator monitoring website **1030**. The accumulator monitoring website **1030** can track the physical location of the integral accumulator/reservoir systems, and receive and display operating information about the integral accumulator/reservoir systems. The accumulator monitoring website **1030** can store accumulator history in an online database **1032**. The sensor module **1000** can also receive queries from the accumulator monitoring website **1030** through the wireless transceiver **1016**. In one embodiment, the sensor module **1000** can also include a GPS/GSM interface **1008** to provide location information for the integral accumulator/reservoir system to the accumulator monitoring website **1030**.

The communication interface **1010** can include a CAN/BUS communication chip **1014**. The CAN/BUS (controller-area network) standard is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer. The can bus communication chip **1014** communicates with the central processing unit **1016** and the physical connector **1012**. In one embodiment, the CAN/BUS communication chip **1014** exchanges information with the central processing unit **1006** and communicates information with the vehicle CAN/BUS **1034** through the physical connector **1012**. In one embodiment, the central processing unit **1006** can also communicate directly with the vehicle CAN/BUS **1034** through the physical connector **1012**. The physical connector **1012** can also lead be used to provide power to the sensor module **1000**.

While the embodiments of the invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the spirit and scope of the invention. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.

The invention claimed is:

1. An integral accumulator/reservoir system, the system comprising:
- a low pressure vessel having a low-pressure vessel wall defining a low-pressure vessel cavity;
- a high-pressure accumulator having a high-pressure accumulator wall defining a high-pressure accumulator cavity, the high-pressure accumulator being disposed in the low-pressure vessel cavity, the high-pressure accumulator wall including an aluminum layer;
- a flexible bladder, the flexible bladder being disposed in the high-pressure accumulator cavity; and
- a sensor module operably connected to the aluminum layer.

2. The system of claim **1** wherein the sensor module includes a strain gauge operable to detect strain in the aluminum layer.

3. The system of claim **2** further comprising a central processing unit operably connected to the strain gauge, the central processing unit being operable to use the detected strain to calculate a parameter selected from the group consisting of number of pressure cycles, maximum pressure, and pressure history.

4. The system of claim **1** wherein the sensor module includes a temperature sensor operable to detect temperature of the aluminum layer.

5. The system of claim **4** further comprising a central processing unit operably connected to the temperature sensor, the central processing unit being operable to use the detected temperature to calculate a parameter selected from the group consisting of tank fluid pressure and tank fluid volume.

6. The system of claim **1** wherein the sensor module comprises:
- a sensor selected from the group consisting of a strain gauge and a temperature sensor;
- an analog-to-digital converter operably connected to the sensor;
- a central processing unit operably connected to the analog-to-digital converter; and
- a communication interface operably connected to the central processing unit.

7. The system of claim **6** wherein the communication interface is selected from the group consisting of a wireless transceiver and a CAN/BUS communication chip.

8. The system of claim **1** wherein the sensor module further comprises a GPS/GSM interface.

9. The system of claim **1** further comprising a carbon/epoxy layer exterior to the aluminum layer, and a plastic layer interior to the aluminum layer and adjacent to the flexible bladder.

10. The system of claim **9** is further comprising a nonstructural fiberglass layer exterior to the carbon epoxy layer.

11. A braking energy regeneration system for use with a vehicle prime mover, the system comprising:
- a power transfer module operably connected to the vehicle prime mover;
- a hydraulic pump system operably connected to the power transfer module, the hydraulic pump system having an axial piston pump in fluid communication with a fixed displacement pump;

an integral accumulator/reservoir system operably connected to the hydraulic pump system, the integral accumulator/reservoir system having a high-pressure accumulator, a low-pressure vessel, and a flexible bladder; and

a control system operably connected to the vehicle prime mover, the power transfer module, the hydraulic pump system, and the integral accumulator/reservoir system;

wherein the fixed displacement pump is in fluid communication with the low-pressure vessel, the fixed displacement pump is in fluid communication with the axial piston pump, and the axial piston pump is in fluid communication with the high-pressure accumulator; and

wherein the integral accumulator/reservoir system comprises;

the low pressure vessel having a low-pressure vessel wall defining a low-pressure vessel cavity;

the high-pressure accumulator having a high-pressure accumulator wall defining a high-pressure accumulator cavity, the high-pressure accumulator being disposed in the low-pressure vessel cavity, the high-pressure accumulator wall including an aluminum layer;

the flexible bladder being disposed in the high-pressure accumulator cavity; and

a sensor module operably connected to the aluminum layer.

12. The system of claim **11** wherein the sensor module includes a strain gauge operable to detect strain in the aluminum layer.

13. The system of claim **12** further comprising a central processing unit operably connected to the strain gauge, the central processing unit being operable to use the detected strain to calculate a parameter selected from the group consisting of number of pressure cycles, maximum pressure, and pressure history.

14. The system of claim **11** wherein the sensor module includes a temperature sensor operable to detect temperature of the aluminum layer.

15. The system of claim **14** further comprising a central processing unit operably connected to the temperature sensor, the central processing unit being operable to use the detected temperature to calculate a parameter selected from the group consisting of tank fluid pressure and tank fluid volume.

16. The system of claim **11** wherein the sensor module comprises:

a sensor selected from the group consisting of a strain gauge and a temperature sensor;

an analog-to-digital converter operably connected to the sensor;

a central processing unit operably connected to the analog-to-digital converter; and

a communication interface operably connected to the central processing unit.

17. The system of claim **16** wherein the communication interface is selected from the group consisting of a wireless transceiver and a CAN/BUS communication chip.

18. The system of claim **11** wherein the sensor module further comprises a GPS/GSM interface.

19. The system of claim **11** further comprising a carbon/epoxy layer exterior to the aluminum layer, and a plastic layer interior to the aluminum layer and adjacent to the flexible bladder.

20. The system of claim **19** further comprising a nonstructural fiberglass layer exterior to the carbon epoxy layer.

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